REAL OPTION APPROACH TO INVESTMENTS IN ELECTRICITY GENERATING CAPACITY

by

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ABSTRACT

With the restructuring of the electricity industry taking shape in the United States and in Europe, utilities and power generators are becoming exposed to volatile spot prices in the new competitive marketplace. This shift from a regulated to a market driven environment has fundamental consequences for many aspects of the electric power plant business. In particular, investment decisions, once driven by long-term off-take contracts, must today incorporate price exposure and volatility.

This thesis examines the trend towards deregulation to discover its implication upon valuation methods used for projects in electricity production. The discussion starts with a review of traditional approaches to investment under uncertainty and presents the main characteristics and advantages of the real option framework.

Then, the thesis develops a case to study an investment decision faced by an electric utility in a deregulated competitive electricity market. A generic model is presented under the assumption of stochastic behavior for electricity price, based on the option to operate or not the plant according to prevailing market conditions. Finally, the use of derivative contracts is integrated in the model, in order to show how generators can hedge against price volatility.

Thesis Supervisor: Massood V. Samii

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INTRODUCTIO N

Power industries around the world have begun to shake off their regulated past. During the last two decades, they have been significantly restructured in order to become more competitive. Power markets have emerged in several countries, including Europe and the United States, with an explicit goal to produce transparent and fair prices for electricity and to insure in the same time a stable flow of physical power to any user.

With this restructuring of the electricity industry, utilities and power generators, who currently enjoy embedded cost recovery regulation, are becoming exposed to volatile prices. This evolution toward a market-driven world is definitely changing the way any company views its business, how it operates and manages its physical assets, as well as how it values and selects investment projects. In order to keep their competitive advantage, market leaders need to understand where value is created in this uncertain environment, as well as to identify and manage the different risks to which they will be exposed.

The purpose of this thesis is to study the different consequences of this trend towards deregulation on valuation of investments in electricity generating capacity. We explain why traditional valuation tools, such as Discounted Cash Flow analysis, must be revised and how they can be adapted to take into account price volatility. We develop a real options framework that incorporates the most significant price drivers and well as the value of managerial flexibility. We show how this methodology can be used to analyze investment opportunities in electricity generating capacity.

The study is organized as follows.

In the first part, we review the literature dealing with investment under uncertainty. Chapter 2 describes the traditional approach to investment valuation, highlighting different techniques, along with their strengths and weaknesses. Chapter 3 introduces the logic behind the real options approach to investment and starts with the basics of financial options. Chapter 4 develops further the analogy between financial options and corporate investments, presenting a framework of analysis as well as pricing methods to calculate real option values.

In the second part, we apply this real options framework to a hypothetic investment decision faced by an electric utility regarding the addition of new production capacity. Chapter 5 reviews how electricity markets are taking shape in the U.S. and describes the behavior of electricity prices. Stochastic models are developed to capture price characteristics and used for derivative valuation. Chapter 6 relates the fundamental behavior of electricity prices to investment analysis and proposes a valuation tool based on spark spread options. A case study with data of the US market is taken to illustrate our point of view. Chapter 7 extends the real options framework and examines the implications of our analysis on operational decisions for owners of power plants, laying the foundation for a risk management strategy.

Chapter 2

TRADITIONAL APPROACH TO INVESTMENT

Behind every major resource allocation decision a company makes lies some calculation of what that move is worth. How a company estimates value is a critical determinant of how it allocates its often-limited resources. And the allocation of resources, in turn, is a key driver of a company's overall performance.

In the 1970's, Discounted Cash Flow (DCF) analysis emerged as best practice for valuing investment opportunities, as well as corporate assets in operation. The Net Present Value rule (NPV), ultimate decision-making criteria of any DCF analysis, helps the firm to pursue its primary financial objective, i.e. shareholders' value maximization. Section I of this chapter will present the main principles of discounted cash flow analysis, as well as the practical issues encountered during implementation.

Other approaches, such as sensitivity analysis, simulation and decision tree analysis, have been proposed in order to deal with uncertainty and complexity embedded in most business decisions. Section II of this chapter will present those 3 approaches, highlighting how useful they may be in improving management's understanding of the structure of the investment decision.

However, even if all those widely used techniques deal appropriately with the risk and timing of any project's cash flows, they appear inappropriate in today's highly competitive and uncertain marketplace, where managerial flexibility is becoming essential. Section III of this chapter will review the validity of DCF analysis for evaluating investments.

2.1 Discounted Cash Flow Analysis

Any investment decision involves sacrificing current consumption in order to achieve consumption in future periods. Similarly, any individual has to choose between alternative patterns of consumptions and investment opportunities so as to maximize his satisfaction (often referred as utility) of consumption across time. Most companies are owned by a certain numbers of individuals, its shareholders. The financial objective of a firm is to help its shareholders achieve their own goal, i.e. to maximize the utility of each owner.

It is well accepted in the standard finance literature (Brealey and Myers, 1996), that this objective can be achieved optimally if the firm maximizes its market value. In turn, the market value depends on the cash flows generated by the firm's assets. Any measure of performance of capital investments should therefore be consistent with the criterion of maximizing the market value of the firm's stock.

Valuation measures have been developed to make sure that investment decisions are consistent with the firm's objective of maximizing its shareholders' wealth. As a result, Discounted Cash Flow Analysis, and its valuation measure Net Present Value, have emerged as the best practice in capital budgeting.

2.1.a Principles of Discounted Cash Flow Analysis

2.1.a.i - Basic Logic of Discounted Cash Flow Valuation

Discounted Cash Flow valuation are all built on a simple relationship between present value and future value:

$$\text{Present Value} = \frac{\text{Future Value}}{1 + \text{Interest Rate}}$$

To apply this fundamental DCF relationship to a business, we modify the relationship so that present value equals the sum of future cash flows adjusted for timing and risk.

$$\text{Present Value} = \sum_{t=0}^{n} \frac{E(CF)_t}{(1+k)^t}$$

This modification takes into consideration:

- **Risk**: Because business cash flows are risky, investors demand a higher return; the discount rate k contains a risk premium. Future value corresponds to future business cash flows, CF. But as business cash flows are also often uncertain, we discount expected cash flows: E(CF).
- **Timing**: Because business cash flows occur over many future periods, we locate them in time, then discount and add them all.

2.1.a.ii - Traditional Discounted Cash Flow Valuation

A discounted cash flows analysis regards any investment opportunity as a series of risky cash flows stretching into the future. A traditional analysis (Luehrman, 1997) has the following steps:

- **Calculate the present value of the expected stream of cash flows that the investment will generate.**

First, the analyst's task is to forecast expected future cash flows generated by the investment, period by period. Second, the forecasts are discounted to present value at the opportunity cost of funds. The opportunity cost is the return a company could expect to earn on alternative investment entailing the same risk. Managers can get benchmarks for the appropriate opportunity cost by observing how capital markets price similar risks. Opportunity cost consists partly of time value (the return on a nominally risk-free investment). This is the return you earn for being patient without bearing any risk. Opportunity cost also includes a risk premium (the extra return you can expect commensurate with the risk you are willing to bear). The cash flow forecasts and the opportunity cost are combined in the basic DCF relationship, giving the Present Value of cash flows that the investment will generate.

- **Calculate the present value of the stream of expenditures required to undertake the project.**

The same basic DCF relationship is applied to calculate this present value.

- **Determine the difference between the present value of expected revenues and costs in order to obtain the Net Present Value (NPV) of the investment.**

- **The decision rule in any DCF analysis is to accept investments with NPV greater than zero.**

NPV represents the value added to the business by the investment or the increase in the market value of the stockholders' wealth. Thus, accepting a project with a positive NPV will make the stockholders better off by the amount of its NPV. On the contrary, investments with negative NPV shall be rejected.

2.1.b Implementation Problems

Implementation problems include inaccuracy and bias in forecasts and the use of an inappropriate discount rate (Luehrman, 1997).

2.1.b.i - Inaccuracy and Bias in Forecasts

A DCF analysis of an investment requires forecasts of operating costs, expenditures in fixed assets and working capital, sales volumes, prices, as well as the timing of each expenditures. Many of those forecasts will contain errors, mainly because of the uncertainty surrounding most activities. Just as important, is the likelihood that biases will influence the forecasts. Common sources of biases include managers' mental models and selective perception, as well as opportunistic behavior. If not taken into account appropriately, any kind of bias in forecasts will undermine the accuracy of the investment analysis.

2.1.b.ii - Use of Inappropriate Discount Rate

Selecting the appropriate discount rate is a difficult matter as well. The discount rate should reflect the risk of the investment under consideration, task that is especially difficult for projects characterized with a lot of uncertainty. A common practice is to use the business's weighted average cost of capital (WACC). It is appropriate only when the systematic risk of the project being evaluated is similar to that of the overall business, which is often an unrealistic assumption for innovative projects. A more appropriate approach may be for the business to develop a project-specific, risk adjusted discount rate based on utilizing the capital asset pricing model (CAPM) (Slater et al., 1998). CAPM says that the cost of equity is the risk free rate, as represented by a government-backed security, plus a risk premium. The risk premium is driven by the project's market risk represented by its beta coefficient, which is a measure of the volatility of that project's equity return in relation to that of a diversified market portfolio. Finally, many companies add an additional risk premium to the discount rate to compensate for high levels of uncertainty.

2.2 Traditional Approaches to Deal with Uncertainty

Other approaches, such as sensitivity analysis, Monte Carlo simulation and decision tree analysis, are elaborated on DCF analysis principles and attempt to deal with uncertainty and complexity. This paragraph describes each technique and presents their advantages as well as their main limitations.

2.2.a Sensitivity Analysis

The estimates of cash flows used in any investment valuation are most likely derived from forecasts of other primary variables (price of the product, size and growth of the market, firm's market share, production costs, etc). Sensitivity analysis aims at identifying the key primary variables and determining the impact upon the project's NPV of a given variation in each key variable, with other variables held constant.

Sensitivity analysis starts with a base case scenario where the decision-maker determines the base-case estimates of the key primary variables from which it can calculate the base-case NPV. Then, while keeping all other variables equal to their base-case values, each variable is changed by a certain percentage below and above its base-case value (pessimistic and optimistic estimates). The resulting perturbed NPV values can then give a picture of the possible variation or sensitivity of the project's NPV when a given risky variable is misestimated.

Sensitivity analysis is useful in identifying the crucial variables that could contribute the most to the riskiness of the investment (Brealey and Myers, 1996). A variable may itself have a large variance but may nonetheless make an insignificant contribution to the riskiness of the project's NPV, in which case the investment decision does not depend crucially on the accuracy of its estimate; on the other hand, a less risky variable may be crucial if even marginal errors in its estimate could have a significant impact on NPV. Whether a variable is crucial or not would indicate whether it is worth investing additional time to gather additional information that could reduce the uncertainty surrounding the variable.

However, sensitivity analysis has its limitations as well (Trigeorgis, 1999). First, it considers the effect on NPV of only one error in a variable at a time, thus ignoring combinations of errors in many variables simultaneously. Moreover, examining the effect of each variable in isolation is even less meaningful when there are interdependencies among the variables. A bigger step forward that considers the impact of all possible combinations of variables is achieved through Monte Carlo simulation, considered in the following paragraph.

2.2.b Simulation

Traditional simulation techniques use repeated random sampling from the probability distributions for each of the crucial primary variables underlying the cash flows of a project to arrive at an output probability distribution or risk profiles of the project's NPV. A Monte Carlo simulation usually follows these steps (Esty, 1999):

- Modeling the project through a set of mathematical equations and identities for all the important primary variables, including a description of interdependencies among different variables and across different time periods.
- Specifying probability distributions for each of the crucial variables, either subjectively or from past empirical data. Sensitivity analysis should precede simulation to determine which variables are important and which are not.
- A random sample is then drawn (using a computer random number generator) from the probability distribution of each of the important primary variables enabling the calculation of the project's NPV for each sample.
- The process is repeated many times, each time storing the resulting NPV sample observations so that finally a probability distribution for the project's NPV can be generated.

Although simulation can handle complex decision problems under uncertainty with a large number of input variables, it is not without its own limitations (Trigeorgis, 1999). First, it is very difficult to correctly capture all the inherent interdependencies among the different variables. Second, even if the management wants to base a decision on the probability distribution of NPV, it still has no rule for translating that profile into a clear-cut decision for action. Third, simulation users may be tempted to use as a relevant measure of risk the variability of the project outcomes (i.e. the project's total risk) instead of its systematic risk. Finally, Monte Carlo simulation is a forward-looking technique based on a predetermined operating strategy, inappropriate to handle the asymmetries in the various probability distributions introduced by the management's flexibility to review its own preconceived operating strategy when it turns out that, as uncertainty gets resolved over time, the realization of cash flows differs significantly from initial expectations. We will come back to this point in the next chapters, when introducing the concept of real option.

2.2.c Decision Trees

Another approach that attempts to account for uncertainty and the possibility of later decisions by management is decision tree analysis (DTA). DTA helps management structure the decision problem by mapping out all feasible alternative managerial actions contingent on the possible states of nature (chance events) in a hierarchical manner (Clemen, 1996). Whereas conventional NPV analysis might be misused by managers inclined to focus only on the initial decision to accept or reject a project at the expense of subsequent decisions dependent on it, DTA forces management to bring to the surface its implied operating strategy and to recognize explicitly the interdependencies between the initial decision and subsequent decisions.

The basic structure of the decision setting is as follows (Clemen, 1996): Management is faced with a decision (or a sequence of decisions) of choosing among alternative courses of action; the consequence of each alternative action depends on some uncertain future event which management can describe probabilistically on the basis of past information or additional future information obtainable at some cost. Management is finally assumed to select a strategy consistent with its preferences for uncertain consequences and its probabilistic judgments concerning the chance events. This means that management should choose the alternative that is consistent with the maximization of the risk-adjusted expected NPV.

Decision tree analysis is well suited for analyzing sequential investment decisions when uncertainty is resolved at discrete points in time. It forces also management to recognize explicitly the interdependencies between immediate decisions and subsequent ones, bringing to the surface management's implied operating strategy based on its current information. However, application of DTA has practical limitations in the real world (Keeney, 1993). First, decision-tree analysis can easily become an unmanageable "decision-bush analysis" when actually applied in most realistic investment settings, as the number of different paths through the tree to be evaluated expands geometrically with the number of decisions, outcomes variables, or states considered for each variable. Also, in the real world chance events may not simply occur at a few discrete points; rather the resolution of uncertainty may be continuous: a continuous-time version of DTA might be in a better position to describe real-world problems. A more serious problem is how to determine the appropriate discount rate used in the present value calculations. In principle, the solution is to use as decision criteria the expected utility maximization, but determining the appropriate utility to use is also not an easy task. Traditional DTA is on the right track, but although mathematically elegant it is economically flawed because of the discount-rate problem. As we will develop later, an options approach can remedy these problems.

2.3 Conceptual Problems Embedded in Traditional Approaches

Beyond the simple implementation problems, a growing body of literature (Dixit and al., 1994; Trigeorgis, 1993; Esty, 1999) is criticizing the NPV rule as built on faulty assumptions. It assumes that either the investment is reversible (in other words, that it can somehow be undone and the expenditures recovered should market conditions turn out to be worse than anticipated); either that, if the investment is irreversible, it is a now-or-never proposition (if the company does not make the investment now, it will lose the opportunity forever). Furthermore critics point out that DCF approach overlooks management's flexibility to alter the course of a project in response to changing market conditions.

2.3.a Irreversibility of Investment

Investment expenditures are irreversible when they are specific to a company or an industry (Dixit et al., 1994). A power plant is industry specific in that it cannot be used to produce anything but electricity. One might think that, because in principle that plant could be sold to another power producer, an investment is recoverable and is not a sunk cost. But that is not necessarily true. If the power industry is reasonably competitive, then the value of the plant will be approximately the same for all electric utilities, so there is little to be gained from selling it. The potential purchaser of the plant will realize that the seller has been unable to make money at current prices and considers the plant as a bad investment. If the potential buyer agrees that it's a bad investment, the owner's ability to sell the plant will not be worth much. Therefore, an investment in a power plant should be viewed largely as a sunk or irreversible cost. When a firm makes irreversible investment expenditure, it gives up any possibility to disinvest later should market conditions change adversely. Traditional NPV rule "invest when NPV is positive" does not take irreversibility into account.

2.3.b Now or Never Proposition

A second aspect that is not well treated by traditional approach is the timing of investment (Trigeorgis, 1993). In most cases, a firm has the opportunity to delay its investments. By postponing its expenditure, the company acquires the possibility to wait for new information (in our case, to learn about the evolution of electricity prices or demand) that might affect the desirability of the investment. Especially in the case of irreversible capital investment decisions, the ability to delay is essential. However, the benefit from waiting for new information may be outbalanced by other considerations, such as the risk of entry by other companies or the loss of cash flows.

Traditional approach fails to take this timing aspect into consideration: "If a project as a positive NPV" does not necessarily mean that it is the best time to invest. The right to make the decision to invest optimally – to do what is best when the time comes – is in itself valuable. The crucial decision to invest or not has to be made either after all major uncertainties are resolved or when the time to postpone the decision runs out. Another valuation technique based on several calculations of project's NPV over time is needed to take into account the timing aspect of investment decision.

2.4 Conclusion: Towards an Option Approach to Investment

The management's ability to time its decision to take maximum advantage of any available information is only one aspect of managerial flexibility.

DCF approaches inherently assume that management's future role is passive (even in the most extreme outcomes) once the original investment decision has been made. They cannot properly capture management's flexibility to adapt and revise later decisions in response to unexpected market developments. Traditional NPV makes implicit assumptions concerning an expected scenario of cash flows and presumes management's passive commitment to a certain operating strategy (to initiate the project immediately and operate it continuously at base scale until the end of its prespecified expected life).

In the actual marketplace, characterized by change, uncertainty and competitive interactions, however, the realization of cash flows will probably differ from what management expected initially. As new information arrives and uncertainty about market condition and future cash flows are gradually resolved, management may have valuable flexibility to alter its operating strategy in order to capitalize on favorable future opportunities or mitigate losses. Management's flexibility to adapt its future actions in response to altered future market conditions expands an investment opportunity's value by improving its upside potential while limiting downside losses relative to management's initial expectation under passive management.

The resulting asymmetry caused by managerial adaptability calls for a new approach able to value not only direct cash flows of an investment opportunity, but also managerial operating and strategic adaptability. The real options approach, presented in the coming chapters, has the potential to conceptualize and quantify the value form active management.

Chapter 3

GETTING STA R TED WITH FINANCIAL OPTION

An option is defined (Brealey and Myers, 1996) as the right, without an associated symmetric obligation, to buy (if a call) or sell (if a put) a specified asset (e.g., a common stock) by paying a prespecified price (the exercise or strike price) on or before a specified date (the expiration or maturity date). If the option can be exercised before maturity, it is called an American option; if only at maturity, a European option.

The underlying asset to an option may be one of a large variety of financial or real assets. In this chapter, we will focus on options traded on individual shares of common stock; but it is common to find options traded on stock indexes, on various types of bonds, on various types of commodities (oil, metal, cereal), or on foreign currencies. In the following chapter, we will extend our study to options on real assets or capital projects, and stress the analogy between financial and real options.

This chapter explains how options work and how they are valued. It is organized as follows. Section 3.1 explains the basic nature of options as well as the main drivers of value. In order to quantify the qualitative insights of the previous paragraph, Section 3.2 describes the Black-Scholes option-pricing model. To extend this model, Section 3.3 reviews basic stochastic processes and describes general approach to the valuation of option and contingent claim in general. Section 3.4 summarizes and proposes and extension of the option approach from traded stocks to real assets.

3.1 Basic Nature of Options – Determinants of Value

3.1.a What is an Option?

Let's examine a simple example of call and put options on Amazon stock in December 1999 (data from Wall Street Journal, December 10th 1999). Amazon stock was trading around $104 per share.

Exercise Date	Exercise Price	Price of Call Option	Price of Put Option
January 2000	$100	$14.75	$10.25
July 2000	$100	$28.875	$21.375
January 2000	$120	$9	$23.875

The first line shows that for $14.75 you could acquire an option to buy a share of Amazon stock for $100 on or before January 2000 (in 1.5 months). Moving down in the table, we can see that for a price of $28.875, you could extend your option to buy Amazon stock until July 2000. The last line shows a decrease in the price of a January call option, with an increase in the exercise price to $120. Similarly, the right-hand column of the table shows the value of an option to sell a share of Amazon stock. The second line shows that for $10.25 you could acquire an option to sell Amazon stock for a price of $100 anytime within the next month.

