Valuing Flexible Resources in an Uncertain Future

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Financial techniques that value the timing and flexibility of resources are being considered as alternatives to traditional uncertainty analysis in Integrated Resource Planning (IRP) and resource acquisition. This paper identifies and reviews the methods of valuing resource flexibility in both long-term resource planning and short-term resource acquisition.

There are three major points presented in this paper. First, traditional methods of IRP uncertainty analysis do not consider managerial and project response to a changing future. They are limited to viewing resources in future scenarios, but do not accommodate changing future strategies. Second, measuring resource flexibility in long-term planning is both more difficult and less useful than in short-term resource acquisitions. In short-term resource planning, a utility can more effectively split projects into stages, value project deferral, compare internal options with external options, and consider dispatch and operational flexibility. Intuitively, the strategic and financial value of flexibility can easily be understood. However, in order to explicitly measure the value of flexibility, analytic techniques such as option valuation, dynamic programming, and monte carlo simulation are used. Monte Carlo models have been used in long-term planning, while option valuation and dynamic programming are used in short-term resource decision-making. The third point of the paper focuses on the application and limitations of option valuation in utility resource planning. Since utility resource investment options possess many of the same characteristics as financial options, the use of financial option valuation is appropriate for utility resource decisions with caveats in data requirements. Option valuation applied to utility resource options requires information on the lead time, the cost of the project, the risk-free interest rate, and the expected volatility of the asset price. The price volatility, or variance, is the only uncertain variable. The existence of a robust commodities market (e. g., natural gas) provides an historical and accurate method of determining price volatility. In the absence of such a market (e.g., electricity), market models or planner's judgment must be relied upon to provide an estimate of price volatility. Option valuation for utility resource decisions is a technique more suitable for the time when there are robust markets for wholesale and/or retail electricity (e.g., Norway and England). Despite these current limitations, there are discrete dynamic programming techniques that mimic option valuation, which can value the flexibility of utility resource plans.

Introduction

As market and competitive processes are incorporated into IRP, financial techniques that measure risk and view future uncertainty will become more valuable to utilities. Dynamic programming and option valuation can use market information to value the flexibility and profit of projects in an uncertain future. The utility industry in the United States appears to be heading towards a more diverse market in electricity where the direct application of these techniques will become an important part of resource planning and procurement.

In traditional cash flow analysis, the decision rule is to, "invest in a project when the present value of its expected cash flows is at least as large as the cost."[1] This rule has been changed from one of profit maximization to cost minimization for utilities. The decision rule which considers project flexibility states, "invest in a project when the present value of its expected cash flows is at least as large as its cost and opportunity cost." Opportunity cost, in this context, is the cost of investing now in an uncertain environment. For instance, building a nuclear plant in light of large demand uncertainty will have large opportunity costs.

The problem with existing decision models is that they ignore several important characteristics of utility investments. First, investments are usually irreversible and have long lead times. Second, the investments can be delayed, giving the firm an opportunity to wait for new information on key uncertainties such as demand and wholesale prices of electricity. Third, investments can be broken into stages in order to reduce risk on long lead time investments. Moreover, the preliminary stages of a project can be treated as an option investment to later project completion.

Background

An option investment is a fixed payment at some initial time, which gives the investor the choice to either buy (i.e., call option) or sell (i.e., put option) the full investment at a given price some time in the future. For instance, a call option for natural gas is an initial investment that will allow the holder the right to buy natural gas at a fixed price some time in the future. Option periods and price will vary depending on the risk and volatility of gas prices. If the price of natural gas goes up, the investor will exercise the option, buy natural gas at the fixed agreed upon price, and make a profit. If the price of gas declines, the investor will not exercise the option, and will have lost his initial option investment. The analogy to real projects rests on the investment flexibility of a company. If a coal plant had a total lead time of 6 years and the investments were broken into 6 yearly stages, each stage could be treated as an option. If a utility's forecasted demand for baseload electricity had declined, later stages could be put-off, or completely abandoned.

