Analysis of Real Options in Hydropower Construction Projects
-- A Case Study in China

by

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Submitted to the Engineering Systems Division
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Abstract

This thesis investigates the application of real options to the design of major civil works. Specifically, it examines several methods to value the options, to determine which are more suitable in the design context.

The thesis applies NPV, NPV with simulation, and binomial options pricing model to study a case on Yalongjiang River basin development. More specifically, a deferral option of Project A is studied. When doing the real options analysis, the thesis compares the usage of the NPV of project and the electricity price as the underlying and finds that the electricity price is a more appropriate underlying for the options analysis.

On the pros side, the study confirms that options analysis overcomes the inadequacy of NPV analysis in uncertain environments, at least partly. Options analysis can evaluate the flexibility intrinsic or built into projects facing uncertain environments. Moreover, options analysis develops contingency strategy in uncertain environments.

On the cons side, traditional options analysis requires the geometric Brownian motion assumption of the uncertainties and relatively high quality of data. The applicability of options analysis depends on the type of uncertainty of the environment and the data availability. The deferral option in Project A fits in the category where options analysis is applicable.

The thesis concludes that real options analysis using the electricity price as underlying is an appropriate method for valuing the deferral options of Project A and similar hydropower projects.

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My sincere thanks to my family. My parents have supported me unwaveringly during my study in the US. As the only child of the family and when my mother is sick, all their understanding and encouragement helped me overcome various difficulties.

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Chapter 1 Introduction

The future is inherently unknown, but the unknown is not unmanageable. It is fascinating to explore designing large systems with full awareness of uncertainties. And no systematic work has been done yet, at least in the area of river basin development. This research develops a preliminary methodology for incorporating options thinking into the valuation of river basin development projects, and compares the methodology with other methodologies such as NPV and NPV with simulation.

1.1. General Methods and Tools

The real options approach is based on the seminal work of Black, Scholes, and Merton that won the Nobel Prize in 1997. Modern Finance theory provides abundant understanding of uncertainties and how to deal with them. It also provides some very useful techniques that engineers can learn to better "optimize" designs in an uncertain world.

Binomial tree and risk-neutral valuation should be introduced to engineers. Cox, Ross, and Rubinstein developed the Binomial Tree Model in 1979. The model represents how the value of an asset evolves where the value is monitored under successive short periods of time. In each short period it is assumed that only two value movements, up or down, are possible. Risk-neutral valuation, assuming the world is risk neutral, gives the correct value for all worlds, not just in a risk-neutral world.

Modern computer technology removes most of the previous computing capacity problems for system designers. People are able to establish huge optimization models on personal computers. But are they fully utilizing the computing capacity they did not possess before? Taking into account uncertainties systematically and productively in systems design has been made possible by the modern computer technology. The key to the success of this study is that, based on traditional optimization models, a simulation model with options thinking can be developed.

1.2. Theme and Structure of the Thesis

This thesis studies the Project A of Yalongjiang river basin development to determine the most appropriate valuation method for this project given the various uncertainties. The valuation methods studied include NPV, NPV with simulation, IRR, IRR with simulation, decision tree analysis, and real options (using electricity price or project value as underlying).

The structure of the thesis is as follows: Chapter 2 reviews literature on real options and water resource planning. Chapter 3 introduces options, both financial and real. Its focus is on the options valuation models and their key assumptions. Chapter 4 introduces the background of Yalongjiang River basin development. Chapter 5 values Project A using NPV, NPV with simulation, IRR, IRR with simulation, decision tree analysis, ROA (real options analysis) with electricity pricing as underlying, and ROA with NPV as underlying. After comparing the methods, it concludes that the ROA with electricity pricing as underlying is most appropriate for Project A valuation. Chapter 6 explores some policy implications of the study. The organizational wisdom to make real impact of real options and the relationship between uncertainty reality and appropriate methodology are the implications. Chapter 7 concludes this thesis and discusses future work.

Chapter 2 Literature Review

This study integrates two threads of research. One is real options research, and the other is water resource planning with regard to facilities design. This chapter reviews the literature of these two threads.

2.1. Real options

Myers [1987] was one of the first to acknowledge that there are inherent limitations with standard discounted cash flow (DCF) approaches when it comes to valuing investment with significant operating or strategic options. He suggested that options pricing holds the best promise for valuing such investments.

2.1.1. Development of the methodology

Dixit and Pindyck [1994] stressed the important characteristic of irreversibility of most investment decisions, and the ongoing uncertainty of the environment in which these decisions are made. In so doing, they recognized the option value of waiting for better (but never complete) information. The focus of their book was on understanding investment behavior of firms, and developing the implications of this theory for industry dynamics and government policy.

Trigeorgis [1996] brought together previously scattered knowledge about real options. Comprehensively, he reviewed techniques of capital budgeting and detailed an approach based on the pricing of options that provides a means of quantifying flexibility. He also dealt with options interaction, the valuation of multiple options that are common in projects involving real options, and the valuation of the impact of competitive interactions. The methodology in this book was theoretical, and helped to shape more practical real options valuation techniques later on.

Besides theoretical development, applications of real options are growing fast in business strategy, corporate finance, market valuation, contract valuation, security analysis, portfolio management, risk management, to engineering design. Real options methodology is applied in industries from natural resources development, real estate, R&D, information technologies, pharmaceutical, manufacturing, venture capital, government regulation, shipping, environmental pollution and global warming, to infrastructure.

Amram and Kulatilaka [1999] wrote an introductory book on real options, including financial options and applications of real options. But it does not provide a detailed practical methodology to evaluate real options. It gives readers an idea how widely real options can be applied.

The beginning of twenty-first century sees a boom in the publication of books on real options with more focus on applications. Rogers [2002] describes his framework and insights in applying real options gained as a consultant with PricewaterhouseCoopers. Mun [2003] provides a qualitative and quantitative description of real options and multiple business cases and real-life scenarios. Brach [2003] explores how to apply real option valuation techniques on a regular basis from the view of a corporate practitioner. Howell et al. [2001] and Boer [2002] aim more at illuminating non-numerate readers of real options.

Although options thinking has been successfully applied to many areas, the application of real options in engineering has been slow, especially regarding building flexibility into the physical systems themselves. de Neufville [2002] suggested distinguishing between real options "on projects" and "in projects". The real options "on projects" concern the project but not system design, for example, the options imbedded in bidding for opening a mine. The real options "in projects" concern the design elements of system and require detailed understanding of the system, for example, options for repositioning of system of communication satellites.

Over around 20-year development of the methodology, thousands of articles have been published on this topic. Alexander Triantis maintains a portal with over 700 articles on real options at http://www.rhsmith.umd.edu/finance/atriantis/RealOptionsportal.html. Another good information center of real options is made by Marco Dias at http://www.puc-rio.br/marco.ind/main.html#contents.

2.1.2. Application of the methodology

This thesis values options imbedded in river basin development. The literature review, thus, focuses more on the application of the valuation methodology, rather than theory.

Valuation approaches

Options valuation is arbitrage-enforced pricing. Sometimes, however, people use decision tree analysis (DTA) to illustrate the idea of options and approximate the value of flexibility for real projects.

Arbitrage-enforced Real Options Valuation

As Baxter and Rennie [1996] explain, if there is arbitrage, it will enforce a price for the options. This price depends neither on the expected value nor on the particular distribution of the underlying. There are three categories of arbitrage-enforced valuation methods: the partial differential equation (PDE) such as the Black-Scholes formula, the dynamic programming such as the binomial tree, and simulation.

The PDE method is the standard and widely used in academic discussion because of the mathematical insights of the method. McDonald and Siegel [1986] studied the value of waiting to invest by PDEs. Siegel, Smith and Paddock [1987] valued offshore petroleum leases using PDE equations. Pindyck [1993] established PDEs to model project cost uncertainty, both technical and as regards input cost. Grenadier and Weiss [1997] studied the options pricing for investment in technological innovations.

The binomial tree method is based on a simple representation of the evolution of the underlying asset's value. It is a powerful yet flexible method to value real options. Luenberger [1998] showed examples using binomial trees to value a real investment opportunity in a gold mine. Cox, Ross, and Rubinstein [1979] developed this widely adopted method. Copeland and Antikarov [2001] elaborated how to use binomial trees to value real projects and proved this method, equivalent to PDE solution, is easy to use without losing the insights of the PDE model.

With development of computer technology, big simulation programs can be constructed to value options that are very difficult to value by establishing/solving equations or building up binomial trees. In the 1980s, Merck began to use simulation to value its R&D real options [Nichols, 1994]. Tufano and Moel [2000] showed an elegant way to use Crystal Ball© to simulate the value of real options inherent in a bidding case for mining. Juan et al. [2002] suggested a simulation methodology to calculate multiple interacting American options on a harbor investment problem.

Expected value decision tree analysis

Strictly, decision tree analysis (DTA) is an expected value approach that does not yield a theoretically correct options value, unless the risk-adjusted discount rates and actual probabilities are used. To find risk-adjusted discount rate for each branch of the decision tree is difficult, if possible. However, people use DTA to illustrate the idea of real options and approximate the value of flexibility.

Faulkner [1996] showed how DTA could do “options thinking” valuation. Though this method does not provide a “correct” options value, it approximates the value, and more importantly, provides insights into options thinking.

Ramirez [2002] compared discounted cash flow methodology, decision tree analysis, and arbitrage-enforced real options. She examined their theoretical advantages/disadvantages, the assumptions, and information required. She also determined the consequences of the application of each approach on the nature of infrastructure projects.. Although the real options methodology is theoretically superior in the pricing of flexibility, its implementation requires information usually not available for infrastructure assets. This makes the results of the analysis imprecise and complicates the process of identifying an optimal strategy.

Hybrid Model

Hybrid real options valuation combines the best features of decision tree analysis and real options analysis. Neely and de Neufville [2001] developed a hybrid real options valuation model for risky product development projects. The traditional valuation methods for risky product development are inadequate to recognize the value of flexibility while the real options method meets with difficulties to obtain the data necessary for a standard real options valuation. Their hybrid method analyzes project risks with real options analysis and market risks with decision tree analysis.

Summary

Table 2-1 illustrates five major types of valuation approaches with some examples:

Table 2-1: Different Valuation Approaches with Examples

Examples	DTA	Hybrid Model	Arbitrage-enforced Real Options Valuation		
			PDE	Binomial Tree	Simulation
Automobile R&D Management (Neely and de Neufville, 2001)		X			
Bogota Water Supply Expansion (Ramirez, 2002)	X		X	X	
Merck (Nichols, 1994)			X		X
Kodak (Faulker, 1996)	X				

Borison [2003] described, contrasted, and criticized the major proposed analytic approaches for applying real options. He observed relative strengths and weaknesses of the approaches and recommended on which ones to use in what circumstance. He thought the integrated approach (the hybrid model) is based on the most accurate and consistent theoretical and empirical foundation.

Several important issues regarding real options valuation

Underlying

Financial options are based on underlying assets such as stocks, stock indices, foreign currencies, debt instruments, commodities, and futures contracts. They are traded in markets. Despite the fact that real options are not traded on markets, Mason and Merton [1985], and Kasanen and Trigeorgis [1993] maintained that real options may be valued similarly to financial options. The existence of a traded portfolio that has the same risk characteristics (i.e., is perfectly correlated) as a non-traded real asset is sufficient for real options valuation. Kulatilaka [1993] used the relative price of oil over gas to value the flexibility of a dual-fuel industrial steam boiler. Luenberger [1998] showed an example using the gold price as the underlying assets to value a real investment opportunity in a gold mine. Similarly, as shown in this thesis, it is possible to use energy price as the underlying asset to value a hydropower project under the assumption of a complete energy market.

However, in many cases, it is hard to find a priced portfolio whose cash payouts are perfectly correlated with those of the project, or in other words, to find market-priced underlying assets.