The position diagram on the left shows the possible consequences of investing in Amazon January call options with an exercise price of $100. The outcome depends on what happens to the stock price. If the stock price at the end of this month turns out to be less than the $100 exercise price, nobody will pay $100 to obtain the share via the call option. Your call option will in that case be valueless and you will not exercise your option. On the other hand, if the stock price turns out to be greater than $100, it will pay to exercise your option to buy the share. In this case the call will be worth the market price of the share minus the $100 that you must pay to acquire it.

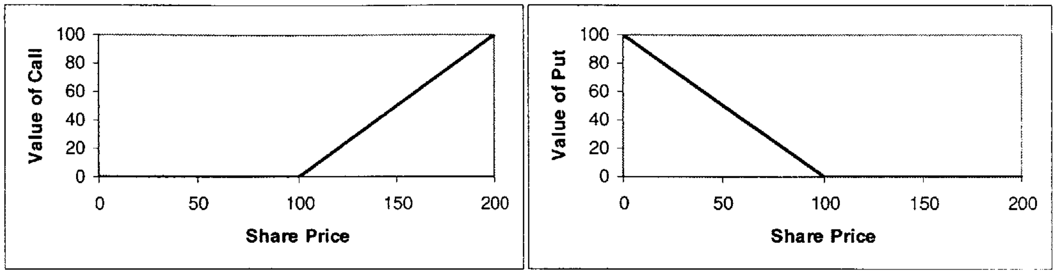


Figure 3.1: Position Diagram for Amazon call and put options.

The position diagram on the right shows the possible consequences of investing in Amazon January put option. The circumstances in which the put turns out to be profitable are just the opposite of those in which the call is profitable. If Amazon share price immediately before expiration turns out to be greater than $100, you won't want to sell stock at that price. You would do better to sell the share in the market and your put option will be worthless. Conversely, if the share price turns out to be less than $100, it will pay to buy a stock at the low price and then take advantage of the option to sell it for $100. In this case, the value of the put option on the exercise date is the difference between the $100 proceeds of the sale and the market price of the share.

Based on Amazon's example, the value of a call at expiration is simply the difference between the stock price and the exercise price, with a minimum value of zero. Similarly, the value of a put is the difference between the exercise price and the stock price, with a minimum value of zero. However, in most cases, when options are traded, there is time left to maturity: the option will have a market value above its value at expiration.

3.1.b What Determines Option Value?

Before attempting formal valuation of options, we can try to understand the determinants of value for an option.

There are upper and lower bounds to which an option can rise and fall (Brealey and Myers, 1996). Figure 3.2 shows the value of a call option for different values of the stock price. The option will never be worth more than the price of the option, because the stock gives a higher ultimate payoff, whatever happens. If at the option's expiration the stock price ends up above the exercise price, the option is worth the stock price less the exercise price. On the other hand, the price of the option can never remain below the value of the call if exercised immediately. It an option was priced below this lower bound, then it would pay any investor to sell a share of stock at its current price and then buy it back by purchasing the option and exercising it immediately.

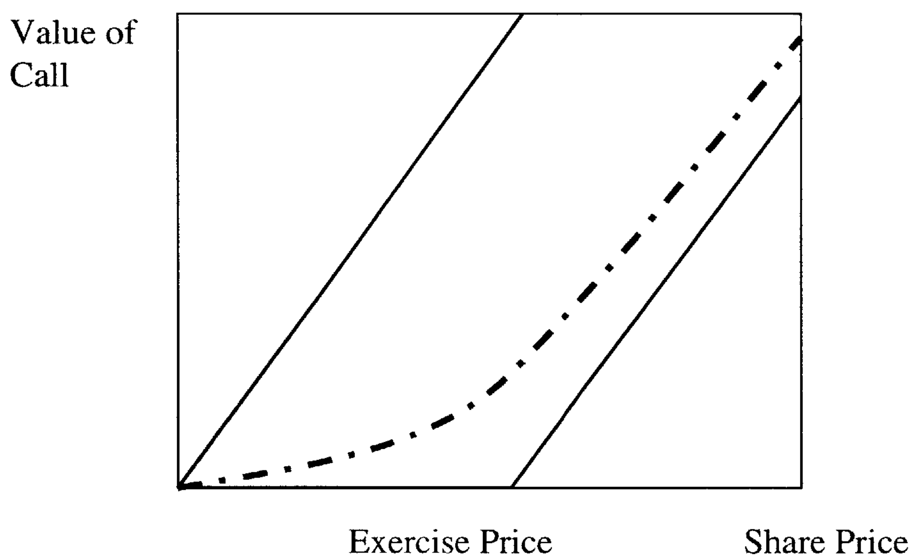


Figure 3.2: Determinants of call option value

In fact, the price of a call option lies on a curved, upward-sloping line like the dashed curved shown in the figure. The line begins at zero then rises gradually becoming parallel to the upward-sloping part of the lower bound. The value of an option increases as the stock price increases, if the exercise price is held constant.

Furthermore, we see that when the stock price becomes large, the option price approaches the stock price less the present value of the exercise price. The higher the stock price, the higher the probability that the option will be exercised. If the stock price is high enough, exercise becomes a virtual certainty; the probability that the stock price will fall below the exercise price before the option expires becomes small. Under these circumstances, buying the call is equivalent to buying the stock but financing the purchase by borrowing the present value of the exercise price. The value of the call is therefore equal to the stock price less the present value of the exercise price. We can also infer from this situation that the value of an option increases with both the rate of interest and the time to maturity.

The value of an option increases with both the variability of the share and the time to expiration. This is because the probability of large stock price changes (and therefore the probability of exercise) during the remaining life of an option depends on the variability of the stock price and the time remaining until the option expires.

The table below summarizes the effect of changes in the key variables on the value of a call option:

Variables	Change in the value of a call option when the variable increases
Stock Price	Positive
Exercise Price	Negative
Interest Rate	Positive
Time to Expiration	Positive
Volatility	Positive

We will in the following section replace the qualitative statements of the previous table with an exact option-valuation model.

3.2 *Black-Scholes Option Pricing*

3.2.a Basic Valuation Idea

The problem of option pricing valuation was finally solved by Fischer Black, Robert Merton, and Myron Scholes by creating an option equivalent portfolio by combining common stock and borrowing (Black and Scholes, 1973; Merton, 1973). The basic idea enabling the exact pricing of options is that one can construct a portfolio consisting of buying a particular number, N, of shares of the common stock and borrowing an appropriate amount at the risk free rate, that would exactly replicate the future returns in any state nature. Since the option and this equivalent portfolio would provide the same future returns, to avoid risk-free arbitrage profit opportunities they must sell for the same price. Thus, the value of the option can be written as:

Value of Call = Value of the number of shares in the equivalent portfolio – Borrowed amount.

The number of shares needed to replicate one call is the hedge ratio or option delta.

The implementation of the dynamic tracking approach is straightforward when we reduce the possible changes in the next period of the stock price to 2, an up move and a down move. This method, known as the binomial method, is very useful to price option in simple discrete-time cases. In theory, the binomial method can be extended by assuming shorter time intervals, with each interval showing 2 possible changes in the stock price. Eventually, we would reach a situation in which the stock price was changing continuously and generating a continuum of possible year-end prices. We could still replicate the call option by a levered investment, but we would need to adjust the degree of leverage continuously as the year went by. Black and Scholes achieved this theoretically and derived a formula for the value of an option.

3.2.b Black-Scholes Formula

The Black-Scholes formula can be written as:

Value of the call option = Delta * Share price – Bank loan
= $N(d_1)*P - N(d_2)*PV(EX)$

Where: $$d_1 = \frac{\log[P/PV(EX)]}{\sigma\sqrt{t}} + \frac{\sigma\sqrt{t}}{2}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

N(d) is the cumulative normal probability density function

EX is the exercise price of the option

PV(EX) is calculated by discounting using the risk-free interest rate r_f

t is the number of periods to exercise date

P is the price of stock now

σ is the standard deviation of the rate of return on the stock.

With this formula, the value of a call option has the same properties that we identified earlier: increases in stock price, uncertainty, time to expiration, and risk free interest rate raise the option value, while increases in exercise price reduce it.

The first term of Black-Scholes formula N(d1)*P represents the expected value of the stock price at expiration. The second term $N(d_2)$ equals the probability to have the stock price greater than the exercise price at expiration.

3.2.c Use of Black-Scholes Formula in Real Life

Black-Scholes formula has been quickly adopted by the financial markets and is currently widely used to price options traded on common stocks. However, to enable an accurate pricing, the formula must be adjusted for dividend effects (Amram et al., 1999). The value of an option on a common stock that distributes dividend is reduced, as the option's holder misses the dividend and should deduct it from the price of the underlying stock. Only, the stockholders obtain the dividend.

The Black-Scholes formula can be adjusted and rewritten as:

Value of the call option = $N(d_1)*P \exp(-\delta*t) - N(d_2)*PV(EX)$

Where: $$d_1 = \frac{\log[P/PV(EX)] + (r - \delta - \sigma^2/2)*t}{\sigma\sqrt{t}}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

δ Is the dividend payout.

The Black-Scholes equation is an elegant and single equation that defines the evolution of the value of an option in terms of the value of its underlying asset, its volatility and the risk-free rate of return. However, this formula is derived from underlying assumptions regarding the evolution process of the stock price and cannot be used in a broad range of situations. Other approaches have been developed to value options in more general and complex situations. We will turn to these valuation methods in the next paragraph.

3.3 Stochastic Process and General Valuation Method

3.3.a Stochastic Process

Stock prices are assumed to follow a stochastic process, i.e. their value changes over time in an uncertain manner. Stochastic processes can be discrete-time (changing only at certain discrete intervals) or continuous-time (subject to change at any time).

A particular type of stochastic process is the Markov process, where only the present state of the process (i.e. the current stock price) is relevant for predicting the future. The underlying idea associated with this model is that the current stock price already reflects all the information contained in the record of past prices, and that the stock prices will change only in response to new information.

A particular type of Markov process is the Wiener process or Brownian motion (Trigeorgis, 1999; Dixit et al., 1994). If a variable z(t) follows a Wiener process, then changes in z, Δz, over small time intervals, Δt, must satisfy 2 important properties:

- Δz over small time intervals are independent. This means that the probability distribution for the change in the process is independent of any other interval.
- Δz are normally distributed, with mean $E(\Delta z)=0$ and a variance that increases linearly with the time interval, i.e. $var(\Delta z)= \Delta t$.

As stock prices are always negative, it is more reasonable to assume that the logarithm of price follows a Wiener process.

The standard diffusion Wiener process (underlying the Black-Scholes formula) can be written:

$$\frac{dS}{S} = \alpha\, dt + \sigma\, dz$$

Where α is the instantaneous expected return on the stock, σ is the instantaneous standard deviation of stock returns, and dz is the differential of a standard Wiener process with mean 0 and variance dt.

The Wiener process is a building block to model a broad range of stochastic variables. However Brownian motions tend to wander far from their starting points: thus, it is sometimes unrealistic in real life situations where for example prices of a commodity tend to come back to their long-run production costs. A mean-reverting process is used to model such behavior (Dixit et al., 1994).

The simplest mean-reverting process is the following:

$$dx = \eta\,(\bar{x} - x)dt + \sigma\, dz$$

Where η is the speed of reversion, and $\bar{x}$ is the normal level of x, that is the level to which x tends to revert. If x is greater (less) than $\bar{x}$. it is more likely to fall (rise) over the next short interval of time.

We will use a mean-reverting process to model the price of electricity (chapter 4) and value any option with this price as underlying asset (chapters 5-7).

3.3.b General Valuation Method – Ito's lemma

The general valuation method is to establish and resolve the partial differential equation that must be satisfied by the value of the option (Trigeorgis, 1999). A partial differential equation describes the conditions that the underlying asset value and the value of the option must satisfy over time with respect of each of the input variables.

Consider an option C(S,t) as a function of an underlying state variable, S, and time, t, only. To value the option or contingent claim, we need to determine how it changes in a small interval of time as a function of the underlying state variable. Ito's lemma is expressing this change as:

$$dC = \frac{\partial C}{\partial t}dt + \frac{\partial C}{\partial S}dS + \frac{1}{2}\frac{\partial^2 C}{\partial S^2}(\sigma^2 C^2 dt)$$

Black-Scholes option pricing is the solution of the following partial differential equation derived from Ito's lemma and the value of the equivalent replicating portfolio for the option:

$$\frac{1}{2}\sigma^2 S^2 \frac{\partial^2 C}{\partial S^2} + rS\frac{\partial C}{\partial S} - \frac{\partial C}{\partial t} - rC = 0$$

The terminal condition of the solution is C(S,0)=max(S-E,0). The lower and upper boundary conditions are C(0,t)=0 and C(S,t)/S→1 as S→∞

Under assumptions different from the one of Black-Scholes solution, we will have to solve the partial differential equation, either analytically or numerically, in order to calculate option values.

3.4 Conclusion: Toward an extension of financial option

In this chapter, we have introduced the basic notion of financial option, determined what was the source of option's value, presented the Black-Scholes formula used widely for option pricing. Finally, a more general approach to valuation has been presented, as well as the concepts of stochastic process and partial differential equation. This overview was aimed at becoming familiar with the option concepts and is the first step towards the option approach to investment.

An opportunity to invest in a project bears an obvious similarity to an option to invest in a corporation's stock. Both involve the right, but not the obligation, to acquire an asset by paying a certain sum of money on or before a certain time. By establishing a mapping between project characteristics and the determinants of option value, a project can be valued in the same way. In the coming chapters, we will use and extend the tools developed for options traded on financial assets to options denominated on real investment opportunities.

Chapter 4

REAL OPTION APPROACH TO VALUATION

The thinking behind financial options can be extended to opportunities in real markets that offer, for a fixed cost, the right to realize future payoffs in return for further fixed investments, but without imposing any obligation to invest.

Companies in every type of industry have to allocate resources to competing opportunities. For existing operating assets or new projects, they have to decide whether to invest now, to take preliminary steps reserving the right to invest in the future, or to do nothing. It is because each of these choices creates a set of payoffs linked to further choices down the line that all management decisions can be thought of in terms of options (Copeland and al., 1998).

This chapter expands financial options to investment opportunities and develops a real options approach to valuation. It is organized as follows. Section 4.1 explains why projects should be viewed as a collection of options on real assets and how to integrate the important operating options. It also defines the most common real options encountered in investment opportunities. Section 4.2 presents real option characteristics, and elaborates on a general classification of capital budgeting situations. To quantify value associated with real options, Section 4.3 describes the different approaches to valuation of real options, e.g. Partial Differential Equation, Dynamic Programming and Simulation.

4.1 From Financial Options to Real Options

4.1.a Managerial Flexibility and Expanded NPV

As we have seen in Chapter 2, the basic inadequacy of the NPV approach lies in its inability to capture management's flexibility. The traditional NPV approach makes implicit assumptions concerning an expected scenario of cash flows and presumes management's commitment to a certain operating strategy. The project's NPV is computed using the expected pattern of cash flows over a prespecified project life and a risk-adjusted discount rate. Treating projects as independent investment opportunities, an immediate decision is then made to accept any project for which NPV is positive.

However, the realization of cash flows will probably differ from what management originally expected. As new information arrives and uncertainty about future cash flows is gradually resolved, management may find that various projects allow it varying degrees of flexibility to depart from and revise the operating strategy it originally anticipated. For example, management may be able to defer, expand, contract, abandon, or alter in various ways a project at different stages during its useful life (Coy, 1999).

Management's flexibility to adapt its future actions depending on the future environment introduces an asymmetry in the probability distribution of NPV that expands the investment opportunity true value by improving its upside potential while limiting downside losses relative to management's initial expectations under passive management (Trigeorgis, 1999). The probability distribution of NPV is truncated with enhanced upside potential as management has the ability to adapt its future decisions in response to the future events evolution. Thus, the true expected value of such an asymmetric distribution exceeds the expected NPV value calculated in absence of managerial flexibility.

This asymmetry calls for an expanded NPV criterion that reflects both components of an investment opportunity's value: the traditional static or passive NPV of expected cash flows and an option premium capturing the value of operating and strategic options under active management (Trigeorgis, 1999). The motivation for using an options-based approach arises from its potential to quantify the option premium or flexibility component of value.

4.1.b Analogy between Fin ancial and Real Options

In order to capture properly the operating flexibility embedded in most projects, we can analyze investment opportunities as collections of options on real assets. Just as the owner of an American call option on a financial asset has the right, but not the obligation, to acquire the financial asset by paying a predetermined price (the exercise price) on or before a prespecified date (the maturity date), and will exercise the option if and when it is in his best interest to do so, so will the holder of an option on real assets.

The owner of an investment opportunity has the right, but not the obligation, to acquire the present value of expected cash flows by making an investment outlay on or before the anticipated date when the investment opportunity will cease to exist. Thus, there is a close analogy between real investment opportunities and call options on stocks, summarized by the following table (Edleson, 1994):

Call option on stock	**Real option on project**
Current value of stock	Present value of expected cash flows
Exercise price	Investment cost
Time to expiration	Time until opportunity disappears
Stock value uncertainty	Project value uncertainty
Riskless interest rate	Riskless interest rate

Most of the value of managerial flexibility can be captured by combining a relative small number of simple options. The most encountered real options can be classified into 6 general categories (Amram et al., 1999; Brealey and Myers, 1996; Leslie and al., 1997): timing (the option to wait or to stage investment), growth options, the option to switch (inputs or outputs), the option to expand scale, the option to contract scale, abandonment options.

4.1.c Common Real Options

The main options are arrayed below on a rough spectrum of the type of news that might cause the managerial respond behind each option (Trigeorgis, 1999):

Abandon **Contract** **Switch** **Wait**

[Currently Invested, Respond to Bad news] [Not Currently Invested]

Expand **Growth**

[Currently Invested, Respond to Good news]

4.1.c.i - Option to wait

Management holds a lease on valuable land or resources. It can wait to see if output prices justify constructing a building or a plant, or developing a field.

Options to wait are important in all natural resource extraction industries, real estate development, farming, and paper products.

4.1.c.ii - Time to build option

Staging investment as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages, and valued as a compound option.

Time to build options are valuable in all R&D intensive industries, especially pharmaceuticals, large-scale construction projects, start-up ventures.

4.1.c.iii - Option to alter operating scale

If market conditions are more favorable than expected, the firm can expand the scale of production or accelerate resource utilization. Conversely, if conditions are less favorable than expected, it can reduce the scale of operations. In extreme cases, production may temporarily halt and start up again.

Options to alter operating scale are valuable in natural resource industries such as mine operations, facilities planning and construction in cyclical industries, consumer goods, and commercial real estate.

4.1.c.iv - Option to abandon

If market conditions decline severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets in secondhand markets.

Options to abandon are valuable in capital-intensive industries such as airlines and railroads; new product introductions in uncertain markets.

4.1.c.v - Option to switch (outputs or inputs)

If prices or demand change, management can change the output mix of the facility (product flexibility). Alternatively, the same outputs can be produced using different types of inputs (process flexibility).

Options to switch are valuable in any industry producing goods subject to volatile demand, e.g. consumer electronics, toys, autos; or using inputs with large price volatility, e.g. oil, chemicals, electric power.

4.1.c.vi - Growth options

An early investment (e.g. R&D, lease on undeveloped land or oil reserves, strategic acquisition) is a prerequisite in a chain of interrelated projects, opening up future growth opportunities (e.g. new generation product or process, oil reserves, access to new market, strengthening of core capabilities).

Growth options are valuable in all infrastructure based or strategic industries, especially high-tech, R&D, or industries with multiple product generations or applications (e.g. computers, pharmaceuticals); multinational operations and strategic acquisitions.

Real options are embedded in most investment opportunities. They are clearly valuable and are an important factor in the resource allocation process (Baghai et al., 1996). In order to take them properly into account, it is important to be able to identify the different types of options embedded in an investment, value them separately and them consider their interactions.

4.2 Real Options Framework

4.2.a Strategic questions

As discussed in the previous paragraph, an investment opportunity can often be analyzed as a real option. In evaluating the value of this option, we must start by considering the 3 following issues (Trigeorgis, 1999; Dixit and al., 1994):

4.2.a.i - Exclusiveness of option ownership

The question of the exclusiveness of option ownership refers to the firm's ability to fully appropriate for itself the option value.