Before considering the analytic techniques of valuing flexible resource alternatives, some intuition for the value of resource flexibility should be mentioned. For example, if you are a utility facing the possibility of industrials buying power from other sources, or demand-side management (DSM) having an unexpected effect on load, then you will likely prefer smaller, more flexible resources to meet future demand. The concept of flexibility is not new. Eric Hirst of Oak Ridge National Laboratory mentions that a strategy of splitting resources into option and build stages is an inexpensive way to shorten construction times and cost-effectively respond to uncertain demand.[2] Also, utilities can adjust participation in DSM programs to better meet future load growth.

In general, resource flexibility has more value when:

- Uncertainty, in general, is high (e.g., as demand uncertainty increases the value of flexibility increases);
- Utility deregulation increases (because the utility is in a riskier environment);
- Pattern of required investments is very uneven (e.g., large one time investments);
- Costs of altering or delaying a project is low (e.g., mothballing costs are low); and
- Demand uncertainty dominates over other utility uncertainties, such as fuel price.

Utilities are facing increasing uncertainties in demand, fuel price, and regulation. The objective of utility regulation is to protect ratepayers, by means of keeping utility profits high and losses low. Historically, investor-owned utilities represent low risk investments to shareholders. As the industry becomes deregulated, competition and risk will both increase. Demand and fuel price uncertainty have competing effects on utility planning. If demand has a larger effect on the value of future resource plans, a utility will likely choose highly flexible resources (e.g., small turbines). If project value is more sensitive to fuel prices than demand, a utility will prefer high fixed cost with low fuel cost alternatives (e.g., renewable and coal). Again, these are general rules of thumb. There are many other utility concerns that may override uncertainty issues such as: construction costs, reliability, regulation, environmental concerns, competition, and diversification.

Since this paper discusses a project's value based on market price, an important distinction should be made between the terms value and price. Value is what an asset is worth to one party. Price is an agreed upon dollar amount by both selling and buying parties. In the utility sector, value has historically been driven by cost minimization and avoided costs. For example, the value of implementing demand-side management (DSM) comes from avoided costs. The value of a chosen generation plant is based on its expectation of being the lowest cost alternative. As the wholesale market for electricity becomes more competitive, the value of utility investments will be derived from the price of electricity in these markets. For instance, a gas exploration firm will value a new project based on the expected future price of natural gas. Option theory is a technique that allows the incorporation of market prices into the valuation of future projects.

Objectives

This paper identifies and reviews the methods of valuing resource flexibility in both long-term resource planning and short-term resource acquisition. The purpose of the paper is to compare the value (e.g., flexibility) and limitations (e. g., lack of electricity market) of using option theory in uncertainty analysis over traditional methods.

This paper neither develops new methods nor describes in detail the background work or mathematics that have been published up to this point. The authors that have made important contributions in option valuation of real projects include Cox, Ross, and Rubinstein (1979), Brennan and

Schwartz (1985), McDonald and Siegel (1986), Majd and Pindyck (1987), Teisberg (1988), Pindyck (1991), and Jacoby and Laughton (1992).[3]

The paper is organized in the following fashion. First, it reviews the traditional methods of uncertainty analysis and discusses their abilities and limitations. Second, it looks at techniques and models that value flexibility in long-term resource planning. Third, it examines the techniques using option theory that could be used in short-term resource procurement. Finally, it offers conclusions about the future role of uncertainty analysis and how the value of flexibility may help utilities compete for their customers while meeting an obligatory and growing uncertain demand.

Traditional Uncertainty Analysis

Traditional uncertainty analysis includes two net present value (NPV) based methods: scenario/sensitivity analysis and dynamic discounted cash flow.