Is it possible to relax the definition of underlying to an agent that determines the value of a project, not necessarily market-traded? Copeland and Antikarov [2001] developed the assumption of "market asset disclaimer" and used the NPV of the underlying project as underlying assets to build event trees to value real options. "Instead of searching in financial market," they recommended, "that you use the present value of the project itself, without flexibility, as the underlying risky asset—the twin security." (pp. 94) This method has the key disadvantages that it makes it impossible to identify the optimal strategy and blurs the exercise condition, because the NPV of a project is not readily market observable. How to find an appropriate underlying is an interesting question.

Volatility

Volatility is a measure of uncertainty, a key input of the options valuation. How to find the volatility is one of the key difficulties of application of real options if there is no market-traded underlying. Luehrman [1998] described three approaches: an educated guess, historical data, and simulation. Copeland and Antikarov [2001] suggested, by estimating first the stochastic properties of variables that drive volatility, using Monte Carlo simulation to estimate it.

The estimate of volatility is often one of the weakest points of a real options valuation, while the valuation is usually sensitive to the volatility. Because the volatility is the essence of a lot of information, it is theoretically impossible to estimate it for some real options valuation simply due to lack of data. Sometimes, therefore, the insights provided by a real options analysis are more important than a specific quantitative result.

Compound options and parallel options

Most real options are not well-defined simple options. They can be compound or parallel. They are often options on options (compound options) and the interactions between options are significant. So the methodology for valuing compound options is very important for the applicability of real options methodology in the real world. Parallel options are different options built on the same project, where those options interact. For example, several possible applications of a new technology or several possible target markets of a new product. Oueslati [1999] described three parallel options for fuel cell development as automotive applications, stationary power, and portable power.

Geske [1979] developed approaches to the valuation of compound options. Trigeorgis [1993] focused on the nature of the interactions of real options. The combined value of a collection of options usually differs from the sum of their separate values. The incremental value of an additional option, in the presence of other options, is generally less than its value in isolation, and declines as more options are present. Oueslati [1999] explored the evaluation of compound and parallel real options in Ford's investment in fuel cell technology.

With all the developments in the application of the real options, the author is confident in applying the methodology on the river basin problem in this thesis. However, a lot of problems still await solutions. Without a market-observable underlying, the parameters used for the valuation are based on model that must be subjective, to a certain extent. So the model risks are not negligible in the method presented in this thesis.

Real Options applied in Energy and Natural Resources

The real options concept has been successfully applied in the energy industry. Siegel, Smith, and Paddock [1987] valued offshore petroleum leases using options, and provided empirical evidence that options values are better than actual DCF-based bids. Since then, research on real options on energy has been a hot topic. Dias [2002] gave a comprehensive overview of real options in petroleum. Miltersen [1997] presented methods to value natural resource investment with stochastic convenience yield and interest rates. Cortazar and Casassus [1997] suggested a compound option model for evaluating multistage natural resource investment. Cherian, Patel, and Khripko [2000] studied the optimal extraction of nonrenewable resources when costs accumulate. Goldberg and Read [2000] found that a simple modification to the Black-Scholes model provides better estimates of prices for electricity options. Their modification combines the lognormal distribution with a spike distribution to describe the electricity dynamics.

Pindyck [1993] studied the uncertain cost of investment in nuclear power plants. He derived a decision rule for irreversible investments subject to technical uncertainty and input uncertainty. The rule is to invest if the expected cost of completing the project is below a critical number. The critical expected cost to completion depends on the type and level of uncertainty. Pindyck's work focused on finance issues of the project, the engineering model was apart from his interest.

Koekebakker and Sodal [2002] developed an equilibrium-based real options model of an operating electricity production unit whose supply is given by a stochastic mean-reverting process. Hlouskova et al. [2002] implemented a real options model for the unit commitment problem of a single turbine in a liberalized market. Price uncertainty was captured by a mean-reverting process with jumps and time-varying means to account for seasonality. Rocha, Moreira, and David [2002] studied the competitiveness of thermopower generation in Brazil under current regulations and used real options to assess how to motivate private investment in thermopower.

2.2. Water Resource Planning with regard to Facilities Design

Water resource planning with regard to facilities design is an area that came into maturity by 1980, though the prevailing methodology does not consider the design issues in the full context of the changing and uncertain world.

2.2.1. Historical development

After economic analysis was brought into water resource planning studies, research on water resource planning with regard to facilities design can be divided into three phases: mathematical programming, multiobjective analysis, and risk recognition.

Mathematical programming

Maass et al. [1962] summarized the contributions of Harvard Water Program (1955 – 1960). They introduced the most advanced techniques at that time: such as linear programming, mathematical synthesis of streamflow sequences, and computer simulation. This study laid foundation for future development of water resource planning.

Hufschmidt and Fiering [1966] described a river basin computer simulation model thoroughly. Before computers became generally available, the simulation models were physical models scaled to maintain static or dynamic similitude. The simulation model of Hufschmidt and Fiering dealt with a large number of randomly selected designs, included generation of long hydrologic sequences, and measured outcomes in economic terms.

Their model was much more advanced than the then prevailing physical simulations. They tested 20 randomly selected designs for 250 years (3000 months) of simulated operations. The 3 designs with the highest net benefits were subjected to further analysis using single-factor and marginal analysis methods. The model was written in FORTRAN. The computer used was the IBM 7094 that had 32,768 directly addressable memory (whereas modern computers have memory measured in Gigabytes!) It took about 7.5 minutes for one single operation of simulation for 250 years.

Jacoby and Loucks [1974] developed an approach to the analysis of complex water resource systems using both optimization and simulation, not as competing techniques but as interacting and supplementing partners for each other. They used preliminary screening models to select several alternative design configurations; then they simulated the preferred designs using the same annual benefit, loss, and cost functions. They estimated the expected benefits for each state for each 5-year period from 1970 to 2010.

Major and Lenton [1979] extended this work in a study of the Rio Colorado river basin development in Argentina. Their system of models consisted of a screening model, a simulation model and a sequencing model. The screening model is a mixed-integer programming model with about 900 decision variables, including 8 0-1 integer variables, and about 600 constraints. Objectives were incorporated either into the objective function or as constraints on the system. Multiobjective criteria underlay the whole formation of the model. The simulation model evaluated the most promising configurations from the screening model in terms of net benefits and hydrological reliability. The runs from the simulation model improved the configurations from the screening model. The simulation model was operated with 50 years of seasonal (4-month) flows. The sequencing model scheduled a candidate configuration optimally in 4 future time periods, taking into account benefits over time, budget constraints, constraints on the number of farmers available, and project interrelationships. The mixed-integer programming sequencing model had about 60 continuous variables, 120 integer variables, and 110 constraints depending on the exact configuration being modeled.

Loucks, Stedinger, and Haith [1981] summarized the art of water resource planning till then, such as evaluation of time streams of benefits and costs, plan formulation, objective functions and constraint equations, Lagrange multipliers, Dynamic Programming, Linear Programming, Simulation, probability and distribution of random events, stochastic processes, and planning under uncertainty.

After the 1980s, developments in water resource planning theory were less concerned with the design of water resource facilities, partly because the water resource systems were almost all developed in the US and partly because the art had matured. Entering the 1990s, powerful computers and computer programs such as GAMS improved the performance of previous methodologies and enabled the solution of much bigger problems.

Multiobjective analysis

There are many different objectives for water resource planning, such as national or regional income maximization, income redistribution, environmental quality, social well-being, national security, self-sufficiency, regional growth and stability, and preservation of natural areas. Some objectives can be easily expressed in monetary terms, while some can not. Some (or all) objectives are conflicting and non-commensurable. Multiobjective analysis does not yield a single optimal solution, but identifies the production possibility frontier and trade-offs among objectives.

Cohon and Marks [1974] discussed an application of multiobjective theory to the analysis of development of river basin systems. Major [1974] provided a case of the application of Multiobjective analysis to the redesign of the Big Walnut Dam and reservoir in Indiana. Major and Lenton [1979] demonstrated the application of mathematical modeling and multiobjective investment criteria to river basin development.

Risk recognition

The above-mentioned studies transformed technical parameters into expected total annual net efficiency benefits (or the utility for human and society) and maximized the net efficiency benefits (or utility) to obtain the “optimal design”. They carefully considered technical uncertainties, such as that of waterflow, and used dynamic models. However, none of them took into account uncertainties in the human and social sphere. Ignoring the human and social uncertainties, the methodology cannot reach the “optimal design” (if such designs exist) by simply recognizing the technical uncertainties.

Recent studies on water resource planning are more explicitly taking human, social, environmental uncertainties into account. Morimoto and Hope [2001, 2002] applied probabilistic cost-benefit analysis to hydroelectric projects in Sri Lanka, Malaysia, Nepal, and Turkey. Their results were in the form of distributions of NPV. These studies recognized the uncertainties from human, social, and environmental perspectives. But they did not take into account the value of options, or the flexibility. Decision-makers do not passively succumb to fate and they will respond to the uncertain environment.

2.2.2. Other important references

Based on Manne [1961], Hreisson [1990] dealt with the problem of obtaining the “optimal design” of hydroelectric power systems regarding sizing and sequencing. The conclusion was to make the current marginal value of each new project equal to the discounted weighted average of the long-term marginal unit cost of all future projects. He further investigated economies of scale and optimal selection of hydroelectric projects. The tradeoff between large and small projects was studied by weighting the lost sales during the period of excess capacity against the benefit of using larger projects due to the economies of scale. All his studies were based on a deterministic view. If uncertainties regarding the demand and supply are high, the rules Hreisson developed may be misleading.

Aberdein [1994] illustrated the case of excess electricity on the South Africa interconnected grid resulted from the mismatch between planned capacity and actual demand. She stressed the importance of incorporating risks into power station investment decisions.

Some papers available on the website of World Commission on Dams (http://www.dams.org) are very helpful. For example, Fuggle and Smith [2000] prepared a report on dams in water and energy resource development in China. It provides important background information on China's dam building program, financing, and policy development. Clarke [2000] reported the findings of a global dam survey covering 52 countries and 125 large dams. This report provides important information for the uncertain factors to build the real options model in this thesis, such as the project schedule performance data, actual-to-planned hydropower energy out, and many others.

2.3. Conclusions from the literature search

Although there is increased interest in real options, research has not expanded its influence into the physical engineering design, where uncertainty and flexibility are key in many circumstances. On the other hand, water resource planning studies focus on the technical sides, including various technical uncertainties, but they have not incorporated the important risks from human and social sides. Anyway, any engineering system is built to serve human and human society. Real options methodology offers the advanced accounts of some of the very important risks on human and social sides.

It would be exciting to look into building real options into the engineering design of water facilities themselves, and develop some general methodology to build flexibility into engineering systems. Throughout the literature research, no prior systematic research on this topic is found. This master's thesis is a first step of this research. A first simple deferral option on a river basin development will be studied.

Chapter 3 Options

According to Hull [1999], Stock options “were first traded on an organized exchange in 1973”. The land-mark Black-Scholes model that won Nobel Prize in 1997. The model was initially developed for financial options in 1973 by Black and Scholes and later modified by Merton. Gradually, options methodology and thinking has been extended to broader areas in finance and non-finance. Its insights into uncertainty and flexibility enhance the ability of human beings to deal with forever-changing environments.

3.1. Financial Options

There are two basic types of options: calls and puts. A call option gives the holder the right to buy an underlying asset for a specified exercise price within or at a specified time. A put option gives the holder the right to sell the underlying under similar circumstances. Expiration date is also called maturity. Exercise price is also called strike price.

Financial options are also categorized by the time when they can be exercised. American options can be exercised any time up to the expiration date. European options can exercised only on the expiration date.

Compound options are options on options. There are four main types of compound options: a call on a call, a put on a call, a call on a put, and a put on a put. Many real options have the compound options features.