If the firm retains an exclusive right as to whether and when to invest, unaffected by competitive initiatives, its investment opportunity is classified as a proprietary option. Investment opportunities with high barriers to entry for competitors, such as patent for developing a product having no close substitutes, or market conditions that competitors are unable to duplicate for at least some time, are proprietary real options. In such cases, management may have the flexibility to abandon a project early or to temporarily interrupt the project's operation in certain unprofitable periods.

If competitors share the right to exercise and may be able to take part of the project's value away from the firm, then the option is shared. Shared real options can be seen as jointly held opportunities of a number of competing firms and can be exercised by any one of their collective owners. Examples of shared real options are the opportunity to introduce a new product unprotected by patents or with close substitutes; or the opportunity to penetrate a new geographic market without barriers to entry.

Our case study in electricity generating capacity will present various types of proprietary options.

4.2.a.ii - Compoundness

The second strategic question addresses the following issue: "Is an investment opportunity valuable in and by itself, or is it a prerequisite for subsequent investment opportunities?" If the opportunity is an option leading upon exercise to further discretionary investment opportunities, then it is classified as a compound option. Such compound option cannot be looked at as independent investments and must be seen as links in a chain of interrelated projects, the earlier of which are prerequisites for the ones to follow. A R&D investment or a lease on potential oil reserves are examples of compound real options that may be undertaken not just for their direct cash flows but also for the new opportunities that they may open up.

A project that can be evaluated as a standalone investment opportunity is referred to as a simple option.

Our case study in electricity generating capacity will present mainly various types of simple options.

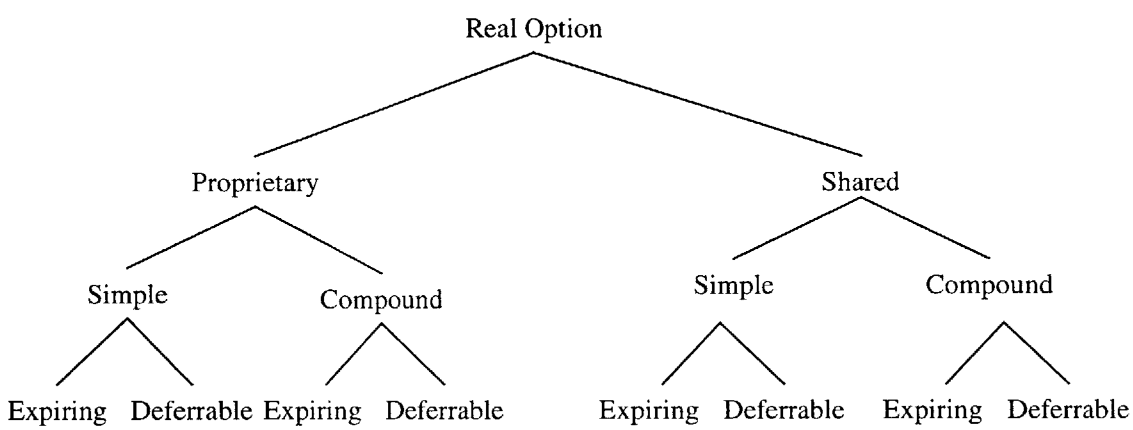
4.2.a.iii - Urgency of decision

The last strategic question refers to the timing nature of investment decision. Management must distinguish between projects that need an immediate accept-or-reject decision, referred to as expiring investment opportunities, and projects that can be deferred for future action, referred to as deferrable real options. Deferrable projects require more extensive analysis of the optimal timing investment, since management must compare the net present value of taking the project today with the net value of taking it at all possible future years. Thus, management must compare the relative benefits and costs of waiting in association with other strategic considerations (threat of competitive entry).

Our case study in electricity generating capacity will present various types of deferrable options.

4.2.b Integrated approach to valuation

Most real investment opportunities can find a place in one of the 8 branches of the options-based classification tree (Trigeorgis, 1999):



For example, routine maintenance can be classified and analyzed as proprietary-simple-expiring option, plant modernization as proprietary-simple-deferrable, a new product introduction with close substitutes as shared-simple-deferrable, an immediate franchise offer as proprietary-compound-expiring, research and development of a unique product as proprietary-compound-deferrable, bidding for the acquisition of an unrelated company as shared-compound-expiring, and the opportunity to enter a new geographic market shared-compound-deferrable.

Our case study in electricity generating capacity will present various types of proprietary-simple-deferrable options.

4.2.c Real Option Value Components

The above options-based classification scheme helps uncover the different value components of the option premium.

The value of the investment is the sum of 2 components (Trigeorgis, 1999):

- Static NPV. Management starts the project immediately and operates is continuously until the end of its preestimated expected useful life.
- Option Premium. The value of premium can be calculated in each of the preceding situations:

Proprietary-Simple-Expiring opportunity (PSE), the possibility of abandonment at an earlier time may become valuable, as well as the value to alter operating scale.

Proprietary-Simple-Deferrable opportunity (PSD), the option premium results from management's flexibility to defer the project, from its ability to abandonment at an earlier time as well as the value to alter operating scale.

Proprietary-Compound-Expiring opportunity (PCE), the option premium equals the sum of value of the PSE opportunity and the value of subsequent investments or compound options.

Proprietary-Compound- Deferrable opportunity (PCD), the option premium equals the sum of value of the PCE opportunity and the value from management's flexibility to defer the project.

Shared opportunities (SSE, SSD, SCE, SCD), the option premium is reduced in comparison with the proprietary case by the amount of the competitive loss. We will not develop shared opportunities in our case study.

This paragraph has allowed us to frame the real option approach to investment valuation, identifying the main characteristics of options as well as explain qualitatively their contribution to the value of a project. The next step is to calculate the option premium value.

4.3 Calculating Real Option Value

There are 3 general ways to calculate the value of an option (Amram et al., 1999):

- The Partial Differential Equation Approach. It solves a partial differential equation that equates the change in option value with the change in value of the underlying assets.
- The Dynamic Programming Approach. It lays out possible futures outcomes and folds back the value of optimal future strategy.
- The Simulation Approach. It averages the value of optimal strategy at decision dates for thousands of possible outcomes.

Within each solution method, there are many alternative computational techniques. Two of them, the binomial option valuation and the Black-Scholes equation, play an essential role and are presented extensively throughout literature.

4.3.a PDE Approach and Black-Scholes Solution

This valuation approach is based on mathematically expressing the option value and its dynamics using partial differential equation (PDE) and boundary conditions. The PDE is a mathematical equation that relates the continuously changing of the option to changes in the values of its underlying assets. Boundary conditions specify the particular option to be valued, its value at known points, and its value at the extremes.

If available, the analytical solution is the easiest and fastest way to obtain the value of an option. In such a solution, the option value is written in one equation as a direct function of the inputs.

The most famous analytical solution is the Black-Scholes equation. A number of others known analytical solutions can be found in many standard references on option valuation. Otherwise, numerical solutions are used to solve the PDE, associated with computational algorithms and integrated software solutions.

With notations used in Chapter 3, the Black-Scholes formula can be written as:

Value of an option = $N(d_1)*P - N(d_2)*PV(EX)$

Where: $$d_1 = \frac{\log[P / PV(EX)]}{\sigma\sqrt{t}} + \frac{\sigma\sqrt{t}}{2}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

N(d) is the cumulative normal probability density function

EX is the expenditures required to acquire the assets

PV(EX) is calculated by discounting using the risk-free interest rate r_f

t is the length of time decision may be deferred

P is the present value of the operating assets to be acquired

σ is the riskiness of the underlying operating assets

The use of this formula allows valuing a project as a European call option, and brings some insight to optimal investment decision.

4.3.b Dynamic Programming Approach and Binomial Option Valuation

Dynamic programming solves the problem of how to make optimal decisions when the current decision influences future payoffs. This solution method rolls out possible values of the underlying asset during the life of the option and then folds back the value of the optimal decisions in the future.

The logic behind this approach is: "Given the choice of the initial strategy, the optimal strategy in the next period is the one that would be chosen if the entire analysis were to begin in the next period." (Bellman principle). The solution solves the optimal strategy problem in a backward recursive fashion, discounting the future values and cash flows and folding them into the current decision.

Dynamic programming is a useful solution method for option valuation because it handles various real assets. Intermediate values and decisions are visible, which allows the user to build a strong intuition about sources of option value. These advantages are present in the binomial option valuation approach.

The binomial option valuation model is based on a simple representation of the evolution of value of the underlying asset: in each time period, the underlying asset can take only one of the two possible values. In the most widely used version, the underlying asset has an initial value A, and within a short period of time either moves up to Au or down to A/u. This process is repeated over time, creating a binomial tree with all outcomes possible for the evolution in time of the underlying asset A.

The calculation is then done using the risk neutral valuation approach. We assume that the investors will be risk-neutral and will be satisfied with a rate of return equal to the risk free interest rate. Given these conditions, it is easy to calculate the implied probability that the asset will rise. We can find the payoff for the option in the next period for the 2 asset values and calculate the expected value of the option. There is generalized formula to determine asset value changes based on the standard deviation of asset returns.

$$Upside\ change + 1 = u = e^{\sigma\sqrt{h}}$$
$$Downside\ change + 1 = 1/u$$
$$\Pr obability\ of\ Upside\ change = \frac{e^{r} - d}{u - d}$$

Where σ is the volatility of the underlying asset, h the interval as a fraction of the year, and r the risk-free interest rate.

4.3.c Simulation Approach

Simulation models roll out thousands of possible paths of evolution of the underlying asset from the present to the final decision date in the option. In the commonly used Monte Carlo simulation method, the optimal investment strategy at the end of each path is determined and the payoff calculated. The current value of the option is found by averaging the payoffs and then discounting the average back to the present.

Throughout the previous 3 chapters, we have introduced, step by step, the real option approach to valuation, comparing it to conventional NPV analysis. Our conclusion is that valuation techniques have to be adapted to the evolution of our economic environment, which is becoming far more volatile and unpredictable. In the second part of this thesis, we will illustrate this point of view by applying this real option framework to electricity market. The power market has known in the last decade a trend towards deregulation and an increasing competition among electricity's producers. As a result, selling price of electricity has become market-driven. Its high volatility has lead to dramatic changes in the economics of electricity production and required development of improved valuation techniques for electricity generating capacity.

Chapter 5

ELECTRICITY MARKET & DEREGULATION

Electric utilities, one of the largest remaining regulated industries in the United States, are in the process of transition to a competitive market. Traditionally vertically integrated, the industry will in all probability be segmented at least into its three component parts: generation, transmission, and distribution.

The old school of thought that considered electric power generation as a natural monopoly has given way to a new philosophy. Today, there is a widespread view among legislators, regulators, industry analysts, and economists that generation of power supply would be more efficient and economical in a competitive market. In contrast, transmission and distribution will remain regulated and non-competitive.

This change began in 1978, when the Public Utility Regulatory Policies Act (PURPA) made it possible for non-utility generators to enter the wholesale power market. Since then, energy commodity markets have been growing rapidly as electricity market reforms are spreading both at the Federal and States levels. The volume of trade for electricity has surged from 27 million MWh in 1995 to 1,195 million MWh in 1997.

This chapter explains how the industry is currently organized and studies the consequences of competition on electricity price. It is organized as follows. Section 5.1 presents the industry structure, the drivers of its change as well as the wholesale markets that have emerged. Section 5.2 describes the consequences of competition on electricity prices and actual characteristics of prices. Section 5.3 explains why electricity derivatives have emerged in conjunction with a competitive marketplace. Finally, it develops a stochastic model of futures contracts prices on electricity that will be used later for real options calculations.

5.1 Electric Power Generation Structure

5.1.a Electricity Generation Players

The different players in the market are divided between utilities and non-utilities. Utilities are public agencies and privately owned companies, which generates power for public use. Non-utilities are privately owned entities that generate power for their own use and/or for sale to utilities.

There are 5 types of utilities in the US:

- Investor (or Privately) Owned Utility (IOU): regulated by State; earn a return for investors; 239 in the country.
- Federally Owned Utility: power is not generated for profit; 10 in the country.
- Other Publicly Owned Utility: are non-profit State and local government agencies; serve at cost; most just distribute power but some large ones produce and transmit; 2,009 in the country; operate virtually in all areas of the United States.
- Cooperatively Owned Utility: owned by members (small rural farms and communities) and provide service mostly to members only; 912 in the country.

- Power Marketers: a new subcategory who buy and sell electricity; do not own or operate generation, transmission, or distribution facilities; approximately 80 are now actively engaged in wholesale trade.

Non-utilities consist of Cogenerator facilities and Small Power Producer. Cogenerators sequentially produce electric energy and another form of energy, such as heat or steam, using the same fuel source. Some are qualified under the Public Utility Regulatory Policies Act by meeting certain criteria and therefore are guaranteed that utilities will purchase their output. Small Power Producers use renewable resources (bio-mass, geothermal, solar, wind, and hydroelectric) as a primary energy source.

The amounts of energy generated by each component of utilities and non-utilities in 1998 are compared with the amounts generated in 1988 in figure 5.1 (Source: www.eia.doe.gov):

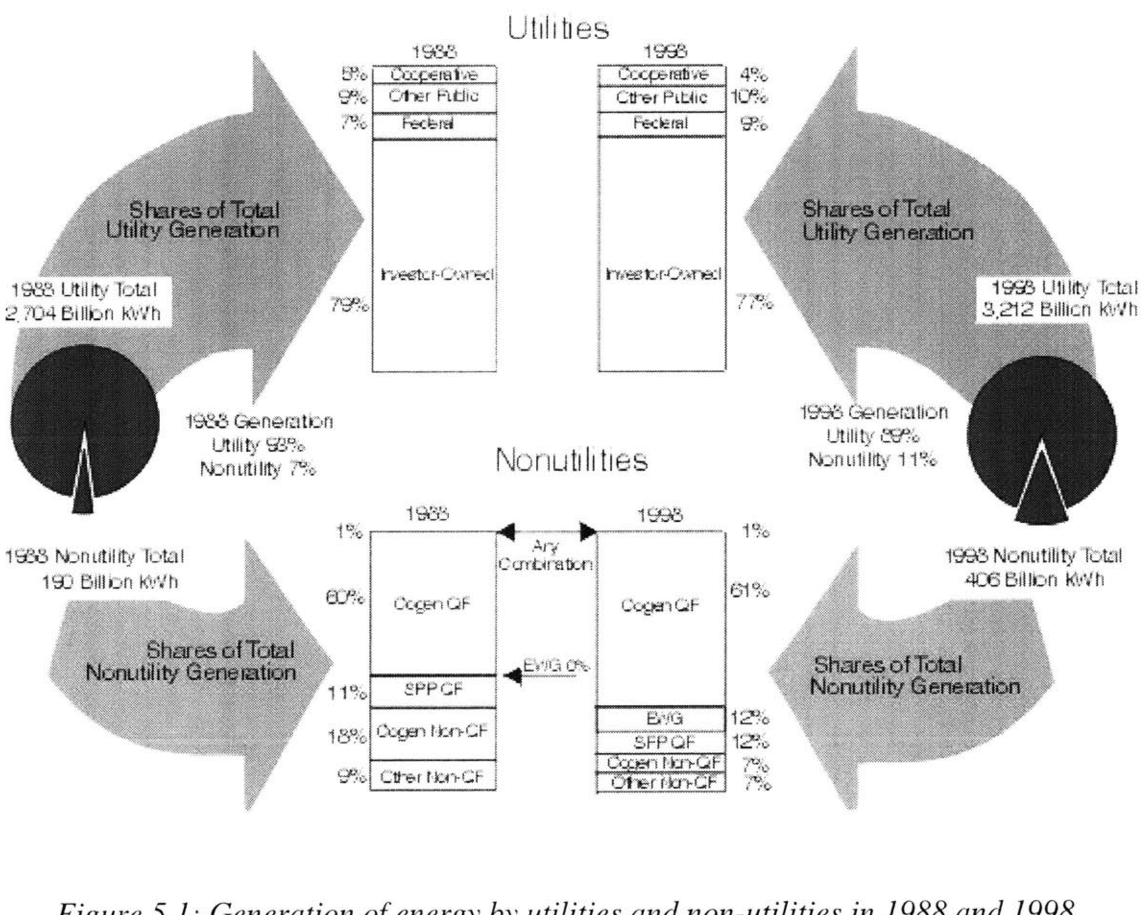


Figure 5.1: Generation of energy by utilities and non-utilities in 1988 and 1998.

From this figure, we can infer the relative position of each component in the energy supply arena, with around 90% of energy produced by utilities (70% by Investor Owned utilities, 20% by other utilities). We can also notice that the non-utility segment has been growing significantly during the past decade (from 7% in 1988 to 11% in 1998).

5.1.b Competitive Market Organization

The US bulk power system has evolved into three major networks, which also include smaller groupings or power pools. The major networks consist of extra-high-voltage connections between individual utilities designed to permit the transfer of electrical energy from one part of the network to another.

The 3 networks are the Eastern Interconnected System, the Western Interconnected System and the Texas Interconnected System, as shown in figure 5.2.

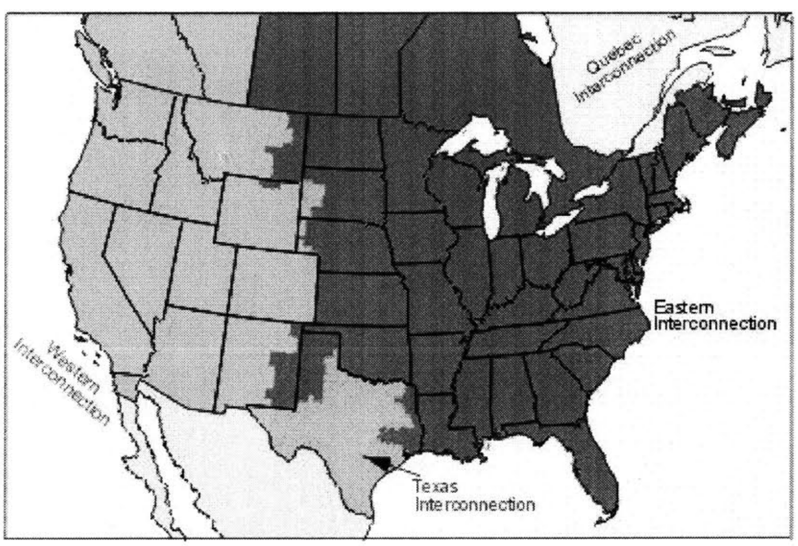


Figure 5.2: Bulk power network in the United States.

The bulk power system makes it possible for utilities to engage in wholesale electric power trade. Wholesale trade plays an important role, allowing utilities to reduce power costs, increase power supply options, and improve reliability. Since 1986, the total amount of wholesale power trade among utilities and non-utilities has grown at an average annual rate of 2.7 percent. In 1998, utilities purchased a total of 1,664 billion kilowatt-hours of wholesale electricity form other utilities and a smaller but increasing amount 249 billion kilowatt-hours from non-utility producers, as shown in figure 5.3 (Source: www.eia.doe.gov):

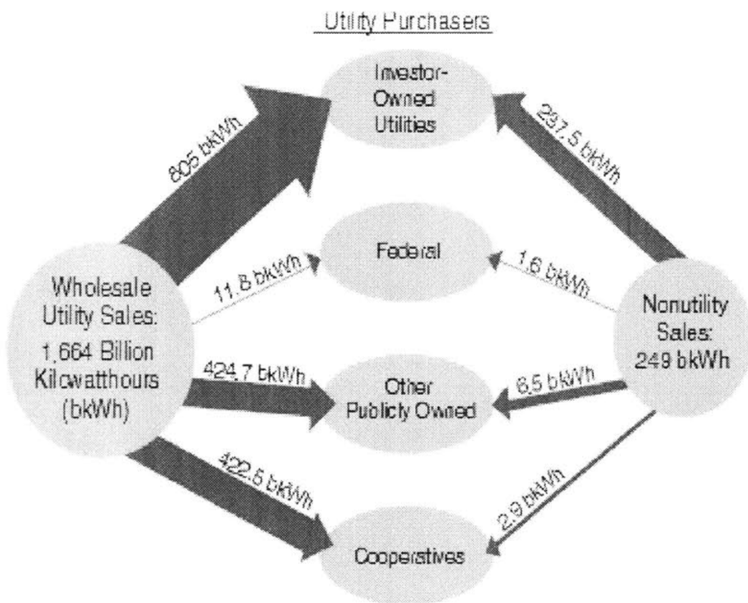


Figure 5.3: Wholesale power sales in 1998.