Scenario/sensitivity analysis, a subset of decision analysis, measures the robustness of a particular resource alternative.[4] In other words, under a diverse set of uncertain futures a "robust" resource will be included in a majority of the low cost plans. The inputs that are difficult to determine include the range and probabilities of uncertain variables. Sensitivity analysis is most useful when:

- market valuation is not important (e.g., government);
- market information does not exist (e.g., R&D);
- identification of a project's most sensitive uncertainties is important (i.e., which variables have the strongest affect on value); and
- robustness is important.

Sensitivity analysis is the predominant form of uncertainty analysis in electric resource planning. Its predominance is due to the following reasons: (1) ease of use, (2) market information on electricity is limited to the wholesale market, (3) utility shareholders are rewarded based on regulatory response, not market response, and (4) robustness is a primary tool for utilities to demonstrate the viability projects. Pressure to find other means of valuing projects under uncertainty is a result of several current industry trends. First, electricity markets are beginning to have more participants and cover more territory. Second, utilities, as sources of electric generation, are becoming competitive entities. Third, utilities need better tools to decide between internal and external investments (e.g., purchased power).

Dynamic discounted cash flow (DDCF) analysis separates the cash flows in a valuation and discounts the different flows by an appropriate risk-adjusted discount rate. While sensitivity analysis varies future cash flows under a constant discount rate, dynamic discounted cash flow keeps cash flows constant while varying discount rates. For instance, the valuation of a gas combustion turbine would separate out costs into those that are "certain" (e.g., construction costs) and those which are "uncertain" (e.g., gas prices). The valuation would then discount construction costs with cost of capital and discount gas prices with a risk-adjusted discount rate (RADR).

The difficult aspect of DDCF is in the determination and use of the RADR. Determination of RADR for electric utilities has been demonstrated by Awerbuch (1992). The technique involves the use of the capital asset pricing model (CAPM) to compare the market behavior of the risky cash flow, in this example natural gas, with the entire market (e. g., the Standard & Poors 500). This relationship dictates the relative riskiness gas has to the market. Two broad assumptions are made. First, the market risk of gas prices is the same risk facing the utility. Second, past risk reflects future price risk. The difficulties in using RADR are the following: (1) it assumes RADR is related to the actual variance of future uncertainty, (2) it assumes risk consistently increases over time, (3) risk in the RADR is systematic risk faced by utility shareholders, not ratepayers, and (4) demand uncertainty cannot be represented in RADR.

Sensitivity and DDCF analysis are both at a disadvantage because they do not consider the flexibility of resources in the planning process. However, both methods benefit the planner by providing useful information about the behavior of resource projects in uncertain worlds.

Long-Term Planning

It is more difficult to value resource flexibility in long-term resource planning than it is in short-term resource acquisitions. Long-term planning has historically been done with the aid of capacity expansion or production costing models which optimize the placement of resources onto a future load growth. These models, at present, do not include explicit uncertainty and do not have the capability to split projects into stages.[5] However, there are a few steps described below that can trick capacity models into considering flexibility. Monte Carlo simulation has been used to value resource plan flexibility, but is limited in several ways. First, the value of a particular resource option cannot be directly measured. Monte Carlo methods can only measure the total cost. Second, it cannot optimize. Therefore, determining the low cost solution requires comparing a bevy of resource plans and strategies.

Adding Flexibility to Capacity Expansion

There are methods to "fake out" these models in order to consider flexibility. These processes, though, are overly simple and do not provide full consideration of project flexibility. Conceptually, they are merely extensions to scenario/sensitivity analysis. The first method attempts to create equal lead times for every resource by placing the costs of preliminary stages at the beginning of the planning horizon. This would penalize long lead time plants by some small amount that can be referred to as the option cost. The second approach takes two steps beyond traditional capacity modeling. First, it splits projects into stages and varies the length of time between stages. Second, it provides the model with a variety of "lumpy" demand forecasts that represent a probabilistic random walk through the future.[6] Lumpy means the demand forecast is not a straight-line. A capacity expansion model will then optimally add projects in preferred stages to the lumpy forecast. The major downfall with these approaches is that the model still assumes perfect forethought and optimizes accordingly. This approach cannot replicate the cost consequences of making decisions every year to build, delay, or abandon resource projects.