The underlying assets for financial options include stocks, stock indices, foreign currencies, debt instruments, commodities, and futures contracts. Besides the real options, this thesis is only discussing the financial options built on underlying assets of stocks, or stock options.

Example of a stock call option:

John buys one European stock call option contract on Lucent stock with a strike price of $1.50. Suppose the current price of Lucent is $1.30, the expiration date is in three months. Because the option is European, John can exercise the option only on the expiration date. If the stock price on the expiration date is less than $1.50, John will choose not to exercise. If the stock price on the expiration date is greater than $1.50, John will choose to exercise. For instance, if the stock price on the expiration date is $1.45, John will not exercise the option, he can buy a share of stock directly on the market for $1.45 less than the exercise of $1.50. If the stock price on the expiration date is $1.60, John will exercise the option and earn $0.10 because he can immediately sell the stock that he buys for $1.50.

Key Property of an Option

The holder of an option has the right to exercise the option, but no obligation to exercise the option. The key property of an option is the asymmetry of the payoff, an option holder can avoid downside risks and limit the loss to the price of getting the option, while she can take advantage of the upside risks and the possible gain is unlimited. See Figure 3-1 for the example of a stock option.

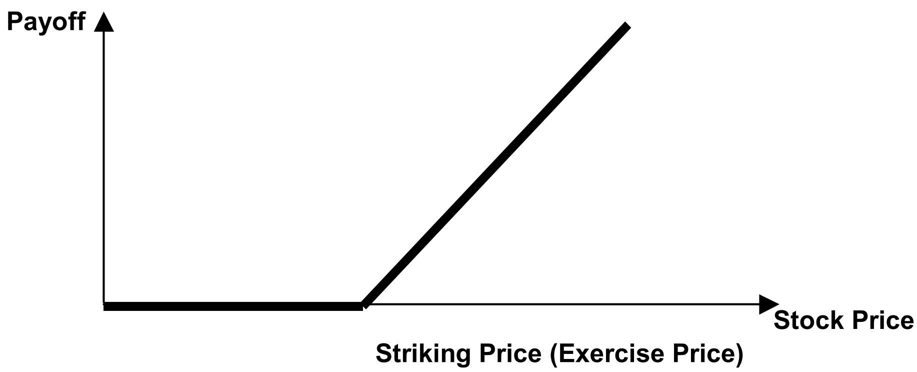


Figure 3-1 Payoff Diagram for a Stock Call Option

For the above stock call option in Figure 3-1, if the current stock price is lower than the strike price, people would not exercise it, the loss is limited to the price to get the option; if the current stock price is higher than the striking price, people would exercise it, and the payoff is the current stock price minus the strike price. There is no upper bound of the payoff and a lower bound of the payoff, so asymmetry exhibits.

3.2. Cornerstones for Options Valuation

The value of an option is not straightforward, and it is an interesting question that how to value an option objectively. The cornerstones for the modern stock options valuation models are two assumptions: no arbitrage and Brownian motion of stock price.

3.2.1. No Arbitrage

Arbitrage involves getting profit by simultaneously entering into transactions in 2 or more markets. See the following example: Considering a stock that is traded on both the New York Stock Exchange and the London Stock Exchange. If the stock price is $17.7 in New York and £10 in London when the exchange rate is $1.8000 per pound. An arbitrager could simultaneously buy 1000 shares of the stock in New York and sell them in London to obtain a risk-free profit of

$$1000 \times [(\$1.8 \times 10) - \$17.7]$$

or $300. Arbitrage opportunities such as the one just described cannot last for long. As arbitrageurs buy the stock in New York, the forces of supply and demand will cause the stock price to rise. Similarly, as arbitrageurs sell the stock in London, the forces of supply and demand will cause the stock price to drop. Very quickly, the two prices will be equivalent at the current exchange rate. Indeed, the existence of profit hungry arbitrageurs makes it unlikely that a major price disparity could ever exist in the first place.

If no arbitrage opportunity exists, a portfolio of the stock and the stock option can be set up in such a way that there is no uncertainty about the value of the portfolio. Because the portfolio has no risk, the return earned on it must equal the risk-free interest rate.

A riskless portfolio consisting of a position in the option and a position in the underlying stock is created. In the absence of arbitrage opportunities, the return from the portfolio must be risk-free interest rate. The reason why a riskless portfolio can be created is the stock price and the option price are both affected by the same courses of uncertainty: stock price changes. In a short period of time, when an appropriate portfolio is established, the gain or loss from the stock option always offset by the loss or gain from the option position so that the value of the portfolio is known with certainty at the end of the short period of time to earn risk-free rate of interest. For that short period of time, the price of a call option is perfectly positively correlated with the price of the underlying stock, and the price of a put option is perfectly negatively correlated with the underlying stock.

For a simple example: A stock price is currently \$10, and it is known that at the end of period of y months the stock price will be either \$11 or \$9. There is a European call option to buy the stock for \$10.5 at the end of y months. This option will have one of the two values at the end of the six months. If the stock price turns out to be \$11, the value of the option will be \$0.5; if the stock option turns out to be \$9, the value of the option will be 0. The situation is illustrated in Figure 3-2:

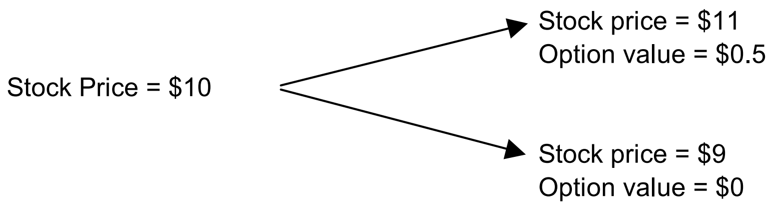


Figure 3-2 Stock Price Movement in Numerical Example

Consider a portfolio consisting of a long position[1] in x shares of the stock and a short position[2] in 1 call option. How to calculate the value of x that makes the portfolio riskless. If the stock price moves up from \$10 to \$11, the value of the share is 11x and the value of the option is 0.5, so that the total value of the portfolio is 11x – 0.5. If the stock price moves down from \$10 to \$9, the value of the shares is 9x and the value of the option is 0, so that the total value of the portfolio is 9x. The portfolio is riskless if the value of x is chosen so that the final value of the portfolio is the same for both cases. This means:

---

[1] A long position is to buy the underlying asset on a certain specified future date for a certain specified price.

[2] A short position is to sell the underlying asset on a certain specified future date for a certain specified price.

$$11x - 0.5 = 9x$$

or

$$x = 0.25$$

If the stock price moves up to \$11, the value of the portfolio is

$$11 \times 0.25 - 0.5 = 2.25$$

If the stock price moves down to \$8, the value of the portfolio is

$$9 \times 0.25 = 2.25$$

Regardless of whether the stock price moves up or down, the value of the portfolio is always \$2.25 after y months.

Riskless portfolio must, in the absence of arbitrage opportunities, earn the risk-free rate of interest of r. It follows that the value of the portfolio today must be present value of 2.25, or

$$2.25e^{-\frac{ry}{12}}$$

The value of the stock price is known to be \$10. Suppose the option price is f. The value of the portfolio is

$$10 \times 0.25 - f = 2.25e^{-\frac{rf}{12}}$$

or

$$f = 2.5 - 2.25e^{-\frac{rf}{12}}$$

3.2.2. Brownian motion and Weiner Processes

The standard model for stock prices is a geometric Brownian motion with constant volatility. Standard Brownian motion is one of the most important basic notions of stochastic processes, and in particular, is the basis of modern options theory.

To develop a sound theory of option pricing, one should describe the stock price evolution using a dynamic model with a reasonable agreement with reality. The exact formulation of the model for stock price evolution was a subject of debates for over a century.

Brownian motion originally refers to the random motion observed under microscope of a pollen immersed in water. Albert Einstein pointed out that this motion is caused by random bombardment of heat-excited water molecules on the pollen. More precisely, each of his steps (in both x- and y- directions) is an independent normal random variable.

Albert Einstein developed the notions of Brownian motion in the beginning of the 20th century. In 1905 he defended his Ph.D. thesis on the subject of the separation of two large particles experiencing random hits from surrounding small molecules. For this work he received the Nobel Prize (Ironically, he did not receive the Nobel Price for the Theory of Relativity). Although he himself considered his work not particularly important, this work laid the ground for the theoretical understandings and beginnings of stochastic processes altogether. Further contributors to the subject were Markov, Uhlenbeck, Khintchine, Weiner, Smoluchowski, Ito, and Stratonovich. It was only in the 1960s that the theory of Brownian motion was applied to modeling stock prices.

Stock prices are influenced by astronomical independent random factors together. Each factor is trivial in the total influence. This kind of random variables, stock prices in this case, usually follows normal distribution approximately. The reason why a normal distribution is not used to describe stock prices is because stock prices cannot be negative. Lognormal distribution describes the change rate of stock prices (expressed using continuously compounding) to be normal. The change of an stock price can be negative, which means the effective market is decreasing while it is still positive.

Consider the following discrete construction. Let Z_{t0} be the position of a particle at time t_0. Let at time t_0 + t the position of the particle be Z_{t0} + ΔZ, where the increments are related:

$$\Delta Z = \varepsilon\sqrt{\Delta t}$$

where ε denotes a random sample from a standard normal distribution (mean 0 and standard deviation 1).

$$Z_{t_n} = Z_{t_{n-1}} + \varepsilon_n \cdot \sqrt{\Delta t}$$

Compounding n such increments, one can get for a finitely large interval of time T=nΔ t:

$$Z(t_0 + T) = Z_{t0} + \sum_{i=1}^{n} \varepsilon_i \sqrt{\Delta t}$$

Here ε_i are all independent samplings from a standard normal distribution. Considering the limit of $\Delta t \to 0_+$, it may be shown that the resulting process converges to a limit, which is called standard Brownian motion, and is also referred to as a Wiener process.

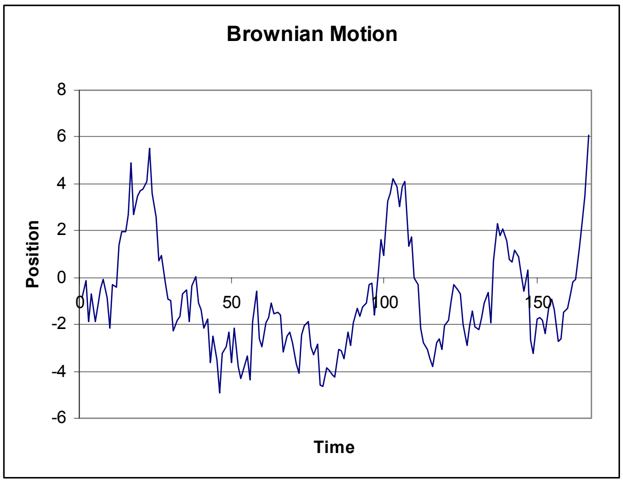


Figure 3-3 One Path of Brownian Motion

Figure 3-3 exhibits a single path of a standard Brownian motion with initial condition X_0 = 0.

Figure 3-4 Two Hundred Paths of Brownian Motion

Figure 3-4, in turn, shows two hundred paths of the standard Brownian motion.

The basic Wiener process, *dz*, has a drift rate (i.e. average change per unit of time) of zero and a variance of 1.0. The drift rate of zero means that the expected value of *z* at any future time is equal to its current value. The variance rate of 1.0 means that the variance of the change in *z* in a time interval of length *T* equals *T*.

A generalized Wiener process for a variable *x* can be defined in terms of *dz* as follows:

$$dx = adt + bdz$$ ***Equation 3-1***

where *a* and *b* are constants, *dz* is the basic Wiener process. The *adt* term implies that *x* has an expected drift rate of *a* per unit of time. If without the *bdz* term, in a period of time of length *T*, *x* increases by an amount of *aT*. The *bdz* term can be regarded as adding noise or variability to the path followed by *x*. The amount of this noise or variability is *b* times a basic Wiener process. A basic Wiener process has a standard deviation of 1.0. It follows that *b* times a Wiener process has a standard deviation of *b*.