Wholesale power sales by non-utilities to utilities and wheeling (the transmission of power from one point to another) by utilities have both grown vigorously. Wholesale sales by non-utilities grew from 40 to 249 billion kilowatt-hours between 1986 and 1995, which yields an average growth rate over the period of 21%. Wheeling grew at an annual rate of 7% over the same period.

5.1.c Drivers of Change

Several Factors have motivated the changes occurring in the electric power industry:

- **Advancements in power generating technology**. New generators are cleaner and use less fuel. Technological advancements have enabled non-utilities to generate electricity at lower cost than utilities that use older fossil-fueled or nuclear-fueled steam-electric technologies. New generators can be built and put into operation quickly, sometimes as an alternative to utility capacity at existing central station plants.

- **Legislative and regulatory mandates.** The Public Utility Regulatory Policies Act of 1978 (PURPA) stipulated that electric utilities had to interconnect with, as well as to buy capacity and energy offered by non-utility facilities. In 1996, Order 888 opened transmission access to non-utilities, thereby establishing wholesale competition. Order 889 requires utilities to establish electronic systems to share information about available transmission capacity.

- **Regional electricity price variations across the U.S.** Large industrial consumers, located in States where electricity prices are significantly higher than those in other States, have used their influence to convince State legislators and regulators to take actions that will lower electricity prices. In 1998, the average revenue from electricity sales to industrial consumers ranged from 2.6 cents per kilowatt-hour in Washington to 9.4 cents per kilowatt-hour in Hawaii. Average revenue from electricity sales to all consumers ranged from 4.0 cents per kilowatt-hour in Idaho to 11.9 cents per kilowatt-hour in New Hampshire and averaged 6.7 cents per kWh nationwide.

5.2 Effect of Competition on Electricity Price

5.2.a Characterizing Competitive Electricity Prices

Electricity production has different characteristics from other commodities. In part this is why electricity production and distribution in the US has been a regulated monopoly for most of the century, and continues to be so in most other countries. The original justifications were the economies of scale in both production and distribution. While those concerns have been mitigated by technology other characteristics continue to make electricity unique among commodities.

They include:

- **Lack of storability**. Electricity is costly to store, resulting in greater price volatility, as it is prohibitively costly to arbitrage across time periods.
- **Inelastic demand**. Existing electricity demand patterns reflect the fact that few customers respond to short-term changes in spot prices for electricity. Most customers still pay fixed prices based on rate schedules set by regulators. Short-run demand curves are nearly vertical. The yearly residential price elasticity in New York State, for example, has been estimated to be an inelastic 0.042 (Ethier and Mount 1998).
- **Restrictive transportation networks**. Electricity supply in a given region is restricted by the transmission network, meaning that outside suppliers are often unable to respond to price signals even if they have available generating capacity. This is exacerbated by problems of market power (Ethier and Mount 1998).
- **Kinked supply curve**. Existing generation plant produces a supply stack, which while flat for much of the stack, becomes steeply sloped as maximum generating capacity is approached. When coupled with inelastic demand, this produces large price swings for small changes in demand when system generators approach maximum capacity.

5.2.b Behavior of Electricity Spot Price

The previous characteristics influence strongly the behavior of electricity spot price. To illustrate this statement, you will see in figure 5.4 the pattern of price spikes in the Californian Power Exchange market (Source: http://www.CalPX.com). The Californian Power Exchange was formed in April 1998 to coordinate buying, selling and transmitting of electricity in California.

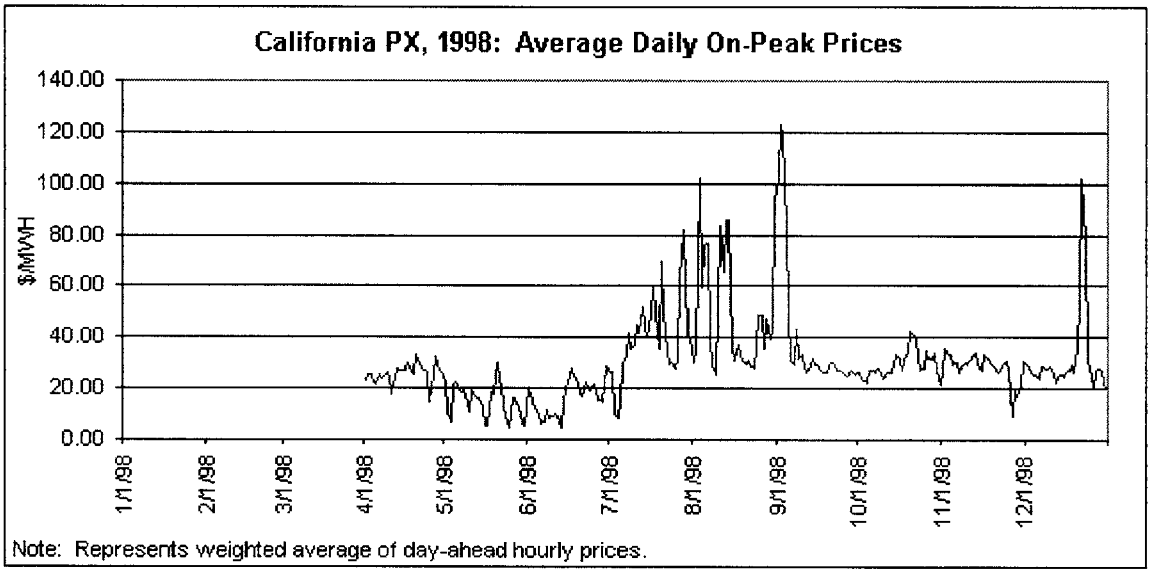


Figure 5.4: Electricity spot price in the Californian Power Exchange Market.

As shown in the above figure, the key properties of electricity prices are:

- **Mean Reversion**. Electricity prices fluctuate around values determined by the cost of production and level of demand. In the short run, mean reversion results from the cyclical, mean-reverting nature of demand, but in the long run it results from bounds imposed by the cost of new generation.
- **Seasonal Effects**. The mean price of electricity in individual markets varies by time of day, week and year in response to cyclical fluctuations in demand of the

same frequencies. The precise shape and magnitude of the price cycles observed depend on the patterns of economic activity and weather in the region, and on the characteristics and ownership structure of the region's generation assets.

- **Price-dependent Volatility.** Like the mean price of electricity, the volatility of electricity varies cyclically with price as fluctuations in demand move different generating assets to the limit of their profitability. Price volatility increases with price level.
- **Occasional Price Spikes.** Electricity prices exhibit occasional positive price spikes when either key generation of transmission assets suffer an outage or, because of an unusual load condition, demand reaches the limits of available capacity. When the relevant recedes, prices quickly return to more typical levels. Negative spikes occur when operating costs or constraints limit the ability of generators to stop production during brief periods of reduced demand.

5.2.c Stochastic models of Price Paths

In order to develop further any real options approach of investment in electricity generating assets, we need to understand the dynamic behavior of spot prices and build effective models of power prices, based on the available data of deregulated electricity markets.

The unique behavior of electricity prices suggests that effective models of electricity prices must include variations in mean price and price volatility by time of day, week and year and must be market specific. They should reflect also the strongly mean-reverting nature of prices, and need to allow for brief positive and negative spikes.

2 models that possess some of these features are presented below: mean reverting process and mean reverting process with jumps. The numerical value of their parameters will be presented based on values found in the literature.

5.2.c.i - Mean-Reverting Processes

The most noticeable price behavior of energy commodities is the mean-reverting effect. When the price of a commodity is high, its supply tends to increase thus putting a downward pressure on the price; when the spot price is low, the supply of the commodity tends to decrease thus providing an upward lift to the price.

As a result, the classical stochastic process, Geometric Brownian Motion (GBM) is an unsuitable process for electricity prices. The variance of GBM increases linearly with time, whereas electricity price exhibit mean reversion and hence bounded variance. Mean reversion is a better choice to model the behavior of the logarithm of electricity spot prices, as noted in Tseng and Barz (1998), and Deng, Johnson and Sogomonian (1998) and for commodity markets in general as in Schwartz (1997).

The simplest mean-reverting process, also known as an Ornstein-Uhlenbeck process, is the following:

$$dx = \eta(\bar{x} - x)dt + \sigma\, dz$$

η is the speed of reversion

$\bar{x}$ is the normal level of x, that is the level to which x tends to revert. If x is a commodity price, then $\bar{x}$ might be the long-run marginal cost of production of this commodity.

σ is the variance parameter and dz is the increment of a Wiener process as defined in Chapter 3.

If the value of x is currently x_0 and x follows a mean-reverting process then its expected value in any future time is $E(x_t) = \bar{x} + (x_0 - \bar{x})e^{-\eta t}$ and its variance is

$$Var(x_t - \bar{x}) = \frac{\sigma^2}{2\eta}(1 - e^{-2\eta t})$$

Dixit and Pindyck (1994) show that the parameters of the mean-reverting process can be calculated using discrete-time data by running the regression

$$x_t - x_{t-1} = a + b x_{t-1} + \varepsilon_t \text{ , and then calculating } \begin{aligned} \bar{x} &= -\frac{a}{b} \\ \eta &= -\log(1+b) \\ \sigma &= \sigma_\varepsilon \sqrt{\frac{\log(1+b)}{(1+b)^2 - 1}} \end{aligned}$$

Where σ_ε is the standard error of the regression.

In addition to mean-reversion, the second important characteristic of electricity spot price is the presence of jumps and price spikes. We will introduce in the next paragraph a two states version of the mean reverting process, in which electricity prices can jump discontinuously between a high and a low state.

5.2.c.ii - Mean-Reverting Processes with Jumps

We extend the previous model for the logarithm of electricity spot price considering a process with two states:

- A low state with a mean reverting process with mean $\bar{x}_1$, a speed of reversion $\bar{\eta}$, and a variance $\bar{\sigma}_1$.
- A high state with a mean reverting process with mean $\bar{x}_2$, a speed of reversion $\bar{\eta}$, and a variance $\bar{\sigma}_2$.

The model allows 2 states, which can persist, rather than isolated and independent jumps. This is important because jumps in electricity prices are often driven by extreme weather or plant outages, which tend to persist for more than one period.

Regime switching is controlled by a two state Markov process, with state specific transition probabilities, which allow different expected duration for each state. The matrix of conditional jump probabilities is written:

$$p = \begin{bmatrix} p & 1-q \\ 1-p & q \end{bmatrix}$$

Where

p is the probability of entering the low state in time t conditional on being in the low state in time t-1.

q is the probability of entering the high state in time t conditional on being in the high state in time t-1.

1-p is the probability of entering the high state in time t conditional on being in the low state in time t-1.

1-q is the probability of entering the low state in time t conditional on being in the high state in time t-1.

Those probabilities mean that conditional on being in the low state, the low state is expected to persist for $\frac{1}{1-p}$ and conditional on being in the high state, the high state is expected to persist for $\frac{1}{1-q}$

For any given day during the forecast period, the unconditional state probabilities can be calculated as $\pi = \frac{1-q}{(1-p+1-q)}$. π is the unconditional probability of being in low state. 1-π is the unconditional probability of being in high state.

5.2.c.iii - Spot Price Data and Parameters Values for Stochastic Model

Ethier and Mount (1998) estimated model parameters for the PJM East hub, using daily on-peak spot price data. PJM is electricity market in North America, with a service area including all or part of Pennsylvania, New Jersey, Maryland, Delaware, Virginia and the District of Columbia, as shown in figure 5.5 (Source: http://www.pjm.com/).

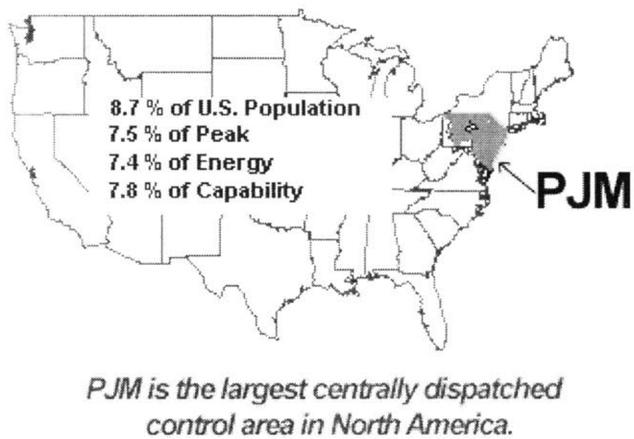


Figure 5.5: Cover area of PJM electricity market

To account for seasonality, the data for each market have been divided into 3-month seasons. Winter is defined as December through February, with the remaining seasons following appropriately. The logarithm of electricity spot price is modeled as a mean reverting process with jump,.

Results of the various regressions are given in the following table:

Season	Mean in Low State x_1 ($/MWh)	Mean in High State x_2 ($/MWh)	Autoregressive Parameter η	Variance in Low State σ_1	Variance in High State σ_2
Winter	3.08	3.25	0.90	0.0035	0.0298
Spring	3.10	3.21	0.73	0.0032	0.0419
Summer	3.21	3.65	0.73	0.0091	0.1177
Fall	3.25	3.43	0.88	0.0028	0.0298

The probabilities are given in the following table:

Season	Prob. Cond. in Low State p	Prob. Cond. in High State q	Prob. Uncond in Low State π	Prob. Uncond in High State $1-\pi$
Winter	0.96	0.74	0.86	0.14
Spring	0.96	0.87	0.78	0.22
Summer	0.89	0.84	0.60	0.40
Fall	0.92	0.64	0.83	0.17

The means of the 2 states are higher in the summer and fall than in the other 2 seasons. They diverge by a larger amount during summer than during other seasons. The variance behaved similarly, with a high level in the summer and similar levels for the other seasons. These results are in accordance with the fact that the system has the highest load in the summer, and prices the highest volatility.

The unconditional probabilities support the mean reverting jump model: prices are generally in a low state but occasionally jump to a higher level. In the summer, electricity prices are significantly in the higher level.

The importance of understanding and effective modeling electricity prices lies in the fact that such models affect the accuracy of the accuracy of activities including the structuring, pricing, trading and risk management of physical and financial contracts. Standard derivative pricing models based upon the dynamic behavior of equity prices (Geometric Brownian Motion) are inappropriate.

5.3 Electricity Derivatives

5.3.a Types of Derivatives

Deregulation is changing the electricity generating industry from an almost regulated environment with fixed output price to a volatile market-based marketplace. To mitigate short-term and long-term output price risk, the energy industry, i.e. producers and consumers, is developing new financial instruments. Generally, energy producers are looking for a fixed income stream, and energy consumers are seeking protection from fluctuating market prices. We will present in this paragraph the main type of electricity derivatives, that have emerged and that we will use in the next chapter to develop our real options approach.

5.3.a.i - Forward markets

A forward power transaction is an agreement to buy or sell a specified amount of power at a specified electrical delivery point at a certain future time for a certain price. A forward contract is generally outside exchanges, in the over-the-counter market.

One of the parties to a forward transaction assumes a long position and agrees to buy electricity on a certain specified future date for a certain specified price. The other party assumes a short position and agrees to sell electricity on the same date for the same price. The price in a forward contract is known as the delivery price.

The success of a forward contract depends on its liquidity (ease with which the commodity can be bought and sold in the market) and the performance of the market players (ability to comply with the terms of the contract).

5.3.a.ii - Futures markets

Like a forward transaction, a futures contract is an agreement between 2 parties to buy or sell electricity at a certain time in the future for a certain price. Unlike forward contracts, futures contracts are normally traded on an exchange.

To make trading possible, the exchange specifies certain standardized features of the contract. As the two parties to the contract do not necessarily know each other, the exchange also provides a mechanism that gives the two parties a guarantee that the contract will be honored.

One way in which a futures contract is different from a forward contract is that an exact delivery date is usually not specified. The contract is referred by its delivery month, and the exchange specifies the period during the month when delivery must be made. The holder of the short position has the right to choose the time during the delivery period when it will actually make delivery.

We will provide examples of forward contracts traded on the New York Mercantile Exchange (NYMEX) in the next paragraph.

5.3.a.iii - Power options

The buyer of a call option has the right, but not the obligation, to receive power in a given location of a given number of MWh at a prespecified price, the strike price of the option. The buyer of a put option has the right, but not the obligation, to sell power in a given location of a given number of MWh at a prespecified price, the strike price of the option.

It should be emphasized that an option gives its holder the right to do something. The holder does not have to exercise this right. This fact distinguishes options from forwards and futures, where the holder is obligated to buy and sell the underlying asset. On the other hand, whereas it costs nothing to enter into a forward or futures contracts, there is a cost to acquire an option.

5.3.b Derivatives traded on the New York Mercantile Exchange

NYMEX is the world's largest physical commodity futures exchange, and the preeminent trading forum for energy, and precious metals, in North America. Futures contracts are traded on electricity, crude oil, gasoline, heating oil, natural gas, propane, gold, silver, platinum, palladium, and copper.

In the development of the electricity futures contract, the Exchange has recognized that a division of the market into 3 broad regions: the eastern United States, the western part of the continent and Texas. To provide companies in the electric power industry with risk management tools, the NYMEX has created a series of electricity futures contracts fashioned to meet the particular regional needs and practices of the industry.

5.3.b.i - Contracts Specifications

The first two electricity contracts that the Exchange created were launched on March 1996 for the Western United States; one is based on delivery at the California/Oregon border, named COBEX, and the other at the Palo Verde switchyard, named Palo Verde futures contracts. Further in time, the NYMEX has designed 2 other futures contracts; one serving portions of Ohio, Indiana and Kentucky, named Cinergy; and the other serving portions of Louisiana, Arkansas, Mississippi and East Texas, named Entergy. Eastern United States has then developed their futures contracts for Pennsylvania, New Jersey and Maryland, named PJM futures contracts.

The contracts specifications are summarized in the following table.

Name	Palo Verde	COBEX	PJM	Cinergy	Entergy
Trading Unit	864 MWh	432 MWh	736 MWh	736 MWh	736 MWh
Delivery Location	Palo Verde Switchyard	California/ Oregon interconnection	PJM western Hub	Cinergy Trans System	Entergy Trans System
Delivery Period	1 month	1 month	1 month	1 month	1 month

5.3.c Futures Contracts Pricing

Prices of futures contracts for different delivery times are given in figure 5.6. Data come from the NYMEX web site www.nymex.com.

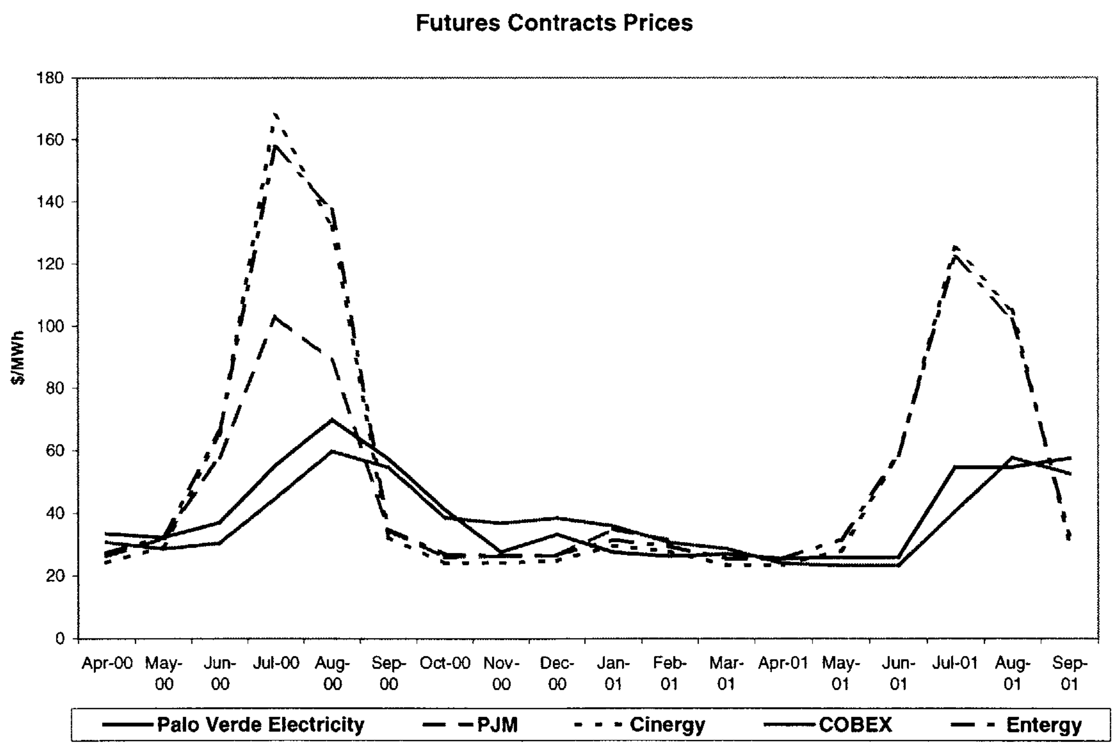


Figure 5.6: Evolution of Futures Contracts Prices.