Monte Carlo Simulation

Monte carlo simulation constructs a plan through sequential decision making (i.e., the future is not known with certainty). The model randomly steps through each branch of a decision tree and making a decision at each branch. The resulting plan may not be optimal but it will represent the flexibility of future strategic decision making. The Northwest Power Planning Council (NPPC) and Bonneville Power Administration developed a monte carlo model to perform long-term resource planning and resource acquisition. The Integrated System for Analysis of Acquisitions (ISAAC) creates an intuitive step-wise system of making resource decisions in every year throughout the planning horizon. I say "intuitive" because this is how resource acquisitions really take place. The difficulties with ISAAC include: (1) it is not an optimizer, therefore optimal plans must be discovered through trial and error, and system constraints may be violated; (2) resource acquisitions meet only energy requirements, not capacity; and (3) depending on planning horizon, the number of strategies, and uncertain variables, the model can quickly become difficult to track.

The benefits of lead time and flexibility are measured by observing the over- or under-build cost consequences of a particular resource portfolio. Because this model is regionally constrained, there is no value in exporting or importing energy. For instance, if over-building left a utility with excess capacity that could be sold at a price greater than marginal cost, the model would not count this sale and thus costs would be higher than an equivalent plan that avoided the excess.

The model randomly generates future load paths with input specified probability distributions. The resulting demand path is "lumpy" due to the random regeneration every year. The model then moves through the future along one of these random load paths, forecasting and making resource decisions consistent with a particular resource strategy. Each strategy is subject to several runs through the model. Important evaluation attributes, such as costs (e.g., Total Resource Cost), emissions, and reliability will be tracked throughout the process. Other uncertain variables following the uncertain load growth are fuel prices, hydro conditions, and resource supply.

Load forecasts developed at each decision point last only as long as the longest lead time of available resources. This makes sense because the only revelation from a 20 or 30 year planning study are decisions made in the first few years. The model uses two forecasts at each decision point. The first is the median or build-level forecast. Build-level determines which resources should be acquired. The second forecast is the option-level. Option-level will represent a high forecast. This forecast defines a level where resource options should be acquired. For example, a resource option investment may be siting, licensing, and design. Figure 1 shows several items. First, each new year brings a now forecast range. Second, given this new forecast range and a strategy, option and build level forecast are constructed. These investments are made and the model goes on to the next year and starts the process over again.

Short-Term Resource Acquisition

Flexibility is more easily valued and considered in the short-term resource acquisition. Long-term resource planning is focused on meeting demand constraints. Short-term resource acquisitions must also meet demand constraints, but include the evaluation of lead time, project stages, purchase contracts, transmission constraints, tradeoffs between projects, and the cost associated with these variables. For instance, utility development projects can be organized to include staging options (e.g., siting, licensing, design, and construction), delay options (e.g., putting contractors on hold at various stages), as well as full abandonment. Of course, there are costs associated with these options. Option valuation and dynamic programming are techniques that can help determine the value of incurring the extra cost of purchasing and exercising real asset options.

Dynamic programming is currently better suited for electric utilities, while option valuation, now being used by the natural gas industry, will become more important