In a small time interval Δt, the change in the value of x, Δx, is

$$\Delta x = a\Delta t + b\varepsilon\sqrt{\Delta t}$$

Since ε is a random number drawing from a standard normal distribution. Thus, Δx has a normal distribution with

Mean of $\Delta x = a\Delta t$

Standard deviation of $\Delta x = b\sqrt{\Delta t}$

Variance of $\Delta x = b^2\Delta t$

Stock Price Process Model

It is usually assumed that asset prices follow Geometric Brownian Motion where the logarithm of the underlying variable follows generalized Wiener process.

If the price of a non dividend paying stock, *S*, follows geometric Brownian motion:

$$dS = \mu S dt + \sigma S dz \qquad \textbf{Equation 3-2}$$

where *S* is the stock price, *μ* is the expected return on the stock, and *σ* is the volatility of the stock price. The volatility of a stock price can be defined as the standard deviation of the return provided by the stock in one year when the return is expressed using continuous compounding. The volatility is also the standard deviation of the natural logarithm of the stock price at the end of one year.

Then, using Ito's lemma (see Appendix I) to get:

$$d \ln S = (\mu - \frac{\sigma^2}{2})dt + \sigma dz \qquad \textbf{Equation 3-3}$$

From this equation, the variable *lnS* follows a generalized Wiener process, the change in *lnS* between *0* and *t* is normally distributed, so that S has a lognormal distribution.

Lognormal Properties of stock price

In general, a lognormal distribution probability density function is as follows:

$$f(x) = \frac{1}{x} \cdot \frac{1}{\sigma\sqrt{2\pi t}} \cdot e^{\frac{-(\ln x - \mu)^2}{2\sigma^2 t}}$$ ***Equation 3-4***

but the following will show a more intuitive explanation of the lognormal distribution of the stock prices. See Figure 3-5 for the shape of lognormal density function.

The lognormal distribution of price means the logarithm of the price has a normal distribution. To illustrate, if a stock is priced at \$100 per share and prices have a normal distribution, the distribution of prices is the familiar bell-shaped curve centered at \$100, but if the prices have a lognormal distribution, then it is the logarithm of the price which has a bell-shaped distribution about ln(100) = 4.605. The logarithm of the prices is equally likely to be 5.298 or 3.912, i.e., 4.605 $\pm$ 0.693 corresponding to prices of \$200 and \$50, respectively. If the lognormal probability density curve is plotted as a function of price rather than as a function of the logarithm of price, the curve will appear positively skewed with tails more nearly depicting the observed behavior of stock prices.

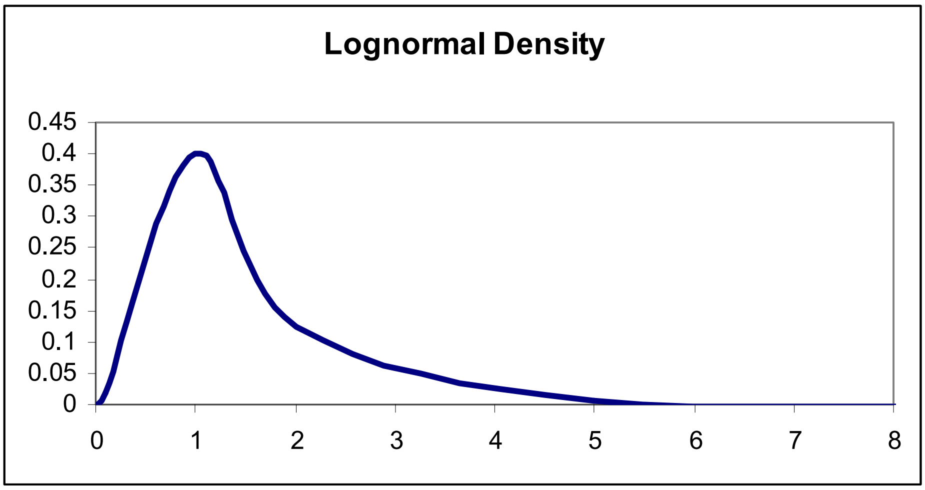


Figure 3-5 Lognormal Density

Lognormality arises from the process of return compounding, in other words, the lognormal property of stock prices apply when the return rate earned on a stock between time 0 and t is continuously compounded. It is important to distinguish the continuously compounded rate of return and the annualized return with no compounding as

$$\frac{1}{t}\left(\frac{S_t - S_0}{S_0}\right)$$

3.3. Options Valuation Tools

The first model to calculate options value is the Black-Scholes formula, which is sometimes deemed arcane. Interests in option pricing, however, has picked up in recent years as more powerful computers can aid very sophisticated model building. With simulation methods available easily as Excel add-ins or more professional alternatives such as @Risk or Crystal Ball, people are able to do a hundred thousand simulations easily and get the payoff distribution as well as the value of real options[1]. Besides, binomial model proves very successful in option pricing and decision analysis is sometimes another approach to value options approximately[2].

---

[1] Simulation generates values of uncertain variables according to the probability distribution of the variables, uses those values as inputs, and gets the output. With a great number of repetitions, the probability distribution of the output is established.

[2] The valuation by decision analysis is not real options valuation strictly because it does not use the risk-neutral valuation (refer to 3.4.).

Five inputs are needed for a options valuation (if considering the simplest situation when there is no dividend):

- strike price
- risk-free interest rate
- time to expiration
- current stock price
- uncertainty (volatility is the measurement)

Among the five inputs of an options model, the first four inputs are relatively easier to get, while the last one uncertainty, which is estimated by volatility in most cases. with a lot of historical data available on the stock market, it is relatively trivial to get σ for a stock option. However, for a real option, lack of historical data is a common problem except a few specific industries, such as pharmaceutical industry. Because of the lack of historical data, it is very hard to justify the choice of volatility. This is one of the practical difficulties facing real options valuation method.

3.3.1. The Black-Scholes Model:

The Black-Scholes-Merton analysis is based on no-arbitrage condition.

The stock price process is the one as we developed in the last section as Equation 3-2:

$$dS = \mu S dt + \sigma S dz$$

Suppose *f(S,t)* is the price of a call option, which is some function of the stock price of *S* and time of *t*. Hence from Ito's Lemma (see Appendix I):

$$df = (\frac{\partial f}{\partial S}\mu S + \frac{\partial f}{\partial t} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)dt + \frac{\partial f}{\partial S}\sigma S dz$$ ***Equation 3-5***

The Wiener processes *dz* underlying *f* and *S* are the same. It follows that by choosing a portfolio of the stock and the stock option, the Wiener process can be eliminated. The appropriate portfolio is short one call option and long an amount $\partial f / \partial S$ of shares. Define $\prod$ as the value of the portfolio. By definition

$$\prod = -f + \frac{\partial f}{\partial S} S$$ ***Equation 3-6***

Note the portfolio is riskless only for an infinitesimally short period of time. As *S* and *t* change, $\partial f / \partial S$ also changes. To keep the portfolio riskless, it is necessary to constantly change the composition of the portfolio.

Because the discrete version of equations Equation 3-5 and Equation 3-2 are

$$\Delta f = (\frac{\partial f}{\partial S}\mu S + \frac{\partial f}{\partial t} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)\Delta t + \frac{\partial f}{\partial S}\sigma S \Delta z$$

and

$$\Delta S = \mu S \Delta t + \sigma S \Delta z$$

Then the change $\Delta \prod$ in the time interval Δt is given by

$$\Delta\prod = -\Delta f + \frac{\partial f}{\partial S}\Delta S$$

$$= -(\frac{\partial f}{\partial S}\mu S + \frac{\partial f}{\partial t} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)\Delta t - \frac{\partial f}{\partial S}\sigma S\Delta z + \frac{\partial f}{\partial S}\mu S\Delta t + \frac{\partial f}{\partial S}\sigma S\Delta z$$ ***Equation 3-7***

$$= (-\frac{\partial f}{\partial S} - \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)\Delta t$$

The equation does not involve Δz , the portfolio must be riskless during time Δt under the assumption of no arbitrage. It follows that

$$\Delta\prod = r\prod\Delta t$$ ***Equation 3-8***

where r is the risk-free interest rate. Substituting from equations Equation 3-6 and Equation 3-7, this becomes

$$(\frac{\partial f}{\partial t} + \frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2)\Delta t = r(f - \frac{\partial f}{\partial S}S)\Delta t$$

So that

$$\frac{\partial f}{\partial t} + rS\frac{\partial f}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 f}{\partial S^2} = rf$$ ***Equation 3-9***

Equation 3-9 is the Black-Scholes-Merton differential equation. Its solution depends on the boundary conditions used. In case of a European call option, the key boundary condition is

$f = \max[S - X, 0]$ when t = T

Solving the differential equation subject to the boundary conditions to get the Black-Scholes formulas for the prices at time zero of a European call option on a non-dividend-paying stock:

$$c = S_0 N(d_1) - Xe^{-rT} N(d_2)$$ ***Equation 3-10***

where

$$d_1 = \frac{\ln(S_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln(S_0 / X) + (r - \sigma^2 / 2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

and N(x) is the cumulative probability distribution function for a variable that that is normally distributed with a mean of zero and a standard deviation of 1.0.

In case of a European put option, the key boundary condition is

$$f = \max[X - S, 0] \quad \text{when t = T}$$

solving the differential equation to get the Black-Scholes formula for the prices at time zero of a European put option on a non-dividend-paying stock

$$p = Xe^{-rT} N(-d_2) - S_0 N(-d_1)$$

After going through all the derivation of the Black-Scholes formula, the two most important assumptions under the options pricing are stressed again here:

- no arbitrage
- geometric Brownian motion

It is key to understand what these two assumption's role in real options valuation. And thus understand the applicability for real options in different scenarios.

3.3.2. Valuation by Simulation

Simulation models roll out a huge number, typically thousands, of possible paths of the evolution of the value of the underlying from today to the final day studied. With options decision rule imbedded in each of the path, the average of the value on the final day is discounted back to today to obtain the options value.

For example, the current price of a stock is $20, volatility is 30% per year, risk-free rate is 5% per year. A stock European call option is built on such a stock with time to expiration of 3 months and strike price of $22.

Simulating the stock price 3 months later to get the distribution of the stock price as of Figure 3-6. With the European option imbedded, the distribution of price less than $22 is cut because people won't exercise it in such case. See Figure 3-7. The average of the chunk of the distribution greater than $22 minus $22 is the future value of the option. The future value of the option is then discounted to get the option value.

One of the advantages of the simulation model is that it can handle path-dependent options, in which the value of options depends not only on the value of the underlying, but also on the particular path followed by the underlying.