The behavior of forward prices presents the same characteristics as its underlying asset, electricity price: mean reversion towards the cost of production (around $25 MWh), seasonal effects and occasional price spikes in summer.

As mentioned in the literature (Eydeland (1999), Ethier (1999)), the main difficulty in the valuation in power derivatives is due to the fact that it is impractical to store electricity. This creates major obstacles for extending the central notion used for valuing commodities derivatives, which is convenience yield.

The convenience yield is by definition the difference between the positive return from owning the commodity for delivery and the cost of storage. These 2 quantities cannot be specified because of the impossibility of storing power. As a result, all classical pricing formulae for futures with delivery at any time in the future cannot be used.

However, as shown by Eydeland (1999), the evolution of the power futures curve can be represented if we model correctly the evolution of fuel prices and demand. Under certain assumptions, the evolution of futures price can be modeled using the standard geometric Brownian motion with an appropriately term structure. Then, we can derive from this structure an implied volatility of futures prices stochastic behavior.

Based on our review of the literature, we will choose for our numerical application an annualized volatility of electricity price movements of 30%. We will also use the PJM futures contract specifications and its current price at $26 MWh.

We have seen in this chapter the main drivers of electricity deregulation as well as its effect on the power generation industry in the United States. The emergence of a competitive market place has a significant impact on electricity price behavior, leading to volatility and uncertainty. To mitigate those new risks, companies are using markets for electric power to buy and sell power in advance for later delivery. We will explore in the coming chapters the consequences of those practices on valuation of investments as well as their impact on producers' operating strategies.

Chapter 6

VALUING CAP A CITY WITH SPREAD OPTIONS

Previous chapters have presented the change in the US electricity market and the development of increasingly complex and volatile wholesale markets. This trend towards deregulation is currently reshaping the way all the players operate in the industry. Traditionally, utilities used to evolve in a price-regulated environment, characterized by stability. Capacity planning was driven by market demand with a long-term time horizon. Electricity price was almost considered as a fixed variable.

The new landscape taking shape differs dramatically from the previous model. Recently in the US, truly competitive generation markets have arrived, supported by an explicit competitive market structure. Clearly, asset development and management strategy that were effective in the late 1980s are not sufficient in such a competitive market environment. Utilities need to rethink their business models as well as operating strategies.

This chapter develops a valuation approach for electricity-generating capacity based on stochastic behaviors of electricity and gas prices. It is organized as follows. Section 6.1 presents the concept of heat rate and spark spread option. Section 6.2 values the option to sell electricity at any time in the future based on the option to exchange one commodity for another. Section 6.3 applies this real-options valuation method to an electricity-generating plant and compares to results obtained with traditional approaches.

6.1 Heat Rate and Spread Option

We consider throughout this chapter the case of a natural gas power plant. It purchases natural gas on the spot market and also sells the electric power on the spot market. The spot market is defined as the shortest time frame that allows trading of both electricity and natural gas commodities, which can be the month ahead market. We will base our application on the electricity futures contracts traded on the NYMEX as presented in Section 5.3 of the previous chapter.

To characterize natural gas futures contracts, we will use the Henry Hub Natural Gas futures contract traded on the NYMEX since April 1990. For numerical application, the current price of this contract is $2.6 /MMBtu and its annualized volatility assumed to be 25%.

6.1.a Heat Rate

A power plant is basically transforming natural gas to electricity. Associated with this transformation is a measure of energy conversion efficiency, or heat rate. Heat rate is the ratio of energy input required to produce one unit of power output.

The standard unit for heat rate is expressed in Btu per kilowatt-hour (Btu/kWh). A lower heat rate implies higher unit operating efficiency. Typical operating heat rates of current state of the art combined cycle gas turbines (CCGT) range from 6,800 to 7,500 Btu/kWh, while older steam units can exceed 12,000 Btu/kWh, depending on the technology employed.

Given the spot prices for electricity and natural gas, the plant operator should run the generation unit only if it is profitable to do so, meaning that:

Spot Power Price > Operating Heat Rate * Spot Natural Gas Price

In the decision to operate or not the plant, only variable costs associated with production are considered. Other fixed costs (staff, overhead, depreciation) don't enter in the decision process as most of them are sunk costs and have to be incurred regardless of the decision to operate or not the plant.

The heat rate represents the quantity of natural gas that the operator must purchase to produce one MWh of electricity output. If the above condition holds, by purchasing natural gas, generating electricity, and selling that electric energy, the plant owner is guaranteed to obtain an operating profit. On the other hand, the operator can choose not to run the generation unit if the prices are not favorable when revenue is less than cost.

We can define a spot market heat rate MHR, which is the ratio of the spot power price to the spot natural gas price $MHR = \frac{P_e}{P_g}$. Whenever this spot market heat rate is above the operating heat rate of a natural gas power plant, its operator makes a profit by purchasing the gas and selling the generated electricity.

6.1.b Option Approach

This ability of the plant owner to elect whether or not to operate confirms that operating a gas power plant has the basic characteristics of owning a real option. Using the terminology of Chapter 4, this option is Proprietary (the generator owns exclusively the option), Simple (standalone decision to operate the plant or not) and Deferrable (the generator can decide whenever he operates its plant).

Throughout the chapter, we will use π as the profit per MWh, P_e as the spot price of electricity in \$/MWh, P_g as the spot price of natural gas in \$/MMBtu and HR as the operating heat rate of the power plant in MMBtu/MWh.

The profit derived from the plant can be written $\pi = \max(P_e - HR * P_g, 0) = \max((MHR - HR)P_g, 0)$.

The profit per MWh is equal to the maximum of the price of electricity minus the product gas price and plant operating heat rate, or zero. Positive profits are earned when the price of electricity is greater than the generation costs. Negative profits are not possible, because under such circumstances the generator would shut down the plant and earn zero profit rather than to operate at a loss.

Looking into the future, both P_e and P_g are uncertain, so the above equation is not just a call option with a fixed exercise price. Rather it is a spread call option, in which the profit margin is exactly the spread between the sale price of electricity and the fuel cost incurred to generate that energy.

6.1.c Numerical Example

We can illustrate the previous equation with a power plant with an operating heat rate of 9 MMBtu/MWh.

We assume the spot electricity price to be traded at $26 /MWh and the gas at $2.6 /MMBtu. The spot market heat rate is therefore 10 MMBtu /MWh. The plant is said to be in the money and the generator should take advantage of the power-gas spread and exercise this option by selling power at $26 /MWh and buying gas at $2.6 /MMBtu.

When the spot market heat rate dips below the operating heat rate, running the unit would incur a net loss, so the best decision is to shut down.

Figure 6.1 presents the profit curve for the plant for different electricity and gas prices.

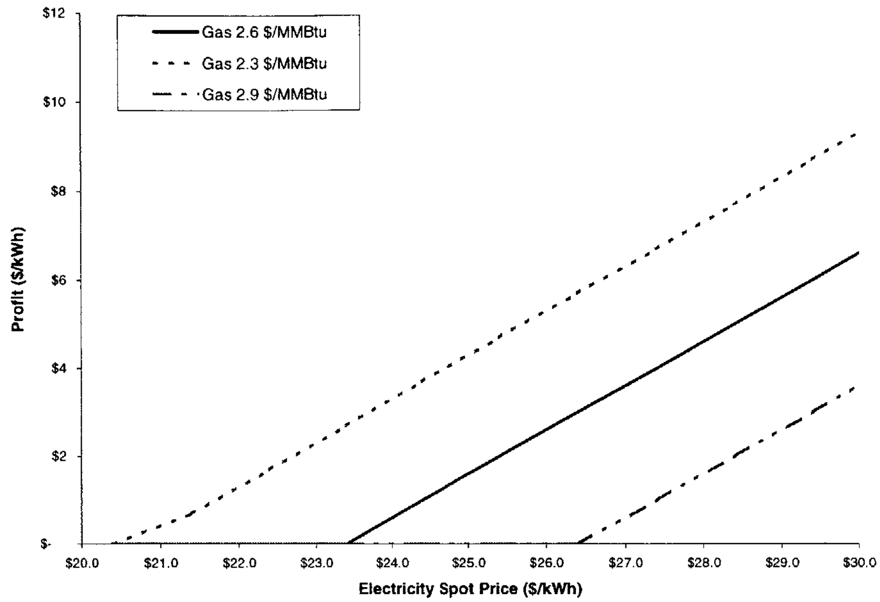


Figure 6.1: Profit curves for different electricity and gas prices.

Owning a natural gas power plant is equivalent to holding a series of spark spread call options with different expiration dates.

6.2 Spark Spread Options Valuation

6.2.a Option to exchange one commodity for another

As seen previously, generating electricity is equivalent to transform gas in electricity, which is one example of exchange between one commodity, natural gas, and another commodity, electricity. The real option to operate or not the plant will be valued using the general model of the option to exchange one commodity for another.

The exchange option model gives the value of an option to exchange the input commodity IN for the output commodity OUT. When the option matures, the payoff will be the maximum between the spread (IN-OUT) and 0. Using Margrabe's (1978) model, the general form for the expression of the current value of the option would be:

$$Value = e^{-rt}(\alpha IOUT_0 - \gamma IN_0)$$

Where OUT_0 and IN_0 represent the present spot prices for the commodities.

R is the risk free interest rate, and t the time to maturity.

The values of α and γ depends upon the time to maturity, the volatility of each commodity, and the correlation between the prices changes of the 2 commodities, and are given by the following relations:

$$\alpha = N(d_1)$$
$$\gamma = N(d_2)$$
$$d_1 = \frac{\ln(OUT/IN)}{\sigma\sqrt{t}} + \frac{\sigma\sqrt{t}}{2}$$
$$d_2 = d_1 - \sigma\sqrt{t}$$
$$\sigma^2 = \sigma_{in}^2 + \sigma_{out}^2 - 2\sigma_{in}\sigma_{out}\rho_{in,out}$$

Where N(..) is the normal probability density function

T is the time

σ_{in} and σ_{out} are the respective variance of the IN and OUT commodities

$\rho_{in,\ out}$ is the correlation coefficient for the price change.

6.2.b Spark Spread Option Calculation

We can apply the previous model for electricity and natural gas. For this purpose, we consider that each month the operator of a plant must decide given the prices of 1-month futures prices on electricity and gas whether to operate or not its plant. The value of any spark spread call option in the future t under the present futures contracts prices is the following: $Value(t) = e^{-rt}(\alpha F_e(0,t) - \gamma HR * F_g(0,t))$

$$\alpha = N(d_1)$$
$$\gamma = N(d_2)$$

Where $d_1 = \dfrac{\ln(F_e(0,t) / HR * F_g(0,t))}{\sigma\sqrt{t}} + \dfrac{\sigma\sqrt{t}}{2}$

$$d_2 = d_1 - \sigma\sqrt{t}$$
$$\sigma^2 = \sigma_e^2 + \sigma_{gt}^2 - 2\sigma_e\sigma_g\rho_{e,g}$$

$F_e(0,t)$ is the current futures price for an electricity forward contract with maturity at time t in the future.

$F_g(0,t)$ is the current futures price for a natural gas forward contract with maturity at time t in the future.

HR is the operating heat rate of the unit under consideration.

σ_e is the annualized volatility electricity price movements, implied from market trading information.

σ_g is the annualized volatility natural gas price movements, implied from market trading information.

$\rho_{e,g}$ is the correlation between electricity and natural gas price movements, estimated from historical spot price data.

6.2.c Application

6.2.c.i - Base Case Value

The previous model has been implemented using an Excel spreadsheet and the following value for the various parameters:

T	F_e	F_g	HR	σ_e	σ_g	$\rho_{e,g}$	r
1 year	$26/MWh	$2.6/MMBtu	9,000 Btu/MWh	30%	25%	0.30	5%

Today's value for a spark spread call option expiring in 1 year is $ 4.45 /MWh. Without the option approach, the discounted profit of operating the plant in 1 year is calculated by the following formula: $\pi = \exp(-0.05*1)(26-9*2.6) = \$2.47 / MWh$

The option premium comes from the volatility of electricity and gas prices and the ability to choose not to operate in case of anticipated operating loss. The option value at any time in the future is shown in figure 6.2.

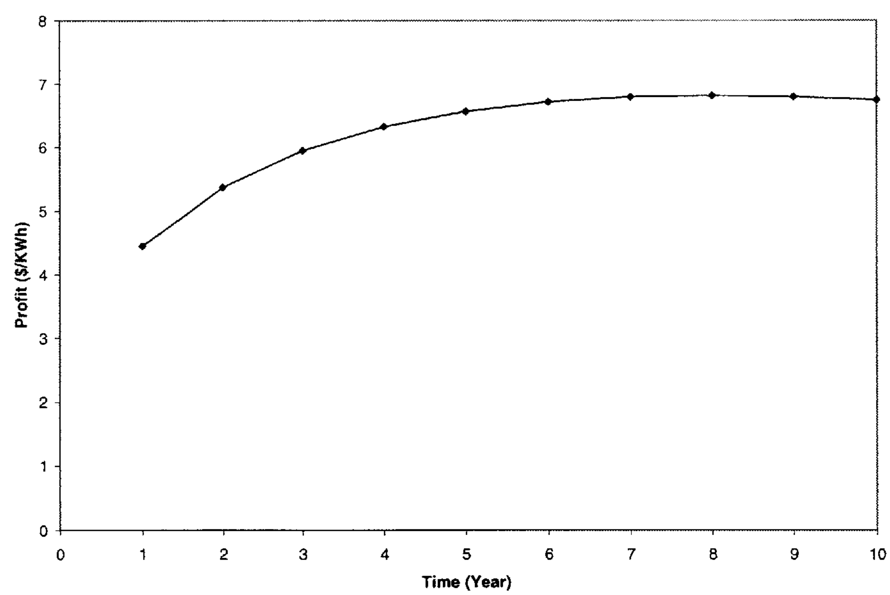


Figure 6.2: Value of spark spread option over time.

The value of the option increases over time as potential price differences between gas and electricity increases, leading to a potential greater profit.

6.2.c.ii - Sensitivity Analysis

We have conducted the following sensitivity analysis of the base case spread option value:

- **Heat Rate**

The sensitivity of the option value to the heat rate is shown in figure 6.3. As heat rate increases, plant are less efficient and requires higher spread between electricity and gas prices to justify a profitable operation. This results in a decrease of option value when heat rates increase.

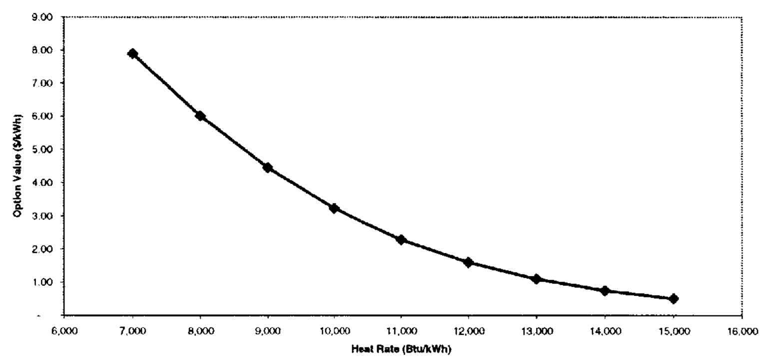


Figure 6.3: Sensitivity of option value to Heat Rate.

- **Price Volatility**

Figure 6.4 plots the sensitivity of the spark spread call option value at various price volatilities for gas and power, with correlation fixed at 0.30. Again, we see that option prices can change greatly depending on our assumptions.

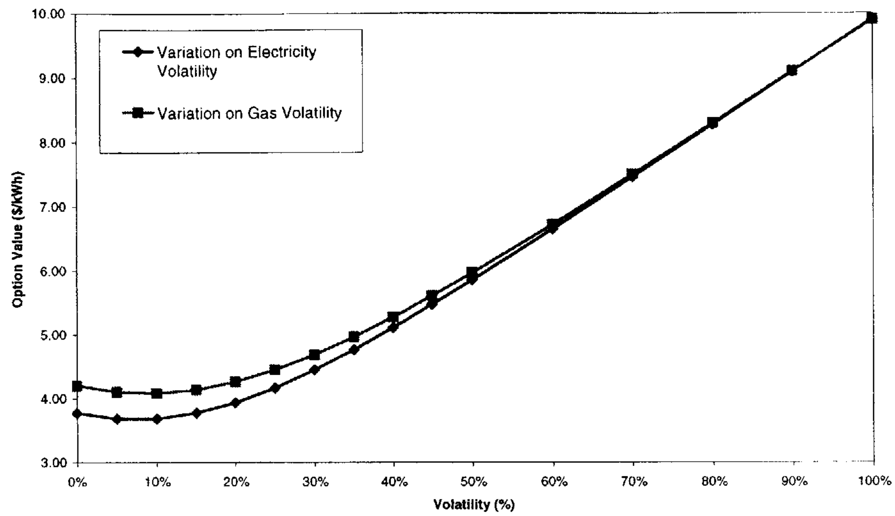


Figure 6.4: Effect of volatility on option value.

The value of the option increases as both volatility increase, as potential price differences between gas and electricity increases.

- **Correlation between price movements**

Figure 6.5 compares the spread option value at different correlation numbers; given other parameters constant. When correlation is negative, power and gas prices tend to move away from each other (e.g., high power prices and low gas prices) implying a high value for the spark spread call option. Conversely, positive correlation suggests that power and gas prices move together so the chance of a big spark spread is low, and so is the value of the option.

A negative correlation between 2 commodities can happen in the short run, especially in situation of disequilibria or shocks. However in the long run, prices tend to move in the same direction, implying a positive correlation.

As the correlation approaches to one, the option value converges to the profit margins derived from current futures prices, or $2.47 /MWh.

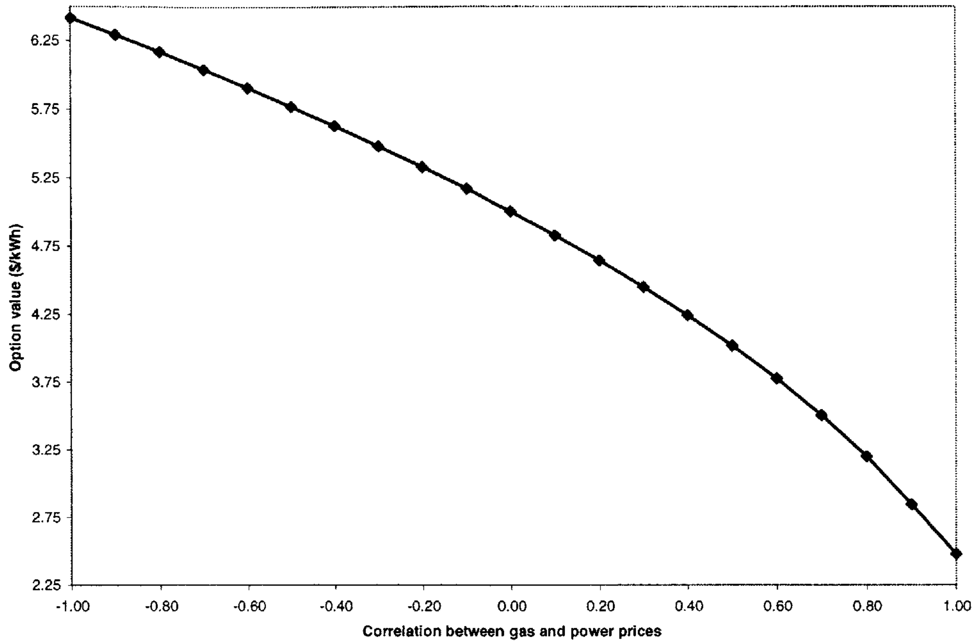


Figure 6.5: Effect of correlation between gas and power prices on option value.