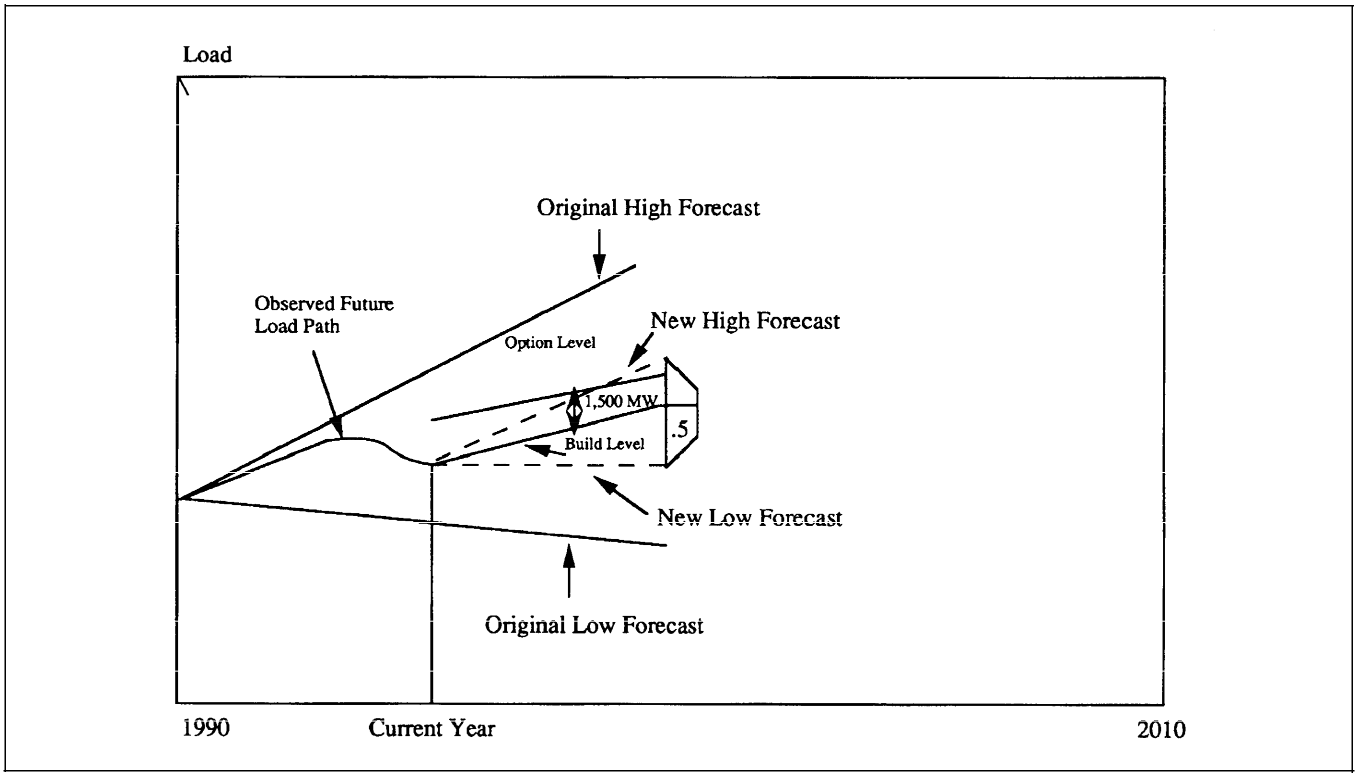

Figure 1. Option and Build Levels

in a deregulated electricity industry. The type of information available to the planner dictates the choice of approaches. In general, option valuation can be used when there is market information available. Market, in this context, refers to a formal liquid market which includes both spot and futures trading (e.g., gold, copper, gas, and oil). Dynamic programming is used when there is no market information on the commodity in question (e.g., automobiles, office furniture, and electricity). The concept of dynamic programming is to construct and model several investment strategies, including option investments, and choose the strategy with the highest NPV. This technique requires no extra information beyond that for traditional uncertainty analysis (e.g., range and probability of uncertain variable). The value in delaying, abandoning, or going forward with a particular investment is determined by comparing traditional "straight line" expected values with contingent expected values. The author is familiar with only one attempt to use dynamic programming in the electric resource planning or procurement process. The work was summarized in the March 1994 "Electricity Journal", and is being conducted at the New England Power Company of the New England Electric System (NEES). The success of the technique applied at NEES is unknown to the author.

The two-step example that follows, demonstrates a simple dynamic programming approach to comparing two purchase power contracts. Though a two period purchased power example is used, the investment could include many periods and 'be applied to utility projects, or DSM investments to delay a transmission line. Table 1 summarizes the following example.