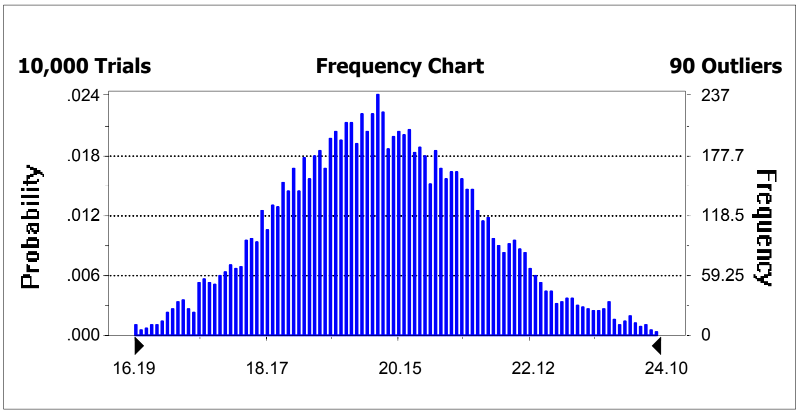


Figure 3-6 Distribution of Stock Price for Valuation by Simulation

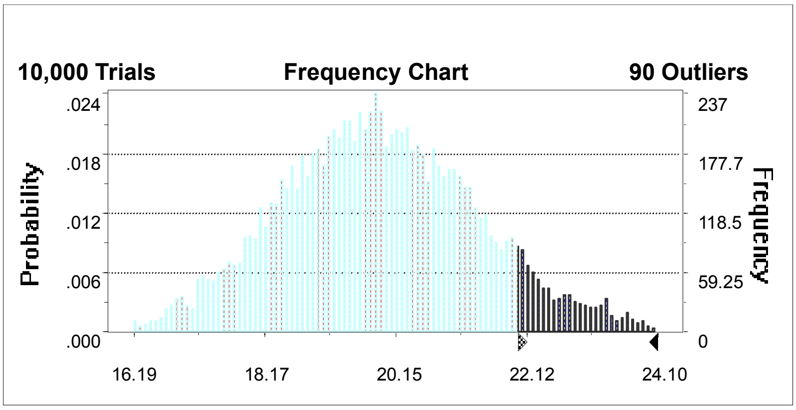


Figure 3-7 Distribution of Exercise of Option for Valuation by Simulation

With the fast development of computer hardware and software technologies, the simulation model has been more and more powerful and easy-to-use. A normal laptop can run thousands of simulations in seconds, and new software program such as Crystal Ball makes the simulation method accessible to everybody.

Find an example of options valuation by simulation in section 3.5.

3.3.3. Binomial Real Options Valuation

Considering a stock whose price is initially S_0 and an option on the stock whose current price is f. Suppose that the option lasts for time T. During the life of the option, the stock price can either move up from S_0 to a new level, S_0u, or down from S_0 to a new level S_0d. The proportional increase in the stock price when there is an up movement is $u-1$; the proportional decrease when there is a down movement is $1-d$. If the stock price moves up to S_0u, the payoff from the option is assumed to be f_u; if the stock price moves down to S_0d, the payoff from the option is assumed to be f_d. Figure 3-8 illustrates the situation:

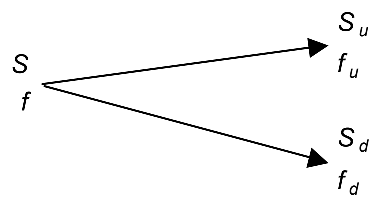


Figure 3-8 Stock and Option Price in a One-step Binomial Tree

Considering a portfolio consisting of a long position of x shares and a short position in one option. If there is an up movement in the stock price, the value of the portfolio at the end of the life of the option is

$$S_0ux - f_u$$

If there is a down movement in the stock price, the value becomes

$$S_0dx - f_d$$

The two are equal when

$$S_0ux - f_u = S_0dx - f_d$$

or

$$x = \frac{f_u - f_d}{S_0u - S_0d} \qquad \textbf{\textit{Equation 3-11}}$$

In this case, the portfolio is riskless. Due to the no arbitrage condition, the portfolio must earn risk-free interest rate. *x* is the ratio of the change in the option price to the change in the stock price.

The present value of the portfolio is

$$(S_0ux - f_u)e^{-rT}$$

where *r* is the risk-free interest rate. The cost of setting the portfolio is

$$S_0x - f$$

It follows that

$$S_0x - f = (S_0ux - f_u)e^{-rT}$$

or

$$f = S_0x - (S_0ux - f_u)e^{-rT}$$

Substituting *x* from Equation 3-11, this equation reduces to

$$f = e^{-rT}[pf_u + (1-p)f_d]$$ **Equation 3-12**

where

$$p_u = \frac{e^{rT} - d}{u - d}$$ **Equation 3-13**

One way to match volatility with u and d is

$$u = e^{\sigma\sqrt{\Delta t}}$$ **Equation 3-14**

$$d = e^{-\sigma\sqrt{\Delta t}}$$ **Equation 3-15**

One more step can be added to the binomial tree as Figure 3-9.

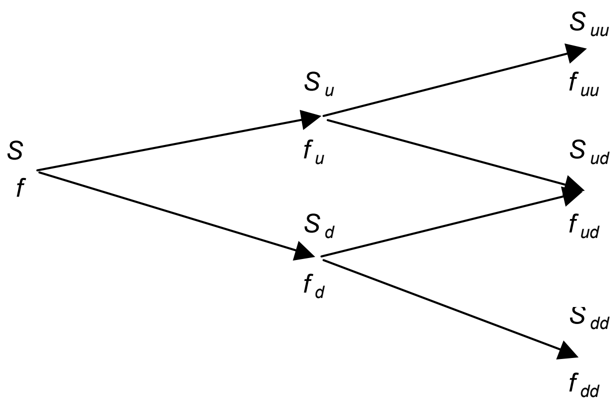


Figure 3-9 A Two-Step Binomial Tree

Repeated application of Equation 3-12 gives

$$f_u = e^{-rT}[pf_{uu} + (1-p)f_{ud}]$$
$$f_d = e^{-rT}[pf_{ud} + (1-p)f_{dd}]$$

And finally get:

$$f = e^{-rT}[pf_u + (1-p)f_d]$$

3.4. Risk-neutral Valuation

Refer to Figure 3-8, the expect stock price at time T, $E(S_T)$, is given by

$$E(S_T) = p_u S_0 u + (1-p_u) S_0 d$$

or

$$E(S_T) = p_u S_0 (u-d) + S_0 d$$

Substituting from Equation 3-13, this reduces to

$$E(S_T) = S_0 e^{rT} \qquad \textbf{\textit{Equation 3-16}}$$

showing the expected growth of the stock price is the risk-free rate. Setting the probability of the up movement equal to p_u is to assume that the expected return on the stock is the risk-free rate.

In a risk-neutral world, all individuals are expected value maximizers and require no compensation for risk, and the expected return on all securities is the risk-free rate. Equation 3-12 shows that the value of option is its expected payoff in a risk-neutral world discounted at the risk-free rate. The risk-neutral valuation principle states that it is valid to assume the world is risk neutral when pricing options. The result is correct for all worlds, not only in the risk-neutral world.

3.5. Options Valuation and Decision Tree Analysis

Options analysis is continuous, but decision tree is discrete. Normally, the decision tree analysis will not give the correct value for options because it is not a risk neutral analysis. Decision tree analysis does not refer to arbitrage-enforced price, and use the actual probabilities of the price movement of the underlying assets. If using risk-neutral evaluation and simulation, however, the decision tree analysis will give the exactly same answer as Black-Scholes.

To a certain extent, what the options theory offers is an understanding of the stock prices that is lognormally distributed. From today's stock price and the volatility of the stock price, the distribution of a stock price on a future date can be derived. With the understanding of the stock price distribution, decision tree analysis can be applied.

An Example of Option Valuation

If there is a stock, the stock price S_0 is \$20 now, the volatility σ is 30%, risk-free interest rate r is 5%. A call option is built on this stock, the strike price X is \$22, and the time to maturity T is 1 year.

Applying two methods to get the value of this call option.

Method 1: Black-Scholes Formula

The Black-Scholes Formula is as Equation 3-10

$$c = S_0 N(d_1) - Xe^{-rT} N(d_2)$$

where

$$d_1 = \frac{\ln(S_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln(S_0 / X) + (r - \sigma^2 / 2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

and N(x) is the cumulative probability distribution function for a variable that that is normally distributed with a mean of zero and a standard deviation of 1.0.

Substitute the actual value of S_0, σ, r, X, and T into the formula, and the value of this call option is \$1.994.

Method 2: Decision Tree Analysis using Monte Carlo Simulation

The basic structure of the tree is as Figure 3-10:

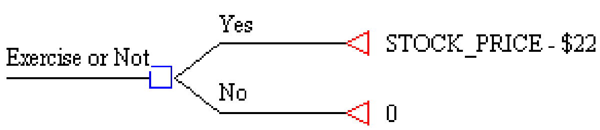


Figure 3-10 Decision Tree for Options Valuation

The rectangle is a decision point at the expiration day, at which there are two possible decisions: exercise the option, and the value of the option is the stock price then minus the strike price of $22; do not exercise the option, the value of the option is 0 in this case.

Now the key of the above decision tree analysis is the stock price. The stock price is a stochastic process. It has a specific distribution on the expiration day that can be derived from the current stock price, volatility, risk-free rate, and time to expiration. The assumptions needed for that deduction is the cornerstone for the modern finance theory, i.e. the geometric Brownian motion of the stock price and the no-arbitrage assumption. These two assumptions also lead to the Black-Scholes formula.

The two assumptions lead to that the stock price on the expiration day must follow a lognormal distribution with a expected value as Equation 3-16

$$E(S_T) = S_0 e^{rT}$$

where T is time to expiration and *r* is the risk-free rate.

Substitute the actual value of S_0, r, and T into Equation 3-16 to get the distribution of the stock price on the expiration day after a year:

$$E(S_T) = \$21.025$$

Two parameters, i.e. μ and σ, are needed to specify the lognormal distribution of the stock price on the expiration day. Please refer to Equation 3-4. In this example, σ is 0.3. μ is the expected value of the annual return expressed using continuous compounding, and

$$\mu \neq \ln[E(S)],$$

but

$$\mu = E[\ln(S / S_0)] = \ln\{E(S)] - \sigma^2 / 2 \qquad \textbf{Equation 3-17}$$

or

$$\mu = \ln(21) - (0.3)^2 / 2 = 3.001 .$$

With the value of μ and σ, the distribution of the stock price on the expiration day is specified. The last thing important is that the option is to expire a year later, but the value of the option as of today needs to be calculated. So the expected value obtained by the decision tree needs to be discounted.

Finally, Monte Carlo simulation is applied to get the value of the option c. The software used is Crystal Ball. The relative precision of the simulation of the mean is set to be 1%. It means that the software will stop simulation after the mean of the simulated results is within ±1% range of true expected mean.

The software simulates 249,500 times before it stops and reaches the relative precision of 1%. Please see the output from Crystal Ball as Table 3-1:

The result of Table 3-1 shows the true expected value or the value of the call option should be in the range \$2.00082 ± 1% x \$2.00082, or (\$1.981, \$2.021). The result from the Black-Scholes formula is \$1.994, exactly in the range. This test shows that the expected value of the tree (after discounted) is the call option value and it is the same as the result from Black-Scholes formula.

Table 3-1 Option Valuation by Decision Tree Results

Statistic	**Value**	**Precision**
Trials	249,500	
Mean	2.00082	1.00%
Median	0.00000	
Mode	0.00000	
Standard Deviation	3.87972	0.88%
Variance	15.05222	
Skewness	2.72981	
Kurtosis	12.53695	
Coeff. of Variability	1.93906	
Range Minimum	0.00000	
Range Maximum	50.71999	
Range Width	50.71999	
Mean Std. Error	0.00777	

The precision of the simulation can be set better, even though the mean of the simulated results fluctuating around the expected value. The Crystal Ball software student version used can only have two decimals to specify the distribution, which means 3.00 have to be used as the μ instead of 3.001. This error is unnecessary and can be eliminated by better programming.

This example shows an interesting result that options can be valued by decision tree analysis with simulation. In some sense, modern finance theory helps people to get the distribution of the stock price at any future day with the observable parameters of the current stock price, the risk-free rate, and the volatility of the stock price.

3.6. Real Options

"The classic way to value businesses is to compute the discounted present value of their future cash payouts. Not good enough, says Michael Mauboussin, the chief U.S. investment strategist at Credit Suisse First Boston. You should also throw in something for the company's 'real options'". [Schoenberger, 2000]

An article published on McKinsey Quarterly argued, "Real Options are especially valuable for projects that involve both a high level of uncertainty and opportunities to dispel it as new information becomes available". [Leslie and Michaels, 1997]

MIT professor Stewart Myers [1984] first coined the term of "real options":

> "Strategic planning needs finance. Present value calculations are needed as a check on strategic analysis and vice versa. However, standard discounted cash flow techniques will tend to understate the option value attached to growing profitable lines of business. Corporate finance theory requires extension to deal with real options." (pp. 136)

3.6.1. What is Real Options Method?

An opportunity is like a call option because the company has the right, not the obligation, to invest in a project. It is possible to find a call option sufficiently similar to the opportunity. The value of the option would tell us something about the value of the opportunity. Although most projects are unique and the likelihood to find a similar option on the market is low, people can reliably find a similar option by constructing one.