- **Risk Free Rate**

The sensitivity analysis on this parameter reveals a low influence of interest rate on option value. A 5% increase in interest rate causes only a \$ 0.3 /kWh decrease in option value. A 5% decrease in interest rate causes only a \$ 0.3 /kWh increase in option value.

We have developed in this section a model to calculate spark spread option value over different time horizons and have seen the influence of the different model parameters on our option value. We will now use this simple option model to value natural gas plant. The present value of the plant is the sum of the present value of each spark-spread option calculated over the life of the plant.

6.3 Valuing Natural Gas Plant

6.3.a Base Case Valuation

We assume that the power plant is a 300 MW unit. In accordance with the futures contract specifications (Section 5.3), it can operate 16 hours a day (on-peak hours) and 23 days a month, leading to 110,400 MWh per month. The plant life is assumed to be 10 years, or 120 months.

The plant value is calculated by:

$$Plant\ Value = \sum_{t=1}^{120} SSC(t) * (110{,}400 MWh)$$

Spreadsheets with detailed calculations are given in Annex 1.

6.3.b Valuation Results and Comparison with traditional approach

The total present value of the power plant in our Base Case is $ 81 million.

We compare this value with the value obtained with the traditional approach. Under the traditional approach, we assume that expected profits (calculated as the difference between futures prices) are discounted to present value using the risk-free rate 5%. The traditional approach value is $ 27 million, or a value inferior by almost 200%.

Thus, the option premium is $ 54 million. This option premium comes from the generator's ability to shut down the plant in case of adverse price conditions, preventing him to incur any operating loss and taking only advantage of favorable spread movements.

In addition, Net Present Value is further reduced if the discount rate is increased to take into account the risk inherent to the operation of the plant. The impact of the discount rate used in the traditional approach is given in figure 6.6:

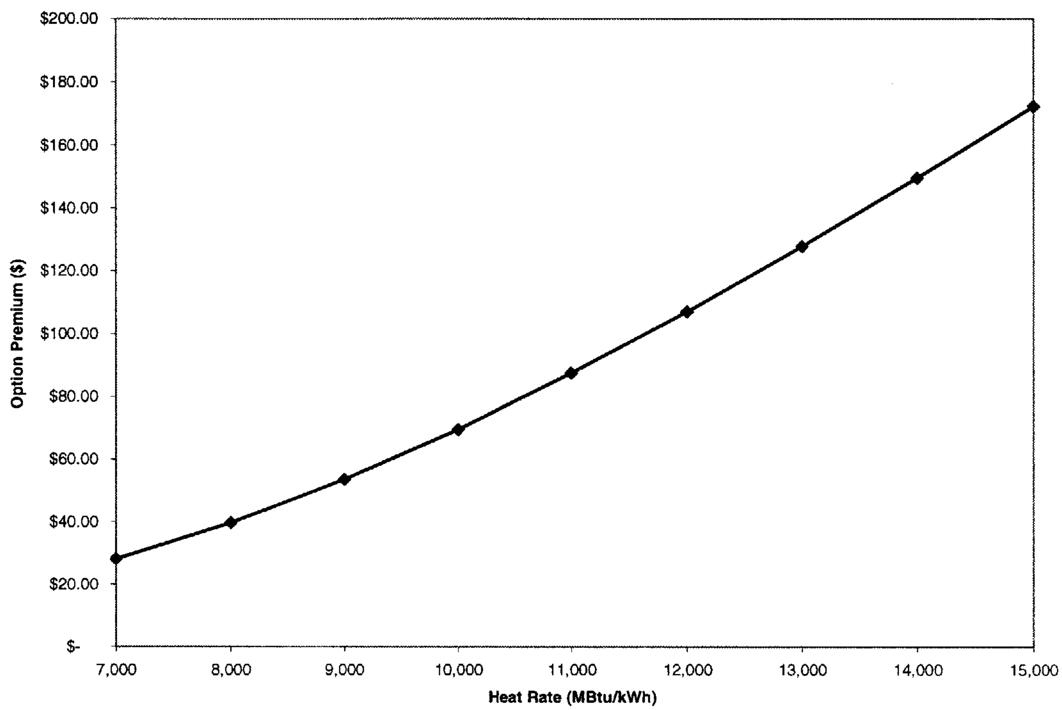


Figure 6.6: Effect of discount rate on the difference between option and traditional approaches.

6.3.c Sensitivity Analysis

6.3.c.i - Heat Rate

The influence of the heat rate on the option premium (difference of profit between the option approach and the traditional approach) is plotted on figure 6.7.

Option premium increases with the heat rate (less efficient plants). We can explain this result by the fact that less efficient plants are operating only on peaking factors and therefore are profitable to the extent that they can be shut down during low price seasons.

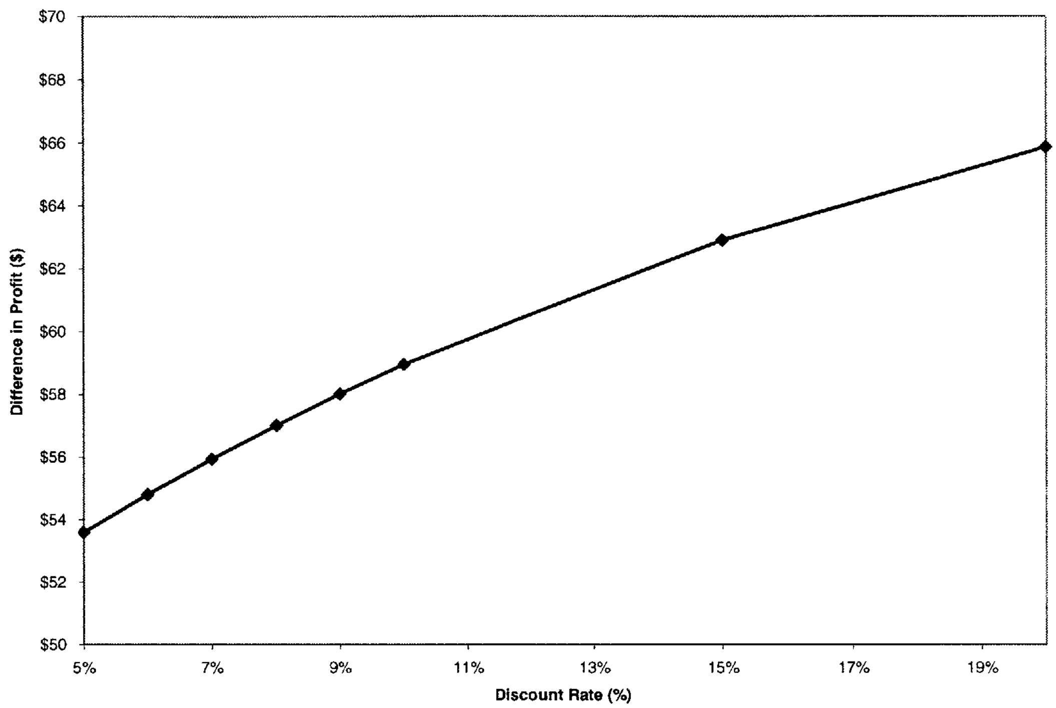


Figure 6.7: Influence of heat rate on option premium.

6.3.c.ii - Volatility

Figure 6.8 plots the sensitivity of the option premium value at various price volatilities for gas and power, with correlation fixed at 0.30.

The explanation is the same as for the value of a simple spark spread option.

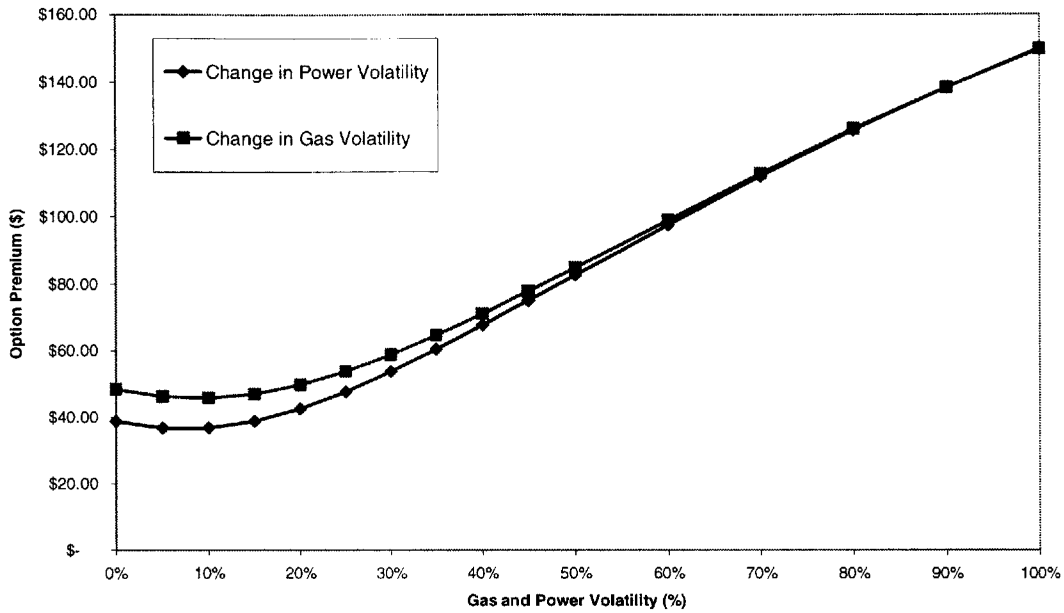


Figure 6.8: Influence of Volatility on option premium.

6.3.c.iii - Correlation

Figure 6.9 compares the spread option value at different correlation numbers; given other parameter values remain the same.

When correlation is negative, power and gas prices tend to move away from each other (e.g., high power prices and low gas prices) implying a high value for the spark spread call option and thus a high option premium. Conversely, positive correlation suggests that power and gas prices move together so the chance of a big spark spread is low, and so is the value of the option premium. As the correlation approaches to one, the option value converges to the profit derived from the traditional approach.

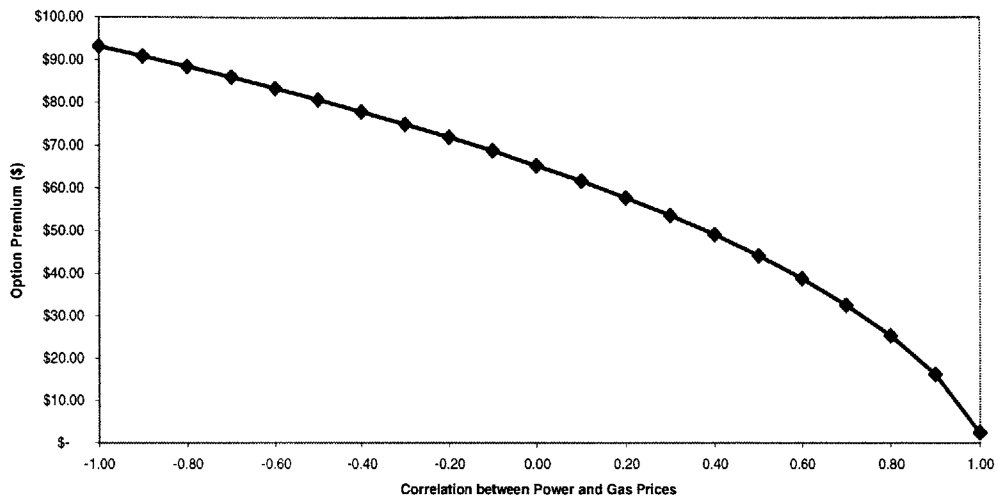


Figure 6.9: Influence of correlation on option premium.

6.3.c.iv - Conclusion

We have seen in this chapter that operating a power plant is equivalent to owning a portfolio of spark spread options between electricity and the plant's input fuel, which was natural gas in our example. Indeed, on any given period of time, one should run the plant only if power market price is higher than the cost of fuel.

This approach allows us to value electricity-generating capacity, taking into account the volatility of electricity and natural gas prices. The most valuable real option in this case is to shut down the plant in order to mitigate anticipated operating loss. The option premium associated represents a substantial amount of a plant's total NPV (around 70%). Its value is influenced by various parameters, such as the heat rate, the volatility of electricity and gas prices, as well as the correlation between the 2 prices movements.

Several directions are possible to extend further our approach:

- A better knowledge of the different parameters will allow more accurate pricing, especially regarding the behavior of futures contracts (volatility and correlation between electricity and gas).
- This real options approach should be adapted to incorporate more realistic situations, such as the presence of fixed operating costs and start-up time.

Another way to extend this approach is to incorporate electricity derivatives in our analysis and see how the combination of trading and asset strategy may affect the expected return of the power generator. We will develop this idea in the next chapter.

Chapter 7

RISK MANAGE MENT USING DERIVATIVES

A direct consequence of deregulation was the advent of a new generation of businesses created for the purpose of marketing electric power. Commonly known as power marketers, these businesses have little or no assets tied to the generation and transmission of electric energy. After few years, utilities realized how successful where those new entrants and that power marketing was becoming a key component in the new competitive environment.

The traditional players of the industry begin to answer to these competitive threats by investing in the creation of their own marketing arms, as well as forming strategic alliances with some of the most successful marketers. In forming these alliances, utilities hoped to better focus on managing the risks associated with electricity distribution, while leaving the supply risks to their more sophisticated allies. The purpose of this chapter is to understand the reasons for this strategic move.

This chapter discusses the strategies that plant operators can use to optimize the revenues from their generating plants. It is organized as follows. Section 7.1 presents the implications of forward contracts on operating profits. Section 7.2 develops a model of different trading strategies based on Monte Carlo simulations. Section 7.3 concludes on the needs for an integrated approach to effectively manage price risk and suggests some further developments.

7.1 Hedging Positions Using Futures Contracts

The purpose of this chapter is to investigate how different hedging positions can impact the profitability of an electricity generating plant. We will continue to use the natural gas plant presented in Chapter 6 as our base case for numerical calculations.

7.1.a Back to back Physical Forward Contracts

We assume in this paragraph that the plant owner has signed one-year back-to-back forward physical contracts at prevailing futures prices, i.e. $26 /MWh for electricity and $2.6 /MMBtu. Heat rate is still assumed to be 9,000 Btu/kWh.

Back-to-back contracts involve simultaneously selling electric energy at $26/MWh and buying enough gas at $2.6/MMBtu to satisfy the electricity commitment, which means for each MWh of electricity sold to buy 9 MMBtu of gas. The effect of back-to-back contracts is to lock in a profit margin of $2.6/MWh over the next 12 months.

7.1.b Effect on Plant Profitability

Evaluating potential profits for next year is more complicated than just simply discounting the margins based on the fixed prices of the previous paragraph. Using put-call parity concepts, we recognize that the combination of a spark spread call option position and forward commitments equals a spark spread put option position plus some discounted profit margin (Shimko (1994)).

$$\text{Value}_{\text{Spark Spread Call Option}} = \text{Value}_{\text{Spark Spread Put Option}} + e^{-rT} * (F_e(0,T) - HR * F_g(0,T))$$

Where $F_e(0,T)$ is the electricity forward contracts expiring a time T

$F_g(0,T)$ is the natural gas forward contracts expiring a time T

e^{-rT} is the discount factor.

The component of the previous equation $e^{-rT} * (F_e(0,T) - HR * F_g(0,T))$ is the present value of the profit margin given the current power and gas futures prices as calculated by the generator. Entering into the back-to-back contracts allows the generator to turn its spark spread call position into a spark spread put position.

A spark spread put position allows him at expiration time T, to buy electricity and sell gas if prices are favorable. Prices are favorable in the case of the put option if

Spot Power Price < Operating Heat Rate * Spot Natural Gas Price

Which is, given our numerical value, if Market Heat Rate < 9,000

So, if the spot market heat rate falls below a plant's operating heat rate, the operator should exercise the put option by buying back the power and selling the gas, which is all done without ever turning on the machine.

7.1.c Numerical Examples

To illustrate the previous concept, consider the following examples.

7.1.c.i - Case 1

Spot price of power rises to $30/MWh while the price of gas spikes to $4/MMBtu.

The implied market heat rate in this case is 30/4, which is 7,500 Btu/kWh. To maximize its profits, the generator should elect not to turn on the unit and simply close the existing electricity and gas positions by buying the power and selling gas on the spot markets at the spot prices, yielding revised profits of:

Profit = ($26/MWh-$30/MWh) + ($4/MMBtu-$2.6/MMBtu)*9MMBtu/MWh

Profit = -$4/MWh + $12.6/MWh = $8.6/MWh

The generator originally sold electricity on the forward market for $26 /MWh. To fulfill this physical obligation, the generator must now purchase replacement power on the spot market at the prevailing price of $30/MWh. Therefore; a $4/MWh loss accrues on the electricity transaction. On the other hand, the generator gained handsomely on the long gas position. The gas originally purchased for $2.6/MMBtu now sells on the open market for $4/MMBtu. Multiplying the $1.4/MMBtu profit by 9 MMBtu/MWh yields a gain of $12.6/MWh on the gas transactions. Consolidating the power and gas positions, we see that the generator comes out ahead to the tune of $8.6 per MWh.

Given that the generator had previously entered into profitable fixed-price contracts for electricity and gas, he made an additional $6/MWh profit when the market heat rate fell below the unit's operating heat rate.

As already noticed in Chapter 6, only variable costs associated with production are considered in the decision to operate or not the plant and in the calculation of our operating profit. Other fixed costs (staff, overhead, depreciation) don't enter in the decision process as most of them are sunk costs and have to be incurred regardless of the decision to operate or not the plant.

7.1.c.ii - Case 2

Spot power price turns out to be $18/MWh and gas price to be $1.5/MMBtu.

The implied market heat rate in this case is 18/1.5, which is 12,000 Btu/kWh. To maximize its profits, should the generator shut down the plant and unwind power and gas contracts? If yes, the profit for the generator would be:

Profit = ($26/MWh-$18/MWh) + ($1.5/MMBtu-$2.6/MMBtu)*9MMBtu/MWh

Profit = \$8/MWh - \$9.9/MWh = -\$1.9/MWh

This negative profit is far below the profit per MWh of \$5/MWh obtained if the generator fulfils its forward contracts, which is to sell electricity at \$26/MWh and buy gas at \$2.6/MMBtu.

Thus, in this case, the generator should operate the plant and fulfils its forward contracts, locking in a \$2.6/MWh profit margin.

7.1.c.iii - Summary

The profit of the plant can be determined in all cases by the following equations:

- If Market Heat Rate > 9,000 then Profit = \$2.6 /MWh. The plant fulfils its forward contracts.
- If Market Heat Rate < 9,000 then Profit = \$2.6 /MWh + Spot Gas Price*(9,000 – Market Heat Rate).

The general formula for this profit is

Profit = \$2.6/MWh + Spot Gas Price*Max (0,9000-Market Heat Rate)

Figure 7.1 illustrates the profit for a gas generator with fixed price contracts on power and gas at different market heat rate and gas price.

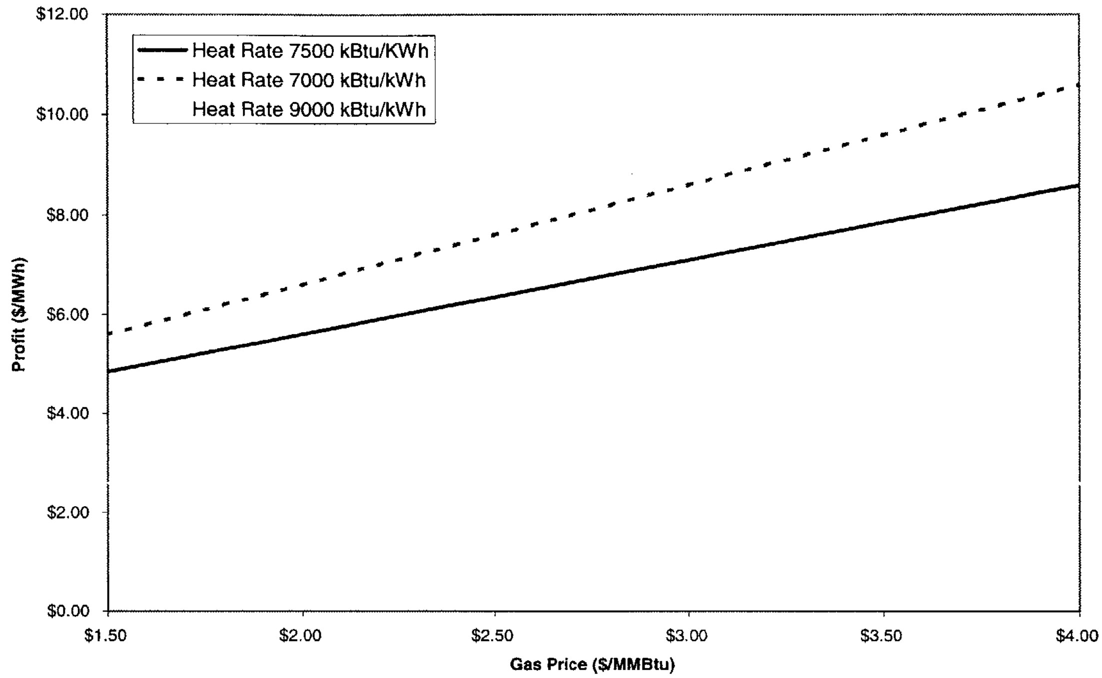


Figure 7.1: Influence of hedging on profit.