Dynamic Programming: Purchased Power Example

A utility is facing a decision between two purchase power contracts. The first contract is a two year take-or-pay capacity contract of $200/kW-year for 5 MW, a total cost of $1 million per year. After two years, in a high demand future (50% probability) this contract would be worth $100,000/yr, based on projected average market costs of capacity of $220/kW-yr. In a low demand future (50% probability) a capacity contract would be worth negative ($100,000)/yr, based on a projected market cost of $180/kW-yr. A traditional expected value analysis excluding discounting, at time zero, yields a contract value of $0. This would be considered an even money investment, and would be subject to risk preference and alternatives.

The second 5 MW contract is for a higher price, but includes an option to discontinue after the first year. The question is whether the option clause is worth the cost given demand uncertainty.[7] The contract costs $205/kW-yr the first year, with an option to continue at $205/kW-yr the next year. This contract will cost $25,000 more the first year than contract 1. This is the option price. After

Table 1. 5 MW Option Contract

		Year 1	Year 2	Total
Contract 1	$200/kW-yr			
High demand	$220/kW-yr	$100,000	$100,000	
Low demand	$180/kW-yr	($100,000)	($100,000)	
Expected value		0	0	0
Contract 2	$205/kW-yr			
High demand	$220/kW-yr	$75,000	$75,000	
Low demand	$180/kW-yr	($125,000)	0	
Expected value		($25,000)	$37,500	$12,500

one year, the expected value is ($25,000), and if evaluated alone, would not be considered. But since there is an option attached, after one year the utility can continue the contract at $205/kW-yr or discontinue. In the high demand case, we would continue the contract at a value of $75,000. In low demand, we would discontinue at a value of $0. This yields a second year expected value of $37,500. The two year expected value of this contract is $12,500 and would be preferred to contract 1.

The contract with the option is, therefore, the better choice given this particular demand and wholesale price uncertainty. In fact, it is $12,500 better than the contract without the option. What is the most one would pay for this contract option? Table 2 summarizes the calculations necessary to answer this question. First, swap out the value $205/kW-year with a variable, such as X. Second, perform the same expected value calculations leaving each year in equation form. Next, add up both years and equate to zero, to find the break even option contract price. An option contract would be preferred to the fixed contract up to $206.67/kW-yr.

This simple example demonstrates the value of contract flexibility. The flexibility that can be written into power contracts can also be applied to many types of investments at utilities. For instance, a DSM program with a poor cost/kW can be halted. A coal project could be staged and valued as options in order to make future decisions on delay or abandonment. Variables that can change to produce different results include the initial price (e.g., $200/kW-year), the probabilities of price (e.g., 50-50), the range of price uncertainty (e.g., $220 to $180), and the option investment (e.g., $25,000/year). The difficulties in using dynamic programming include the estimation of the range and variance of the uncertain variables, and the difficulty of tracking a multiperiod/multi-uncertainty analysis.

Option Valuation: Natural Gas

Option valuation uses price volatility information along with the current asset price, lead time, project costs, and a risk-free interest rate to calculate the option value of a potential project. Price volatility is the only uncertain variable and may be measured using the aid of key market data. For instance, projects that yield a tradeable asset, such as natural gas, can use historical statistics on price and volatility to help determine future prices, standard deviation, and expected returns. Since electricity wholesale power markets are not efficient markets, NEES has constructed a model of the capacity market in New England that will project capacity values based on predictions of the regional capacity position. This model in turn estimates price volatility.