Before the formalization of the options theory, people intuitively know the benefit of options, such as the ancient Chinese proverbs " a cunning rabbit has three caves" and "never put all the eggs in one basket". With the development of option theory, people can now estimate the value of opportunities more precisely, which enabling them to compare the value of an option with its cost. A more sensible decision can be reached, and people shouldn't spend more for an option than it's worth.

Example 1: Petroleum chemical company

Paraphrasing an example from Amram and Kulatilaka [1999], a petroleum Chemical company might begin to invest in new capacity, but is worried about the size of the market opportunity and whether the manufacturing process could meet the government regulations regarding environment protection. Traditional Net Present Value (NPV) analysis suggested that the project should not be pursued. A real options analysis, however, valued the exit option held by the company – the option that the company could walk away if there were bad news about the market or the government regulation. Although there would be a loss of initial investment if the project were cancelled, including the abandonment option, the project value increased and the company began to construct new capacity.

Example 2: Oil exploring

Paraphrasing an example from Leslie and Michaels [1997], a North Sea oil company accumulated a portfolio of license blocks – five-years rights to explore and produce oil and gas. The development was unsuccessful and left it with unwanted blocks that were consuming cash. The company decided to sell the blocks initially. During the divestment program, it was suggested, however, instead of calculating what the block would be worth if the company started developing them immediately, the company should value its opportunity as an option to develop if, at sometime in the future, recoverable reserves could be increased through new technologies. A simple financial model was developed to show how to price the blocks at their option value over 5 years, incorporating uncertainty about the size of the reserve, the oil prices, and room for flexible response to the outcome. The managers reevaluated the company's portfolio, and instead of letting blocks go, they held on to those with high option value and to sold the rest at the revised values.

3.6.2. Comparison of Real Options Method and Traditional NPV Method

Often, although the NPV proves to be negative, the management team decides to go ahead anyway; or the NPV is positive, but intuition warns people not to proceed. It is not the intuition is wrong, but the time-honored NPV decision-making tool. As a practical matter, many managers seem to understand there is something wrong with the simple NPV rules, i.e., there is a value to waiting for more information and the this value is not reflected in the standard NPV calculation.

Traditional NPV valuation tools ignore an important value of a project - the value of flexibility. The traditional NPV method assumes, if an investment is irreversible, the investment is now-or-never, or in other words, if the company does not make the investment now, it will lose the opportunity forever. The traditional NPV method does not take into account an important reality: business decision in many industries and situations can be implemented flexibly through deferral, abandonment, expansion, or in a series of stages that in effect constitute real options.

Please see the following example based on Prof. De Neufville's class notes [2002] for MIT engineering school-wide elective, Engineering Systems Analysis for Design:

Suppose a project can be started for $100, and $1100 more will be required to complete. We must decide whether or not to continue after observing the initial result. And the commercial feasibility is decided by the initial result and the market condition then. Our final objective is to license the technology to a bidder who offers the highest price. The revenue estimate is shown in Table 3-2.

Table 3-2 Revenue Estimate for Technology Development

Revenue	**Chance**
License for \$2000	50%
License for \$100	50%

Assuming the discount rate is 10%, the question is: do we fund the project?

Table 3-3 shows traditional discounted cash flow (DCF) and net present value (NPV) valuation:

Table 3-3 NPV Valuation of Technology Development

	Year 0	**Year 1**	**Year 3**
Initial cost	*-\$100*		
Development		*-\$1100*	
License revenues			*0.5x\$2000 + 0.5x\$100*
Present Value	*-\$100*	*-\$1000*	*\$868*

The traditional NPV valuation is -\$232, so the project should be rejected.

But if we employ Real Options thinking, we understand that we have the option to develop only if \$2000 license is expected. Now the analysis is as Table 3-4:

Table 3-4 Approximate Options Valuation of Technology Development

	Year 0	**Year 1**	**Year 2**
Initial cost	*-\$100*		
Development		*0.5×\$1100*	
License revenues			*0.5×\$2000 + 0.5×\$0*
Present Value	*-\$100*	*-\$500*	*\$826*

And the new NPV is $226, so we should accept the project[1]. The thinking of option is always natural and intuitive for managers even without the formal option valuation tools. However, we were not able to valuate options strictly and rigidly before we have the option valuation models. Now, with those option valuation tools, the option thinking can be applied from the state of qualitative intuition to the state of quantitative rigidity.

In addition, there is another key difference between Real Options valuation and NPV. NPV needs an appropriate discount rate to bring the future cash flows back into present dollars, while real options models are attractive because they eliminate the need to resolve this issue. Black Scholes Formula (Equation 3-10) shows that options pricing does not require a discount rate. The question about an appropriate discount rate has a lot of debates, and there is no consensus or natural way to get an appropriate discount rate for a project. Real Options approach can circumvent the pain of discount rate choice.

3.6.3. Types of Real Options

Some options occur naturally (e.g., to defer, contract, shut down or abandon), while others may be planned and built-in with extra cost (e.g. to expand growth options, to default when investment is staged sequentially, or to switch between alternative inputs or outputs). Table 2 describes briefly the most common categories of real options.

[1] Note this $226 is not the options value. It is only an approximation of the options value because it is not a risk-neutral valuation.

Table 3-5 Types of Real Options

Category	Description	Important In
Option to defer	Management holds a lease on (or an option to buy) valuable land or resources. It can wait (x years) to see if output prices justify constructing a building or plant, or developing a field.	All natural resource extraction industries; real estate development; farming; paper products
Time to build option (staged investment)	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.	All R&D intensive industries, especially pharmaceuticals; *long-development capital-intensive projects, e.g., large-scale construction or energy-generating plants*; start-up ventures
Scaling Option (e.g., to expand; to contract; to shut down or restart)	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 halt or start up again.	Natural resource industries such as mine operations; facilities planning and construction in cyclical industries; fashion apparel; consumer goods; commercial real estate.
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.	Capital intensive industries, such as airlines and railroads; financial services; new product introductions in uncertain markets.
Option to switch (e.g., outputs or inputs)	If price 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")	Output shifts: Any good sought in small batches or subject to volatile demand, e.g., consumer electronics; toys; specialty paper; machine parts; autos; Input shifts: All feedstock-dependent facilities, e.g., oil; electric power; chemicals; crop switching; sourcing

Growth option	As early investment (e.g., R&D, lease on undeveloped land or oil reserves, strategic acquisition, information network/infrastructure) is a prerequisite or link in a chain or interrelated projects, opening up future growth opportunities (e.g., new generation product or process, oil reserves, access to new market, strengthening of core capabilities). Like interproject compound options.	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; strategic acquisitions.
Multiple interacting options	Real-life projects often involve a "collection" of various options, both upward-potential enhancing calls and downward-protection put options present in combination. Their combined option value may differ from the sum of separate option values, i.e., they interact. They may also interact with financial flexibility options.	Real-life projects in most industries discussed above.

(Source: Lenos Trigeorgis, 1993. Real Options and Interactions with Financial Flexibility. Financial Management. Autumn.)

3.6.4. Some Implications of Real Options Method

Valuation of projects incorporating flexibility

Applying real options thinking, people can actively manage risks and uncertainties, not passively perceive the value of options vaguely as before. People can systematically identify and establish options into a project, increasing the value of the project, appreciating the value of the project wholly, and taking advantage of upside risks while avoiding downside risks.

Appreciating that a project is like a financial call option can help people recognize the crucial role that uncertainty plays in the investment decisions. With a financial call option, the more volatile the price of the stock in which the option is established, the more valuable is the option and the greater incentive to keep the option open. This is true because of the asymmetry in the option - the higher the price rises, the higher the payoff is; however, if the stock price falls, one can lose only what for the price of the option.

The same goes for project investment decisions. The greater the uncertainty of a project, the greater the value of the opportunity and the greater incentive to wait and keep the opportunity alive rather that exercise it immediately. Of course, the traditional NPV method also considers the uncertainty by way of the choice of discount rate. But in the real options thinking, uncertainty is far more important and fundamental.

In addition to understanding the role of uncertainty, the real option thinking helps companies to think systematically and actively to obtain options by their technological knowledge, reputation, managerial resources, market position, and possible scale. People need to understand options and get opportunities in hand first.

With some data, real options approach can add a quantitative rigor to the valuation of the flexibility. Flexibility comes with cost. Using quantitative real options valuation, people can maximize the net value of an option, i.e., the value of an option minus cost, given a certain amount of investment budget. With binomial and simulation valuation, moreover, people can get the possibility distribution of a project's payoffs with/without options. In this way, people can have a more holistic understanding of the project than only given a single prediction of payoffs as in the traditional NPV method.

Investment with Options Thinking

In an uncertain world, strategic investment can be analyzed from a real option perspective:

Irreversible investments

Irreversible investment requires more careful analysis because, once the investment takes place, the investment cannot be recouped without a significant loss of value. With the real options analysis, it is understood that irreversible investments, for most of the cases, should be delayed until a significant amount of the uncertainty is resolved, or the investments should be broken into stages.

Flexibility investments

Flexibility investment builds options into the initial design. Flexible design allows a production line to be easily switched across products. The option to switch is part of the capital investment.

Insurance investments

Insurance investments reduce exposure to uncertainty. Investment in excess capacity ensures against if demand surges, but with a cost or “insurance premium”. Decision-makers using real options approach are able to value the flexibility and check to see whether the value exceeds the cost.

Platform investments

Platform investments create valuable follow-on contingent investment opportunities. Using Real Options approach, managers can create a portfolio of projects, maximizing the value of the portfolio, balancing the portfolio with high-risk-high-return and low-risk-low-return projects, and align the projects tightly with the corporate strategy.

Growth investments

Growth investments are made to obtain information that is otherwise unavailable. For example, oil exploration is a growth investment because it generates geological information.

Value of Real options Method in Different Situations

Real options valuation is important in situations with high uncertainty and people have many options when new information received. If the uncertainty is low and the available practical options are few, the Real Options approach will not add much insight into traditional NPV method. This is because the flexibility value is near zero. Please see Figure2:

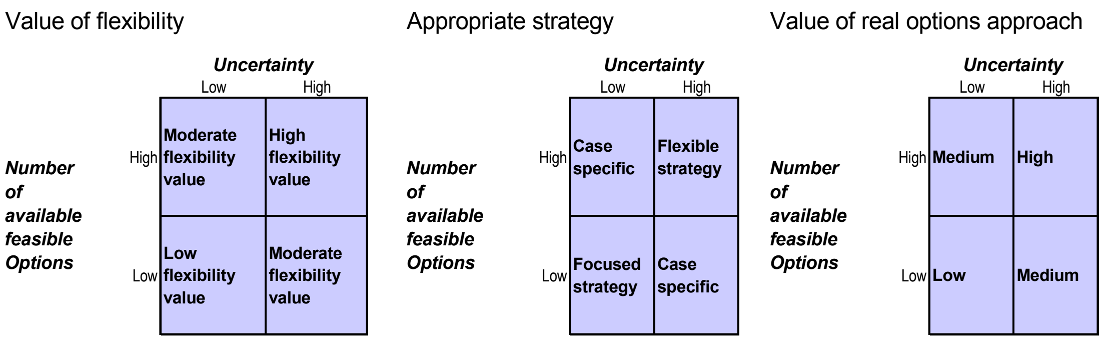


Figure 3-11: Applicability of Real Options Method

For the case of high uncertainty and a big room for options, the flexible strategy and the real options approach are most valuable. And the Real Options approach will provide a much better result than NPV method.