The plant owner has exchanged the upside profit potential for the put option's protection against downward movements in the market heat rate.

7.2 Hedging Analysis Using Monte-Carlo Simulation

In this paragraph, we will try to develop further the results found previously using probability distributions for electricity and gas prices. We will build a valuation model of our plant under different hedging schemes. We will run Monte Carlo simulations using Crystal Ball software.

The model is presented in Annex 2.

7.2.a Value of an Unhedged Plant

As we have seen before, an unhedged plant (or naked plant) has an intrinsic value stream that can be earned by buying gas on the spot market and placing the plant's output into the electricity spot market. This is simply the value of the option to convert gas to power when the price relationships favor it. Again, there is no loss from this option because the plant buys fuel only when it exercises its option to make electricity. It has no forward obligations. In our model, we have used normal distribution for spot prices of electricity and gas with the following parameters:

	Electricity	Natural Gas
Mean Price	$26 /kWh	$2.6 /MMBtu
Standard Deviation	30%	25%

We used a normal distribution for spot prices as, a monthly forward purchase of natural gas has a near zero present value on the day it is transacted (J. Hull (1998), J. Roark (1999)). Thus, the value of monthly position liquidated in the market has a symmetric distribution of possible outcomes with an expected value at the forward price. Heat Rate is assumed to be 9 MMBtu/MWh. Profit is calculated as Max (0, Electricity Price -9*Gas Price).The probability outcomes for profit is given in the figure 7.2:

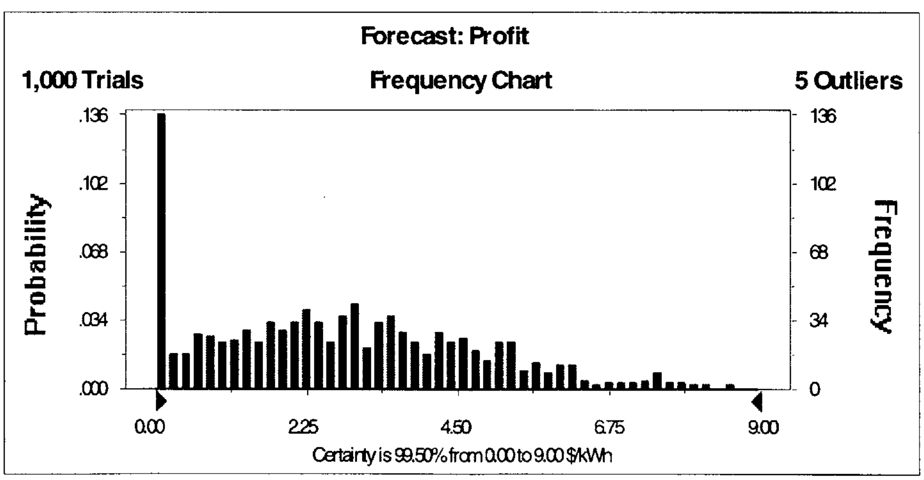


Figure 7.2: Profit distribution – Base Case

This graph can be interpreted as follows:

- Expected Profit is $2.8 /kWh.
- The plant is not operating in around 15% of total trials.
- The standard deviation is $2.1 /kWh.

The value of the plant is very sensitive to its physical heat rate. You will find in figure 7.3 the probability outcomes for profit for power plant with respectively 8 MMBtu/MWh and 10 MMBtu/MWh.

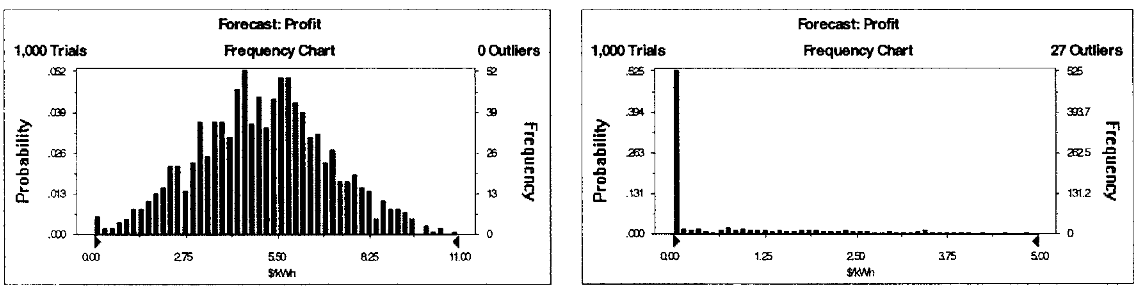


Figure 7.3: Influence of heat rate on profit distribution.

This graph can be interpreted as follows:

Heat Rate (MMBtu/kWh)	Expected Profit ($/kWh)	Standard Deviation ($/kWh)	% Shut Down
8	5.1	2.0	5%
10	1.08	1.6	50%
9	2.8	2.1	15%

The value of a plant located in a given market is determined by the relationship between its physical heat rate and the implied market heat rate. Given our parameters, the implied market heat rate has the following distribution:

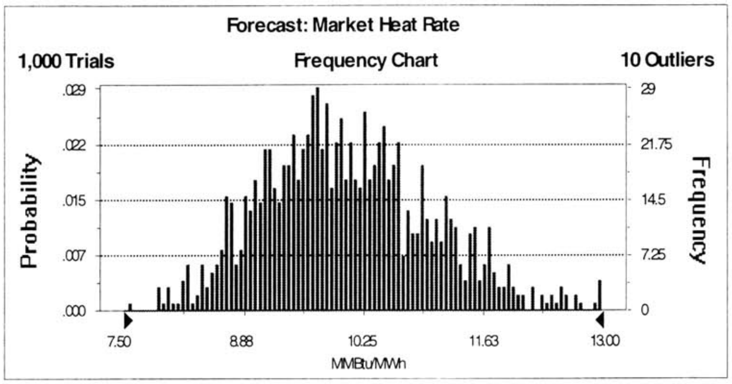


Figure 7.4: Implied market heat rate distribution.

Thus, a plant with a lower physical heat rate (more efficient) brings more value than does a high heat rate, as it can operate in a wider range of situations. The distributions narrow considerably as the physical heat rate rises to a level above the market heat rate, and the plant takes on more a role of a peaker role. A unit with a heat rate much lower than the market heat rate is a base load price taker, and although its value is much higher, the range of its outcomes is almost as wide as the variation in the market itself.

7.2.b Value of Forward Contract Combined with a Plant

7.2.b.i - Value of a Forward Gas Purchase Combined with a Plant

A forward gas purchase allows the producer to buy gas at $2.6 /MMBtu. It can then choose to produce electricity if its spot price is greater than $23.4 /kWh. When we combine a forward gas purchase with a gas burning plant, the distribution of possible outcomes for profit is represented by figure 7.5.

This graph can be interpreted as follows:

- Expected Profit is $2.6 /kWh.
- The plant is always operating.

- The standard deviation is $0.3 /kWh.

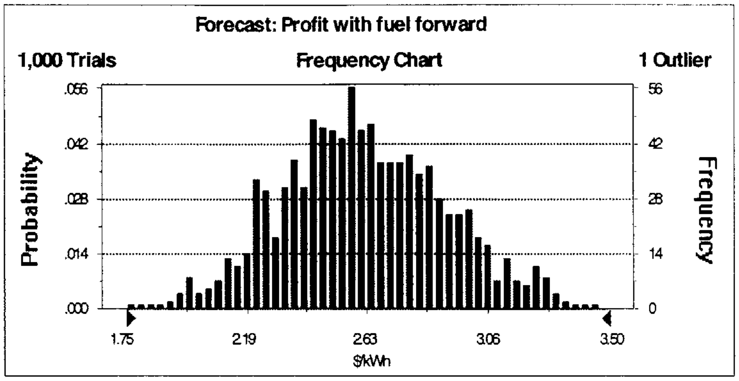


Figure 7.5: Profit distribution for a forward gas purchase combined with a plant

We can see that the combined value distribution is narrower than the one of the plant alone. This happens because the plant creates value out of the downside outcomes on the gas side, when gas drops in price relative to power, the plant converts the lower valued commodity into the higher valued commodity. Expected profit is slightly lower as the plant operator has to buy gas at the forward price and cannot take advantage of gas prices lower than the forward price. However, risk is much lower in this situation as shown by the difference in standard deviation.

7.2.b.ii - Value of a Forward Power Sale Combined with a Plant

The forward power sale allows the producer to sale its power at $ 26 /kWh.

The result of combining a forward power sale with a generating plant is shown in figure 7.6.

This graph can be interpreted as follows:

- Expected Profit is \$2.9 /kWh.
- The plant is not operating in around 15% of total trials.
- The standard deviation is \$2.1 /kWh.

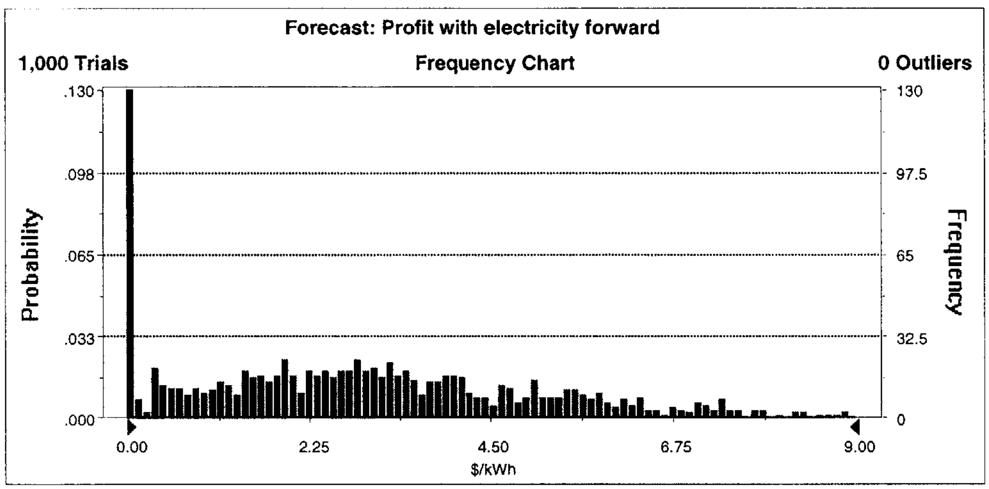


Figure 7.6: Profit distribution for a forward power sale combined with a plant.

7.2.c Value of Forward Heat Rate Transaction

To make a forward heat rate transaction, we will forward sell power and forward buy gas. As we own a plant, we have the option to convert gas to power at the physical heat rate of the plant. As already explained in Section 7.1, we will exercise this option only when the value of the gas is lower in the gas market than the value of the equivalent power in the electricity market. If gas is more valuable, we sell it and buy power.

The combination of a forward heat rate transaction with a power plant is depicted by figure 7.7.

This graph can be interpreted as follows:

- Expected Profit is \$2.7 /kWh.
- The plant is always in operation.
- The standard deviation is \$0.5 /kWh.

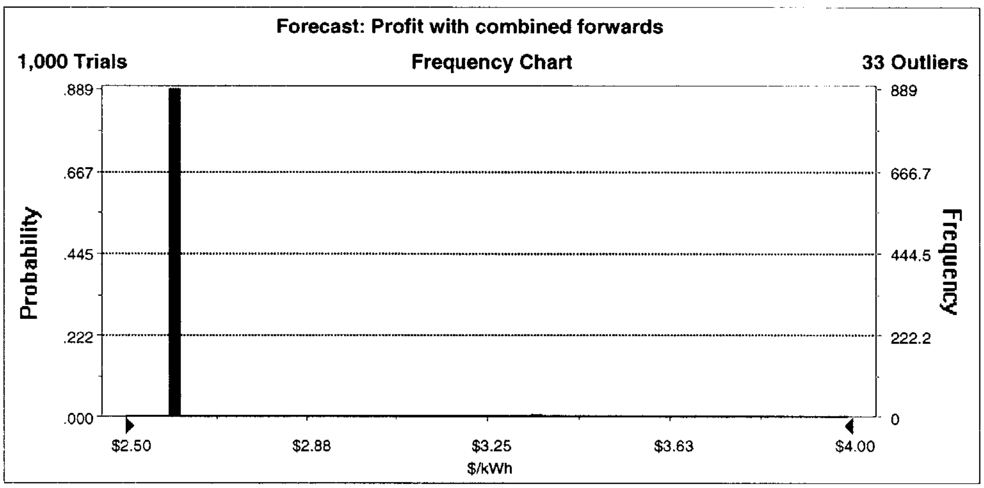


Figure 7.7: Profit distribution with combined forwards.

The heat rate transaction greatly narrows the width of the plant distribution of possible profit outcomes.

If we come back to the equations given in 7.1.c, we see that the profit is greater than \$2.6 /kWh when the market heat rate is lower than 9: the plant is said to be in the market. When this condition is fulfilled, then the operator takes advantage of prevailing market prices and realized a higher profit. Given our distribution for market heat rate, we can see that the probability of the market heat rate to be lower than 9 is only 0.1. Thus, the plant has 90% chance to operate and fulfills its forward contracts and realized a profit of \$2.6 /kWh. The plant is said to be out-of-the market.

Furthermore, the risk mitigation effect of a forward heat rate transaction increases as the physical heat rate of the plant decreases. You will find below the probability outcomes for profit for power plant with respectively 8 MMBtu/MWh and 10 MMBtu/MWh.

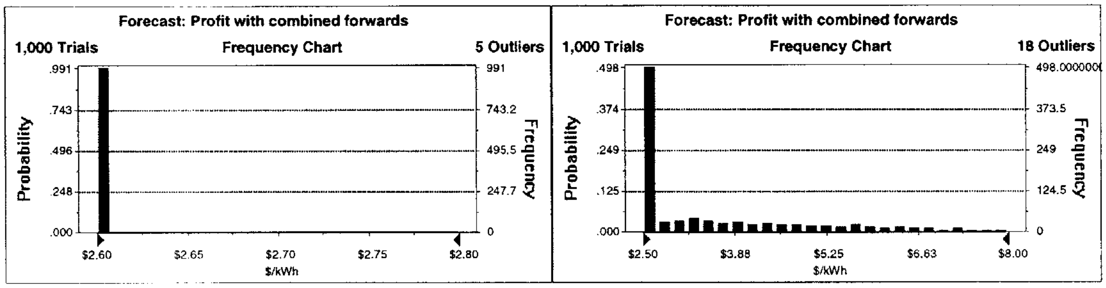


Figure 7.8: Influence of market heat rate on profit distribution.

A plant with a low heat rate is almost always in the money, which means that most of the time the market heat rate is superior to the plant heat rate (case 8 MMBtu/MWh). Every dollar price change affects the value of this type of plant, meaning that the total value of the plant is as volatile as the electricity prices. In this scenario, a forward heat-rate transaction keeps the value of the plant very near to its expected value, cutting off most of the variation.

7.3 Conclusion: Towards integrated operating and trading strategies.

The previous analysis have shown that combining adequate trading strategies with asset operating strategies will allow generators to hedge against the volatility of electricity and natural gas prices. Generators can lock in minimum profits, and sometimes trade some of the upside potential of market price volatility for insurance in future profits.

Being able to design and implement an integrated strategy will be a key component to remain a successful player in the electricity generating industry. The business of developing and financing power plants will also change considerably with deregulation. Where once a plant could be built and financed around a 30-years off take contract, future plants will be built and financed with no off take contracts at all. Whereas financing such a plant was once an exercise in writing tight contracts, tomorrow the job of financing power plants will become much more complex. The financing plan will have to be built using mechanisms of wholesale electricity market.

As shown in this chapter, hedging strategies will permit to lock in future cash flows, enabling debt financing and guaranteeing principal repayment. Another solution would be to operate a portfolio of power plant, with different characteristics (heat rate, input) that will allow generators to hedge against input and output prices 's fluctuations. This concept of plant portfolio should be the subject of further investigations.

Chapter 8

CONCLUSION

The actual restructuring taking shape in the electricity industry calls for a revision of valuation tools used to evaluate major investment opportunities. The marketplace, once regulated, stable and fairly predictable, is now characterized by change, uncertainty, price volatility and competitive interactions.

Traditional Discounted Cash Flow approaches to capital budgeting are becoming inadequate in that they cannot properly capture dynamic interactions between managers and information available from the marketplace. More specifically, as new information arrives and uncertainty about market conditions is gradually resolves, management has a valuable flexibility to alter its initial operating strategy in order to capitalize on favorable future opportunities or to mitigate losses. Passive management is over: flexibility and derivative thinking are the new drivers of value.

Throughout this thesis, we have focused on one major source of flexibility for a power generator: the ability to shut down and restart his plant according to prevailing market conditions. Operating a power plant is equivalent to owning a portfolio of spark spread options between electricity and the plant's input fuel. Indeed, on any given period of time, one should run his plant only if the power price is higher than the cost of fuel used to produce this power. We calculated the option premium associated with this operating flexibility using an extended Black-Scholes option pricing formula. Our results show that this premium represents a substantial amount of the plant's total value, up to 70%.

Our second main conclusion is that the use of derivative contracts on electricity and/or the input fuel needs to be integrated in any development plan of electricity generating plant. The combination of adequate trading strategies with asset operating policies will allow generators to hedge against price volatility, and realize trade-off between their need for profit locking and upside potential of volatile markets. We used Monte Carlo simulation to analyze different simple combinations of derivative investments and operating scenarios. Those building blocks lead us to design an integrated strategy, pointing the risk mitigation efficacy of various alternatives. Alignment of trading and asset strategies is key to succeed in the deregulated marketplace.

Further developments to this work can be suggested:

- Our framework can be extended to incorporate additional real options. For example, we could consider a technology of production allowing the use of different input fuels. An option to switch from one input to another would provide additional flexibility. It will allow to take maximum advantage of input price volatilities, to reduce exposure to input price risk, and to enhance upside potential derived from plant operation.
- Our analysis could be adapted to more realistic situations and take into account the presence of start-up time, fixed operating costs and other physical constraints on the plant's availability. Instead, in this study, we have decided to focus on the main drivers of value in order to build an intuition of tomorrow's important decision criteria. However, an exact valuation would certainly require considering those important operating aspects.
- Our integration of trading and asset strategies was done using the case of a single power plant. However, it seems more adequate for a power generator to base its strategy on the portfolio of assets that it may operate. Owning different power

plants with specific operating characteristics (heat rate, generating technologies or input fuel) is a way to mitigate electricity price risk and take advantage of a large range of market situations. Such a portfolio strategy would allow managers to enhance their company's flexibility and create a wide set of options, ultimate answer to an uncertain world.