Option valuation requires the existence of a market-traded asset, or a modeled asset, that has the same value as the completed project in all possible future states of the world. In other words, if the project being valued is a gas well, a portfolio consisting of gas shares and riskless bonds could be constructed to mimic the future value of the well. In the case of decisions for utility generation, this "underlying asset" could be "guess"-stimated from wholesale electricity contracts and riskless bonds. Assuming this asset could be constructed, the next step is to build a decision tree with relevant uncertainties. With the underlying asset able to provide value at each stage of the tree, the rest is a contingent claims analysis that can be stepped back from the ending values. At each stage the

Table 2. Contract Option Value

Price	Probability	Year 1		Year 2		Total
220	.5	[.5(1,100 - 5X)		[.5(1100 - 5X)		
180	.5	+ .5(900 - 5X)]		+ .5(0)]		
Expected Value		1,000 - 5X	+	550 - 2.5X	= 0	: 7.5X = 1550 X = 206.67

threshold price to obtain an option to own the underlying asset can be determined. Option valuation, in other words, assumes ownership of the underlying asset at the end of all periods, and discovers the correct option prices that should be paid throughout the planning period. For better descriptions of this method see Pindyck (1991) and Teisberg (1988). The example that follows demonstrates the value of waiting to invest in a natural gas development.

To purchase and develop a gas well today would cost \$104 million. A one year lease option has been proposed to hold the site. The decision is to: (1) develop now, (2) don't do the project at all, or (3) buy the lease and wait for a year. In order to make this decision, we need to know the value of holding a lease for one year.

The value of the lease is dependent on the current price and future volatility of gas. Volatility is obtained from an historical time series of commodity prices. Other information for the analysis include the risk-free rate at 8 percent, and the cost of developing the well is \$104 million.

From the market information we construct a decision tree that resembles the market uncertainty. The current price is \$20/mcf, and has a .59 annual standard deviation. From Cox, Ross, and Rubinstein this yields an 80% rise (or \$36/mcf) on the high side, and a 40% decline (or \$12/mcf) on the low side.[8] With the risk-free rate, the current commodity price, and the possible ranges for price we can determine the risk-neutral probabilities. These probabilities, seen in Equation (l), are also called the "martingale" probabilities, and were developed from the arbitrage-free comparison of project returns to the "underlying" asset. [9]

$$p = \frac{(1+r)S-S_l}{S_h-S_l} \qquad (1-p) \qquad (1)$$

With r equal to 8 percent, the current commodity price S equal to \$20/mcf, the low commodity price S_l equal to \$12, and the high price S~ equal to \$36, the martingale probabilities are .4 for the high case and .6 for the low case. The project value is related to the underlying asset in the following way: if gas prices increase to \$36/mcf, the plant output yields \$180 million. If gas prices decrease to \$ 12/mcf, the plant output is \$60 million. Equation (2) represents the expected value of this project which is [(180 x .4) + (60 x .6)]/1.08 = \$100 million. Since the project cost is \$104 million, there is a negative \$4 million static NPV to start the project now. There are two important features in the following value equation: (1) risk probabilities are based on stock movements, and (2) the only uncertain variable is the price of the commodity.

$$V = \frac{[180p + 60(1-p)]}{(1+r)} \qquad (2)$$

In order to find the value of the license option we need to see what a contingent situation would look like. First, the cost of the plant after one year has increased to \$104 x 1.08 = \$112.32M. Second, the company will invest if the price of gas has gone up (payoff = \$180-\$112.32 = \$67.68M), but will not invest if prices have gone down (payoff = \$0). Third, the expected value of the option is, (4 x \$67.68 + .6 x \$0)/1.08 = \$25.07M. The entire value is then the option NPV minus the static NPV, or \$25.07- (-4) = \$29.07M. In other words, to defer the investment, one avoids losing \$4 million and instead makes an expected \$25.07M, which totals to \$29.07M of option value.

In this example, the decision was over only one period of uncertainty. As the number of periods increase, the problem becomes more difficult to solve discretely and approaches a continuous calculation. The solution to a continuous option model will be necessary for project budgeting only when investment decisions are made on a continuous basis (e.g., constant trading of natural gas).