3.6.5. Framework of Real Options Valuation

Before using real options to evaluate a project, people first need to understand clearly what decision to be made and check if it is advantageous to use this approach over traditional NPV method. If so, the valuation can be divided into 5 steps, as shown in Figure 3-12:

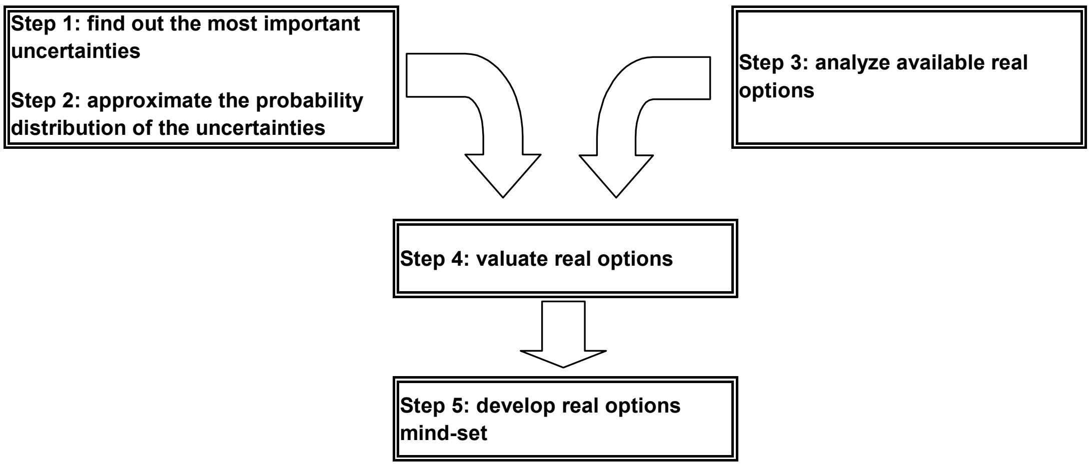


Figure 3-12 Framework of Real Options Method

The first step, most important drivers and uncertainties of the project should be found out. Usually uncertainties include market risk (such as the market demand, price of the product, economic cycle), technical risk (such as if the project can be finished on time, if the project can achieve its technical objectives).

The second step, an approximate probability distribution should be assigned to each uncertainty. In many cases, a lognormal distribution is used for a market risk. If there are other project-specific risks associated with the project, their probability distributions should be studied case by case.

The third step, the most important options should be identified. Possible options practical to the project studied can be identified with reference to Table 3-5 of the types of real options.

The fourth step, appropriate method among Black-Scholes formula, binomial model, and simulation is identified and applied to obtain the value of the options.

The fifth step, by comparing the value of the options and cost to obtain options, a set of strategies and decisions can be reached.

Meanwhile, the mind-set regarding flexibility available and different is established. Valuators need to be careful of the false precision of the value of an option, because the value is established on many approximations and assumptions. This is why a sensitivity analysis is sometimes needed. Nevertheless, the mind-set to value the flexibility is one of the major gains of this project.

3.6.6. Real Options versus Financial Options

To use the methodology originally developed for financial options, there should be an appropriate underlying. For the most talked-about stock options, the underlying is the stock price. In real options study, however, a generalized concept of underlying is needed. An underlying is the agent that determines the value of a project or an investment. An underlying can be assets, but it also can be other agents such as market size or utility price. To use Black-Scholes or binomial model, the underlying should follow the Geometric Brownian motion like stock prices.

If the underlying is not following a geometric Brownian motion, the options thinking can still be applied. The reason is that the key for options thinking has not necessarily to resemble financial options. The essence is the right not the obligation for a property or project. If appropriate distribution for the underlying can be found, people can use mathematical deduction to get the valuation (like Black-Scholes formula to get option value based on the assumption of geometric Brownian motion), or can just use Monte Carlo simulation to get the option value.

There are a number of difficulties to apply real options to the fields other than financial area where the options theory was originally developed. The key problem is that no market exists for the object studied, so the most powerful characteristics of financial options theory is partly gone. For financial options theory, the power originates from the efficient market where the stock price contains all the information. While there is no market, it is very hard to find out these information.

Often, the real options approach is hard to be applied because of no justifiable σ. One of the ways to circumvent this problem is to use hybrid real options method [Neely and de Neufville, 2001] that uses decision analysis for the part of analysis where historical data is not sufficient, e.g., the R&D stage for a new product, and real option analysis, e.g., the marketing of a new product.

Chapter 4 Yalongjiang River Basin

Chinese central government and Sichuan local government are planning a number of big projects on the Yalongjiang River in the near future, total investments near $10 billion.

4.1. Introduction of Sichuan

Yalongjiang River is located in Sichuan Province, the West of China. See Figure 4-1.

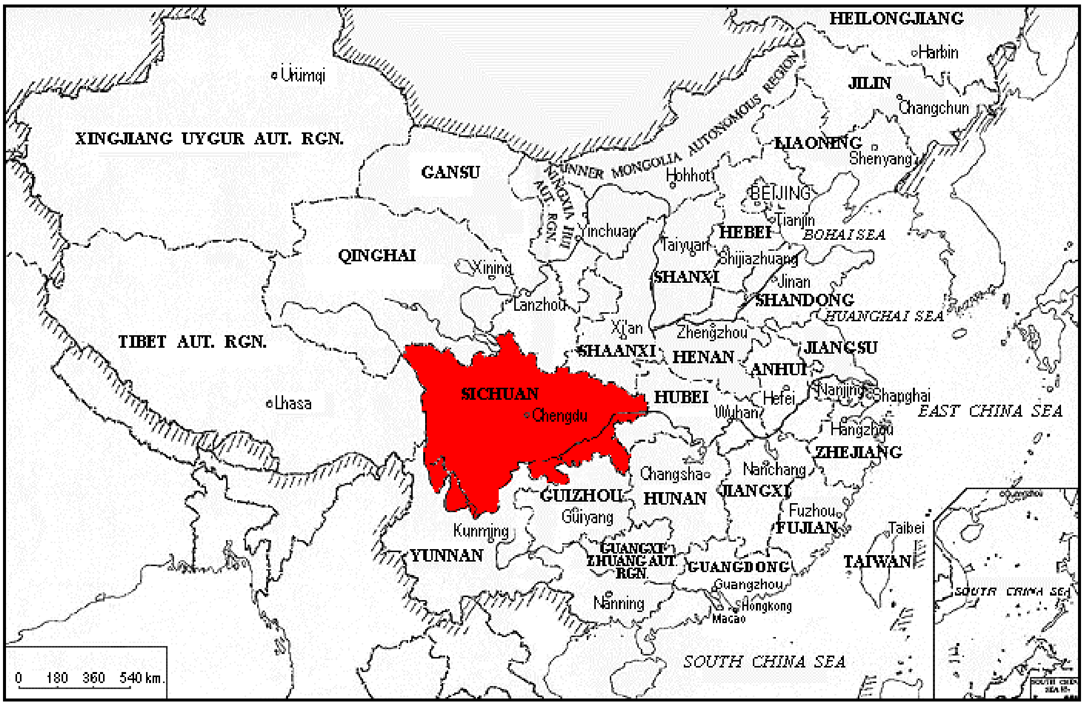


Figure 4-1: Sichuan in China

Sichuan has an area of 485,000km^2. The population is 83,000,000 (figure as of November, 2000. Source: Sichuan Provincial Statistics Bureau.). Sichuan locates in the upstream of Yangtze River. Sichuan has a rich cultivable land resource, ranking fifth among the provinces of China. However, the per capita land area is low because of the province's large population, which has been one of its major challenges. The province is rich in biological resources, with more than 10,000 kinds of utilizable plants, and ranks second in China in terms of its flora and fauna resources. Sichuan is an important forest area in China, and it has rich grassland and animal resources. Sichuan is the home of panda. One hundred and twenty-three kinds of mineral resources have been discovered. It is also rich in water transport channels, coal, natural gas, and biological forms of energy. In addition, the natural and man-made landscape in Sichuan has also contributed to the exploitation and development of the local tourism resources.

Sichuan tops China in hydropower resources. Sichuan is close to Tibet and its west part features a very high altitude that leads to tremendous hydropower resources in this province. According to the data from Sichuan Hydrology and Hydropower Institute, theoretically, total hydropower resource in Sichuan is 143,000,000kW, or 27.4% of all that of China; the technically exploitable total hydropower is 103,460,000kW, or 29.0% of all that of China. Among all technically exploitable hydropower resources in Sichuan, only 10.6% has been exploited (as of 2002). Given China's gross theoretical capability and technically exploitable capacity are ranked number one in the world (see Table 4-1: World Hydropower Capacity). The great potential of hydropower in Sichuan is obvious.

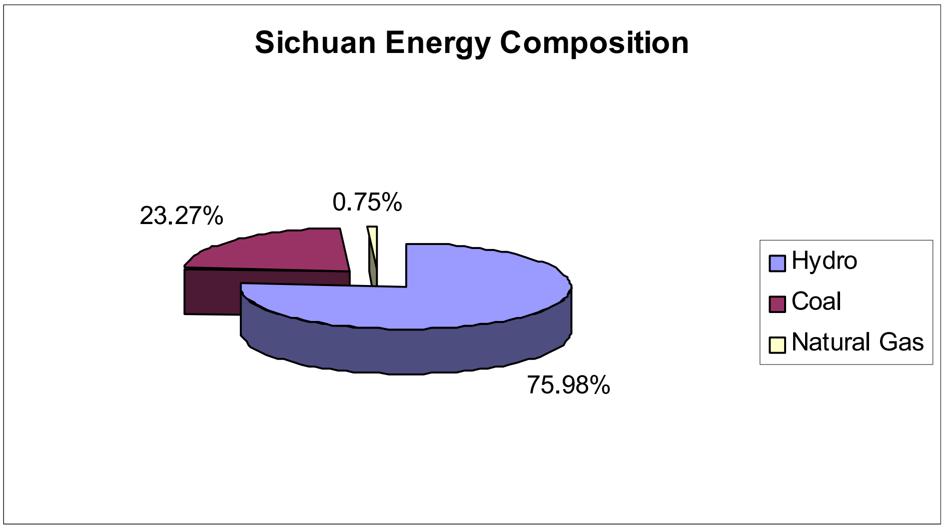
The hydropower resources in Sichuan mainly reside in Jinshajiang River, Yalongjiang River, and Daduhe River in the West. These rivers have technically feasible capacity of 82,700,000kW, or 80% of all that of Sichuan. The scale of the step hydroelectric stations on mainstream of the three rivers is mostly over 1,000,000KW. It is China's largest base of hydropower exploitation and transmission from west to east China.

Table 4-1: World Hydropower Capacity

World Hydropower Capacity (TWh/yr)		
	Gross theoretical	**Technically exploitable**
Indonesia	2 147	402
India	2 638	660
Russian Federation	2 800	1 670
Brazil	3 040	1 488
United States of America	4 485	529
China	5 920	1 920

(Source: World Energy Council, 1999)

The features of energy resources in Sichuan is few coal, no petroleum, lack of natural gas, and very abundant of hydropower. The composition of the energy resources in Sichuan is as Figure 4-2.



(Source: Sichuan Hydrology and Hydropower Institute, 2002)

Figure 4-2: Sichuan Energy Composition

4.2. Sichuan power market

By the end of 2000, the total power generating capacity in Sichuan was 17,000 mW. The amount of power generated in 2000 was 55.638Twh and grew 13.0% more than 1999. The composition of the capacity and power generated is as Table 4-2.