REFERENCES

Amram Martha, Kulatilaka Nalin (1999) "Real Options – Managing Strategic Investment in an Uncertain World", *Harvard Business School Press.*

Amram Martha, Kulatilaka Nalin (1999) "Disciplined Decisions. Aligning Strategy with the Financial Markets", *Harvard Business Review, January-February 1999, p. 95-104.*

Baghai Mehrdad, Coley Stephen C., White David (1996) "Staircases to growth.", *The McKinsey Quaterly, 1996 Number 4, p. 39-61.*

Baldwin Carliss Y., Clark Kim B. (1997) "Managing in an Age of Modularity.", *Harvard Business Review, September-October 1997, p. 84-93.*

Black F., Scholes M. (1973) "The pricing of options and corporate liabilities.", *Journal of Political Economy, May-June 1973, p. 637-659.*

Brealey R., Myers S. (1996) "Principles of Corporate Finance", *5th e. New York, Irwin McGraw-Hill.*

Chen Andrew H., Kensinger John W., Conover James A. (1998) "Valuing Flexible Manufacturing Facilities as Options", *The Quarterly Review of Economics and Finance, Vol. 38, 1998, p. 651-674.*

Clemen Robert T. (1996) "Making Hard Decisions. An introduction to Decision Analysis.", *Duke University, Second Edition.*

Copeland Thomas E., Keenan Philip T. (1998) "How much is flexibility worth?", *The McKinsey Quaterly, 1998 Number 2.*

Copeland Thomas E., Keenan Philip T. (1998) "Making real options real.", *The McKinsey Quaterly, 1998 Number 3.*

Coy Peter (1999) "The real-options revolution in decision-making", *Business Week, June 7, 1999.*

Deng, Shijie (1998) "Stochastic Models of Energy Commodity Prices and Their Applications: Mean-reversion with Jumps and Spikes", *Working Paper, University of California at Berkeley, CA.*

Deng, Shijie, Blake Johnson, Aram Sogomonian (1998) "Exotic Electricity Options and the Valuation of Electricity Generation and Transmission Assets.", *Presented at the Chicago Risk Management Conference, Chicago, May 1998.*

Dixit Avinash K., Pindyck Robert S. (1994) "Investment Under Uncertainty", *Princeton N.J, Princeton University Press.*

Dixit Avinash K., Pindyck Robert S. (1995) "The Options Approach to Capital Investment", *Harvard Business Review, May-June 1995, p. 105-115.*

Dixit Avinash K., Pindyck Robert S. (1998) "Expandability, Reversibility, and Optimal Capacity Choice.", *Working Paper 6373.*

Edleson Michael E. (1999) "Real Options: Valuing Managerial Flexibility", *Harvard Business School, Case 9-294-109, June 1999.*

Esty Benjamin C. (1999) "Improved Techniques for Valuing Large-Scale Projects.", *The Journal of Project Finance*, Spring *1999, p. 9-25.*

Ethier, R. and T. Mount (1998) "Estimating the volatility of spot prices in restructured electricity markets and the implications for option values", *Working paper, Cornell University, NY.*

Eydeland Alexander, Geman Heylette. (1999) "Fundamentals of Electricity Derivatives", *Energy Modeling and the Management of Uncertainty, Risk Books 1999, p. 35-43.*

Felder Frank A. (1996) "Integrating Financial Thinking with Strategic Planning to Achieve Competitive Success.", *The Electricity Journal, May 1996, p. 62-67.*

Fitzgerald Jay, Pokalsky Joseph T. (1995) "The Natural Gas Market", *Managing Energy Risk, London Risk Publications 1995, p189-211.*

Fusaro, Peter C. (1998) "Energy risk management: hedging strategies and instruments for the international energy markets", *Mc Graw-Hill 1998.*

Froot Kenneth A., Scharfstein David S., Stein Jeremy C. (1994) "A Framework for Risk Management", *Harvard Business Review, November-December 1994, p. 91-102.*

Hamel Gary (1996) "Strategy as Revolution.", *Harvard Business Review, July-August 1996, p. 69-82.*

Hayes, Garvin (1982) "Managing as if tomorrow mattered.", *Harvard Business Review, May-June 1982, p. 71-79.*

Hoare James (1995) "The UK Electricity Market", *Managing Energy Price Risk, London Risk Publications 1995, p213-289.*

Hsu Michael (1998) "Spark Spread Options are Hot!", *The Electricity Journal, 1998, p. 28-39.*

Hull John C. (1997) "Options, Futures, and Other Derivatives", *Third Edition. Prentice Hall.*

Jameson Rob (1999) "Modeling Market Realities", *Energy Modeling and the Management of Uncertainty, Risk Books 1999, p. XI-XVII.*

Johnson Blake, Barz Graydon (1999) "Selecting Stochastic Processes for Modeling Electricity Prices", *Energy Modeling and the Management of Uncertainty, Risk Books 1999, p. 3-21.*

Kemna Angelien G.Z. (1993) "Case Studies on Real Options", *Financial Management, Autumn 1993, p. 259-270.*

Keeney Ralph L.., Raiffa Howard (1993) "Decisions with Multiple Objectives", *Cambridge University Press.*

Kester W.Carl. (1984) "Today's options for tomorrow's growth.", *Harvard Business Review, March-April 1984, p. 153-160.*

Kosecki Roman (1999) "Fuel-Based Power Price Modeling", *Energy Modeling and the Management of Uncertainty, Risk Books 1999, p. 91-98.*

Kulatilaka Nalin (1993) "The Value of Flexibility: The Case of a Dual-Fuel Industrial Steam Boiler", *Financial Management, Autumn 1993, p. 271-280.*

Laughton David G., Jacoby Henri D. (1993) "Reversion, Timing Options, and Long-Term Decision Making", *Financial Management, Autumn 1993, p. 225-240.*

Leslie Keith J., Michaels Max P. (1997) "The real power of real options.", *The McKinsey Quaterly, 1997 Number 3.*

Lo Andrew W., Wang Jiang. (1995) "Implementing Option Pricing Models When Asset Returns Are Predictable.", *The Journal of Finance, Vol. L, March 1995, p. 87-121.*

Luehrman Timothy A. (1995) "Capital Projects as Real Options: An Introduction", *Harvard Business School, Case 9-295-074, March 1995.*

Luehrman Timothy (1997) "Using APV: A Better Tool for Valuing Operations", *Harvard Business Review, May-June 1997, p. 145-154.*

Luehrman Timothy (1997) "What's it worth? A General Manager's Guide to Valuation", *Harvard Business Review, May-June 1997, p. 132-142.*

Luehrman Timothy (1998) "Investment Opportunities as Real Options: Getting Started on the Numbers", *Harvard Business Review, July-August 1998.*

Luehrman Timothy (1998) "Strategy as a Portfolio of Real Options", *Harvard Business Review, September-October 1998, p. 89-99.*

Margrabe William (1978) "The Value of an Option to Exchange one Asset for Another", *The Journal of Finance, Vol. XXXIII, No. 1, March 1978, p. 177-186.*

Mc Donald Robert L. (1998) "Real Options and Rules of Thumb in Capital Budgeting.", *Working Paper, Northwestern University.*

Merton R. C. (1973) "Theory of rational option pricing.", *Management Science, September-October, Number 1, p. 141-183.*

Nichols Nancy A. (1994) "Scientific Management at Merck.", *Harvard Business Review, January-February 1994, p. 89-99.*

Roark Jeffery D. (1999) "Trading and Asset Strategies in Bid-Based Markets", *Energy Modeling and the Management of Uncertainty, Risk Books 1999, p119-134.*

Ross Stephen A. (1995) "Uses, Abuses, and Alternatives to the Net Present Value Rule", *Financial Management, Vol. 24, No.3, Autumn 1995, p. 96-102.*

Ruijter Paul, Janssen Nico. (1999) "Option Thinking and Scenarios.", *Working Paper, 1999.*

Slater Stanley F., Reddy Venkateshwar K. Zwirlein Thomas J. (1998) "Evaluating Strategic Investments. Complementing Discounted Cash Flow Analysis with Options Analysis", *Financial Marketing Management 27, 1998, p. 447-458.*

Smit Han T.J., Ankum L.A. (1993) "A Real Options and Game-Theoretic Approach to Corporate Investment Strategy Under Competition.", *Financial Management, Autumn 1993, p. 241-250.*

Smith Jim (1999) "Much Ado About Options?", *Duke University, working Paper 1999.*

Schwartz Eduardo S. (1997) "The Stochastic Behavior of Commodity Prices: Implications for Valuing and Hedging.", *The Journal of Science, Vol. LII, July 1997, p. 923-973.*

Shimko David C. (1994) "Options on Futures Spreads: Hedging, Speculation, and Valuation.", *The Journal of Futures Markets, Vol. 14, No 2, 1994, p. 183-213.*

Teisberg Elizabeth O. (1994) "An Option Valuation Analysis of Investment Choices by a Regulated Firm.", *Management Science, Vol. 40, April 1994, p. 535-548.*

Trigeorgis Lenos (1993) "Real Options and Interactions With Financial Flexibility", *Financial Management*, Autumn *1993, p. 202-224.*

Trigeorgis L. (1996) "Real Options – Managerial Flexibility and Strategy in Resource Allocation.", *Cambridge, Mass, MIT Press.*

Tufano Peter (1996) "How Financial Engineering can Advance Corporate Strategy", *Harvard Business Review, January-February 1996, p. 136-172.*

Tseng Chung Li, Barz Graydon. (1998) "Short Term Generation Asset Valuation.", *Working Paper.*

WEB SITES

www.real-options.com

www.puc-rio.br/marco.ind/ro-links.html

www.realoptions.org

www.rogroup.com

www.energy.com

www.eia.doe.goev

www.nemmco.com.au

www.alpx.com

www.pjm.com

www.nymex.com

www.oilworld.com

ANNEX 1

Annex 1:Plant Valuation

Month per Year	12
Risk Free Rate	5%
Maturity	1

Electricity St Dev	30%
Gas St Dev	25%
Correlation	0.30

Heat Rate	9

Electricity Future Price	26.00
Gas Future Price	2.60

Spark Spread Option Model

Parameter v^2	0.1075
Parameter v	0.3279

Maturity	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1		1.16	0.85	0.72	0.65	0.60	0.57	0.55	0.53	0.51	0.50	0.49	0.49	0.48	0.47	0.47	0.47	0.47	0.46	0.46	0.46	0.46
d2		1.07	0.72	0.56	0.46	0.39	0.34	0.30	0.26	0.23	0.20	0.18	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.05	0.04	0.03
N(d1)		0.877	0.803	0.766	0.743	0.727	0.716	0.707	0.701	0.696	0.692	0.689	0.686	0.684	0.682	0.681	0.680	0.679	0.678	0.678	0.677	0.677
N(d2)		0.857	0.764	0.713	0.678	0.652	0.633	0.616	0.602	0.591	0.580	0.571	0.563	0.555	0.548	0.541	0.535	0.530	0.525	0.520	0.515	0.510
Spark Spread Call Option		2.744	2.980	3.195	3.386	3.558	3.715	3.860	3.994	4.119	4.237	4.347	4.451	4.550	4.643	4.732	4.817	4.898	4.976	5.050	5.121	5.189

Maturity	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1	0.48	0.48	0.48	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.51	0.51
d2	(0.13)	(0.13)	(0.14)	(0.15)	(0.15)	(0.16)	(0.16)	(0.17)	(0.17)	(0.18)	(0.18)	(0.19)	(0.19)	(0.20)	(0.20)	(0.21)	(0.21)	(0.21)	(0.22)	(0.22)	(0.23)
N(d1)	0.683	0.684	0.684	0.685	0.686	0.686	0.687	0.687	0.688	0.689	0.689	0.690	0.691	0.691	0.692	0.692	0.693	0.694	0.694	0.695	0.696
N(d2)	0.449	0.446	0.444	0.442	0.440	0.438	0.436	0.434	0.432	0.430	0.428	0.426	0.424	0.422	0.420	0.419	0.417	0.415	0.413	0.412	0.410
Spark Spread Call Option	6.126	6.158	6.188	6.218	6.246	6.274	6.300	6.326	6.351	6.374	6.397	6.419	6.441	6.461	6.481	6.500	6.519	6.536	6.553	6.569	6.585

Maturity	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1	0.55	0.55	0.55	0.56	0.56	0.56	0.56	0.56	0.56	0.57	0.57	0.57	0.57	0.57	0.58	0.58	0.58	0.58	0.58	0.58	0.59
d2	(0.30)	(0.31)	(0.31)	(0.31)	(0.32)	(0.32)	(0.32)	(0.33)	(0.33)	(0.33)	(0.33)	(0.34)	(0.34)	(0.34)	(0.35)	(0.35)	(0.35)	(0.36)	(0.36)	(0.36)	(0.36)
N(d1)	0.709	0.709	0.710	0.711	0.711	0.712	0.713	0.713	0.714	0.714	0.715	0.716	0.716	0.717	0.718	0.718	0.719	0.719	0.720	0.721	0.721
N(d2)	0.381	0.380	0.379	0.377	0.376	0.375	0.374	0.372	0.371	0.370	0.369	0.368	0.367	0.365	0.364	0.363	0.362	0.361	0.360	0.359	0.358
Spark Spread Call Option	6.783	6.788	6.792	6.796	6.800	6.804	6.807	6.810	6.812	6.814	6.816	6.817	6.818	6.819	6.820	6.820	6.820	6.819	6.818	6.817	6.816

Profit per kWh	$ 730

kWh per month	110,400

Total Profit	$ 80.6

Annex 1:Plant Valuation

Traditional DCF Model

Maturity		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.94	0.94	0.94	0.93	0.93	0.92	0.92	0.92
Present Profit		2.589	2.578	2.568	2.557	2.546	2.536	2.525	2.515	2.504	2.494	2.484	2.473	2.463	2.453	2.442	2.432	2.422	2.412	2.402	2.392	2.382

Maturity		**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	0.84	0.84	0.84	0.83	0.83	0.83	0.82	0.82	0.82	0.81	0.81	0.81	0.80	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78
Present Profit		2.192	2.183	2.174	2.164	2.155	2.147	2.138	2.129	2.120	2.111	2.102	2.094	2.085	2.076	2.068	2.059	2.050	2.042	2.033	2.025	2.016

Maturity		**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	0.71	0.71	0.71	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.68	0.68	0.68	0.68	0.67	0.67	0.67	0.66	0.66	0.66	0.66
Present Profit		1.855	1.848	1.840	1.832	1.825	1.817	1.809	1.802	1.794	1.787	1.780	1.772	1.765	1.757	1.750	1.743	1.736	1.728	1.721	1.714	1.707

Profit per kWh	$ 245

kWh per month	110,400

Total Profit	$ 27.0

Annex 1:Plant Valuation

Month per Year	12
Risk Free Rate	5%
Maturity	1

Heat Rate	9

Electricity Future Price	26.00
Gas Future Price	2.60

Spark Spread Option Model

Parameter v^2	0.1075
Parameter v	0.3279

Maturity	**12**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1		0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.48
d2		0.02	0.01	(0.00)	(0.01)	(0.02)	(0.03)	(0.04)	(0.05)	(0.06)	(0.06)	(0.07)	(0.08)	(0.09)	(0.09)	(0.10)	(0.10)	(0.11)	(0.12)	(0.12)
N(d1)		0.677	0.677	0.677	0.677	0.677	0.677	0.678	0.678	0.678	0.678	0.679	0.679	0.680	0.680	0.681	0.681	0.682	0.682	0.683
N(d2)		0.506	0.502	0.498	0.494	0.491	0.487	0.484	0.481	0.478	0.475	0.472	0.469	0.466	0.463	0.461	0.458	0.456	0.453	0.451
Spark Spread Call Option		5.254	5.317	5.377	5.435	5.491	5.545	5.597	5.647	5.695	5.741	5.786	5.830	5.871	5.912	5.951	5.988	6.025	6.060	6.094

Maturity	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1	0.51	0.52	0.52	0.52	0.52	0.52	0.53	0.53	0.53	0.53	0.53	0.53	0.54	0.54	0.54	0.54	0.54	0.55	0.55
d2	(0.23)	(0.24)	(0.24)	(0.24)	(0.25)	(0.25)	(0.26)	(0.26)	(0.26)	(0.27)	(0.27)	(0.27)	(0.28)	(0.28)	(0.28)	(0.29)	(0.29)	(0.30)	(0.30)
N(d1)	0.696	0.697	0.698	0.698	0.699	0.700	0.700	0.701	0.702	0.702	0.703	0.704	0.704	0.705	0.705	0.706	0.707	0.707	0.708
N(d2)	0.409	0.407	0.405	0.404	0.402	0.401	0.399	0.398	0.396	0.395	0.393	0.392	0.391	0.389	0.388	0.387	0.385	0.384	0.383
Spark Spread Call Option	6.600	6.614	6.628	6.641	6.654	6.666	6.678	6.689	6.699	6.709	6.718	6.727	6.736	6.744	6.751	6.758	6.765	6.771	6.777

Maturity	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**	**120**
Electricity Future Price	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
d1	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.60	0.60	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.62	0.62
d2	(0.37)	(0.37)	(0.37)	(0.38)	(0.38)	(0.38)	(0.38)	(0.39)	(0.39)	(0.39)	(0.40)	(0.40)	(0.40)	(0.40)	(0.41)	(0.41)	(0.41)	(0.41)	(0.42)
N(d1)	0.722	0.722	0.723	0.724	0.724	0.725	0.725	0.726	0.727	0.727	0.728	0.728	0.729	0.729	0.730	0.731	0.731	0.732	0.732
N(d2)	0.357	0.355	0.354	0.353	0.352	0.351	0.350	0.349	0.348	0.347	0.346	0.345	0.344	0.343	0.342	0.341	0.340	0.339	0.338
Spark Spread Call Option	6.815	6.813	6.811	6.808	6.806	6.803	6.800	6.797	6.793	6.790	6.786	6.781	6.777	6.772	6.768	6.763	6.757	6.752	6.746

Profit per kWh	$ 730

kWh per month	110,400

Total Profit	$ 80.6

Annex 1:Plant Valuation

Traditional DCF Model

Maturity		22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	0.91	0.91	0.90	0.90	0.90	0.89	0.89	0.89	0.88	0.88	0.88	0.87	0.87	0.86	0.86	0.86	0.85	0.85	0.85
Present Profit		2.372	2.362	2.353	2.343	2.333	2.323	2.314	2.304	2.294	2.285	2.275	2.266	2.257	2.247	2.238	2.229	2.219	2.210	2.201

Maturity		62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	0.77	0.77	0.77	0.76	0.76	0.76	0.75	0.75	0.75	0.74	0.74	0.74	0.73	0.73	0.73	0.73	0.72	0.72	0.72
Present Profit		2.008	2.000	1.991	1.983	1.975	1.967	1.958	1.950	1.942	1.934	1.926	1.918	1.910	1.902	1.894	1.886	1.879	1.871	1.863

Maturity		102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Electricity Future Price		26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Gas Future Price		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Expected Profit		2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Discount Rate	5%	0.65	0.65	0.65	0.65	0.64	0.64	0.64	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.61	0.61	0.61	0.61
Present Profit		1.700	1.693	1.686	1.679	1.672	1.665	1.658	1.651	1.644	1.637	1.630	1.624	1.617	1.610	1.603	1.597	1.590	1.584	1.577

Profit per kWh	$ 245

kWh per month	110,400

Total Profit	$ 27.0

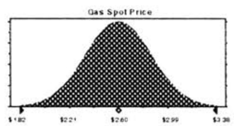
ANNEX 2

Annex 2: Plant Valuation with Hedging Analysis

Operating Heat Rate	9
Average Profit	$ 2.60

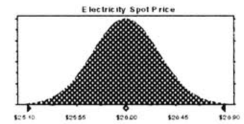
Forward Gas	
Price	$ 2.60
St Dev	25%

Gas Spot Price	$ 2.60



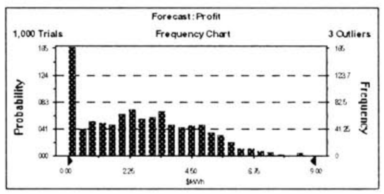
Forward Electricity	
Price	$ 26.00
St Dev	30%

Electricity Spot Price	$ 26.00

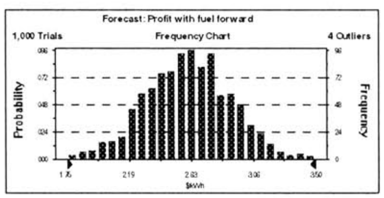


Market Heat Rate	10

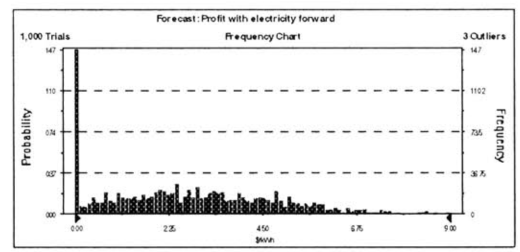
Profit Naked Plant	2.6



Profit with fuel forward	2.6



Profit with electricity forward	2.6



Profit with combined forwards	$ 2.60