The example of natural gas has two simplifications not present in electric utility investments. First, the costs of producing gas are known, and second, gas prices are the only unknown. Electric utilities have unknowns on both sides of the profit equation. Costs are unknown due to fluctuating fuel prices, and prices are unknown due to uncertain demand and a competitive wholesale market. A developer of natural gas does not have an obligation to provide gas, and does not lose revenue by doing nothing. An electric utility, on the other hand, has an obligation to provide power. Therefore, the cost of doing nothing is the cost of relying on wholesale spot prices to meet any unmet demand. As the cost of waiting increases (e.g., unmet demand) the value of the option decreases. Utilities with large reserve margins and high wholesale spot prices may find that most option values cannot exceed the high cost of waiting. However, as reserve margins become flexible and wholesale prices more competitive, knowing the value of project deferral, staging, and abandonment will become "invaluable".

Conclusion

Flexibility in IRP uncertainty analysis is a relatively new consideration. Traditional methods have considered resource "robustness" and risk adjusting cash flows, but have not considered managerial and project response to a changing future. Option valuation is one response to addressing the value of flexibility. In the last two decades, option theories have been applied to tradeable securities and to real projects. In the utility sector it is feasible to use option theory to help construct short-term resource plans and to value flexibility. Valuing flexibility will help utilities, (1) negotiate power contracts, (2) split projects into stages, (3) constrain projects to more accurately meet uncertain demand, and (4) consider investment decisions in a market price environment. The accurate use of sophisticated market valuation models, though, will necessitate a more diverse market in electricity. In the NEES case, price volatility was estimated from a model of the capacity market in New England. Option valuation model will be more applicable as markets progress, demand uncertainty grows, and competition increases, In long-term resource planning, the difficulties of accurately valuing flexibility may not be worth. However, there are some simple sensitivity techniques that can be included in long-term uncertainty analysis that will shed light on flexible resource options.

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Endnotes

1. Pindyck (1991)

2. Hirst (1989)

3. Real project valuation, as opposed to security valuation, are expenditures in projects rather than in stocks and bonds. Stock and bond valuation is relatively easy compared to valuing actual projects. Securities and some commodities are liquid, and can be purchased in either the cash, futures, or option market. The risk and uncertainty of security values are incorporated into the market prices. Since there are many players involved in owning these securities, the price reflects an overall view of uncertainty. Because real projects are not easily liquidated and have substantial lead times, valuation becomes more difficult.

4. Scenarios define a set of uncertain variables, such as demand forecasts or fuel price forecasts. Sensitivity analysis records the resulting cash flows from performing NPV calculations while changing the scenarios or uncertain variables.

5. Some capacity expansion models have the ability to have contingent plants, or can add several expansion stages to a project. These still require capacity expansion at every stage. In order to really value an option, the model must add project cost in different time intervals without adding capacity.

6. A demand forecast which follows a probabilistic random walk could be constructed with Monte Carlo simulation. This simulation would require a percent load growth number (e.g., 2%) and a probability (e.g., 25% chance). The simulation steps through each year and randomly chooses a load growth based on the probability. The result is a "lumpy" demand forecast. "Lumpy" means that the forecast is not straight line. This will create a much different optimal plan than the straight line forecasts now in use for most IRPs .

7. I have assumed the following relationship between demand uncertainty and wholesale cost: If demand is high, then the price of power increases, and if demand is low then the price of power decreases.

8. Cox, Ross, and Rubinstein (1979) show the relationship between the tree movements of the commodity price (e.g., $20 to $36, or $20 to $12) and the standard deviation in commodity prices, the number of periods, and the length of calendar time.

$$u = e^{\sigma\sqrt{\frac{1}{n}}} \qquad d = e^{-\sigma\sqrt{\frac{1}{n}}}$$

u = upward movement of price
d = downward movement of price
a = standard deviation of price
n = number of periods

In our example the number of periods is 1 and the standard deviation of gas prices is assumed to be .59. This yields a u = 1.80 and a d of .60.

9. Arbitrage-free means there is no opportunity to make risk-free profit from buying the replicating portfolio and selling the option, or visa versa. See Cox, Ross, and Rubinstein (1979).

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