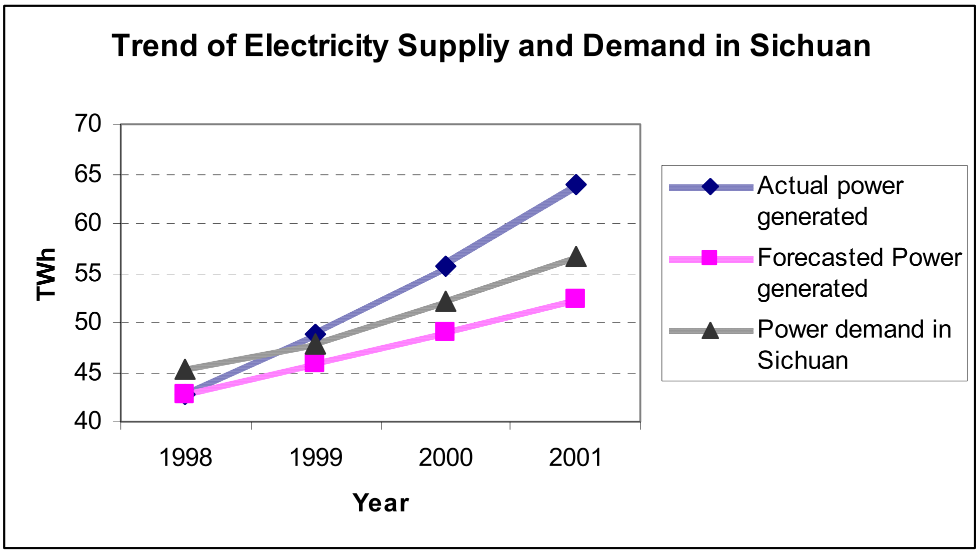
Table 4-2 Sichuan Electric Power Generation Composition

	Total	**% Hydro power**	**% Thermal power**
Capacity	17,000 mW	64.4%	35.6%
Power Generated	55.64 TWh	66.3%	33.7%

(Source: Sichuan Hydrology and Hydropower Institute, 2002)

Interestingly, in 1996, it was expected that the amount of electricity power generated would be increasing at a rate of 6 –7 % per year till 2020. However, the actual rate was almost double this figure till 2001. The total demand of the electricity power in Sichuan was 52.123 TWh, grew 11.37% more than 1999 (Source: Sichuan Hydrology and Hydropower Institute). The GDP growth rate of Sichuan was 5.6% in 1999, 9.1% in 2000, and 8.9% in 2001, it is expected to grow at a rate of 8% in 2002 (Source: Sichuan Bureau of Statistics). So the growth of power generating capacity is faster than the growth of the demand. (Source: Sichuan Hydrology and Hydropower Institute, 2002)

Figure 4-3 illustrates the trend of electricity power supply and demand in Sichuan.



(Source: Sichuan Hydrology and Hydropower Institute, 2002)

Figure 4-3 Trend of Electricity Power Supply and Demand

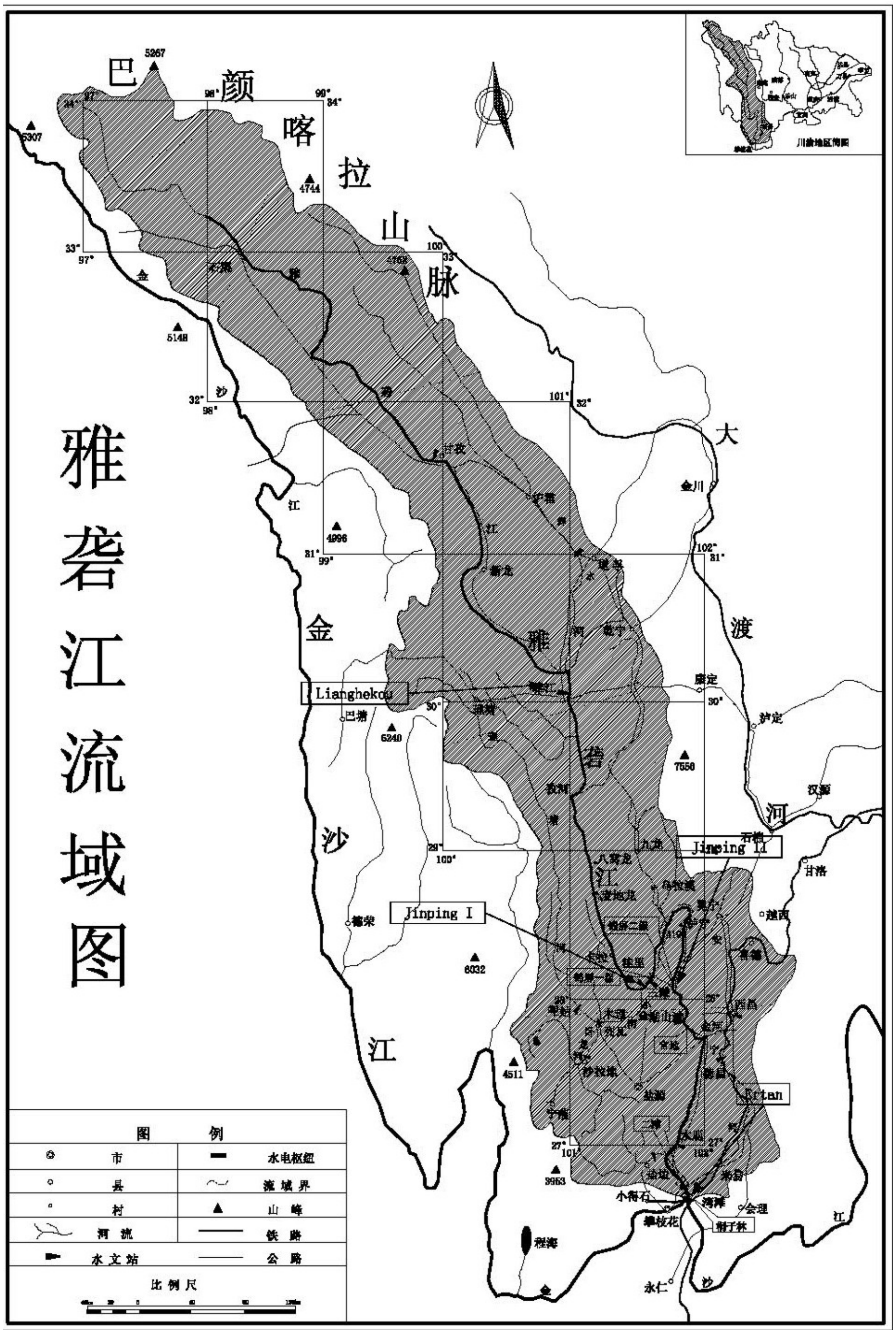
It has already been over-supply of electricity in the region, as the World Bank financed Ertan Hydropower plant is losing money because they cannot sell all the power that can be generated. Though the demand of electricity is growing faster than expected, too much new power generation capacity is built, especially many small thermal power plants built by local governments. Since the growth of electricity power generating capability is faster than the local economic growth, the oversupply is expected to continue. So the current stress of the strategy of energy development in Sichuan is to send power out of the province to the economically more developed east part of China, or so-called “West-to-east power transfer”. However, this project involves huge amount of investment to establish the grid.

Though, from a holistic view of China energy development, the hydropower resources in Sichuan are more environmentally friendly and cheaper than thermal power burning coal in the eastern economically more developed part. Although the hydro resources in Sichuan are likely to be developed one day, the key question is how long this will happen according to many factors, such as the grid build-up, the conflicts of interests of different regions, and other political and economical problems. Especially China's economy is under transformation to market economy, in other words, not a established market economy now. So even if the region develop low cost and high quality electricity, it does not necessarily mean that the region is able to sell it and pay back the loans, as it is happening to the first Dam on Yalongjiang River, the Ertan Hydropower plant.

4.3. Introduction to Yalongjiang River

Yalongjiang River is the biggest tributary of the Jinshajiang River, which is a section of the upstream of Yangtze River. It originates from Yushu County in Qinhai Province, enters Sichuan near Kayishi. It turns 180 degrees around Mount Jinping, forming the famous 150 km "great bend-over". It enters Jinshajiang River near Panzhihua. The total length of the river is 1570 km, watershed area 128,400 km^2. The Yalongjiang River Basin is located between 26º32' ~ 34º20'N and 96º52' ~ 102º48'. The average length of the river basin is 950 km, and its average width is 137 km. The river drops quickly, from the origin at an elevation of 5400m to the mouth at an elevation of 980m, total drop is 4420m. Figure 4-4 provides a map of Yalongjiang River Basin.

The mainstream from Project C to the river mouth has a theoretical gross capacity of 18,140,000 kW, equals to 82.4% of the total of Yalongjiang River. To date, the only hydropower plant has been built is Ertan. There are a lot more to do on the further development on this section of the Yalongjiang River.



(Source: Sichuan Hydrology and Hydropower Institute, 2002)

Figure 4-4: Map of the Yalongjiang River Basin

4.4. Dams built and proposed

There are 4 major projects built or under serious scrutiny for further development. The four projects are Ertan (built), Project A, Project B, and Project C as described below. These hydro projects are mainly for energy production, with a secondary purpose of flood control for Yangtze River. Because Yalongjiang River is located in a remote area with few human activities where the economy is primitive and natural conditions are not suitable for agriculture, the projects have virtually taken no consideration of the irrigation, drinking, and recreational purposes.

4.4.1. Ertan

Ertan comprises a 240m concrete arch dam and Asia's largest underground powerhouse, which is 280m long by 25.5m wide and 65m high. The construction began on 1991. Loans for the project came from World Bank and China Development Bank. The project was completed in 2000. It added a capacity of 3,300MW with annual energy output of 17 TkWh to the Sichuan and Chongqing grids. It eliminated power shortages in Sichuan for the first time in 27 years, and also enhanced service quality and reliability. See Figure 4-5 for some pictures of the Ertan Dam.

(Source: http://www.power-technology.com/projects/ertan/)

Figure 4-5: Picture of Ertan Dam

Ertan hydroelectric power station is the biggest power station China built in the 20th century. It is an "engineering" success. However, it failed to pay back World Bank loans for 2 years after it was put into use. When people designed the dam, few had expected the current energy market in Sichuan and thought about taking any " insurance" measure.

4.4.2. Project A

Project A has already passed the feasibility study period, and people are doing final design on the project. The hydropower station is to be located between Santan and Shoupagou, around the beginning part the huge bend-over of the river around Mount Jinping. The considered design options are described in Table 4-3:

Table 4-3: Project A Design Alternatives

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Normal Water Storage Level	m	1870	1880	1890	1900
Dead Water Level	m	1790	1800	1810	1820
Reservoir Capacity	billion m^3	6.97	7.76	8.62	9.64
Adjustable Capacity	billion m^3	4.52	4.91	5.32	5.75
Installed Capacity	mW	3060	3240	3420	3600

(Source: Sichuan Hydrology and Hydropower Institute)

All the alternatives will add power-generating capacity of the Ertan Hydroelectric Plant as Table 4-4.

Table 4-4: Project A Adding Capacity to Ertan

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Increased Ertan Dry Season Power Generating Capacity	mW	381	415	447	477
Increased Ertan Yearly Power Generation	TkWh	0.94	1.05	1.13	1.22

(Source: Sichuan Hydrology and Hydropower Institute)

The streamflow data for Project A is provided in Table 4-5.

Table 4-5: Streamflow for Project A

Unit: m^3/s	**Average**	**Qp**		
		p = 10%	p = 50%	p = 90%
Yearly	1200	1510	1180	904
Dry season (Dec - May)	437	505	435	371

(Source: Sichuan Hydrology and Hydropower Institute)

4.4.3. Project B

As the map of Yalongjiang River Basin as Figure 4-4, Yalongjiang River has a very big turn-around at the Mount Jinping area. Project A is built at the beginning of the turn-around. The Project B project will dig an 18 km long tunnel that bypasses 123 km of the river. Shallow gradient river sections are bypassed and approximately 300m head can be captured.

The choices for the installed capacity are 1,500 MW, 1,600 MW, and 1,700 MW. The choices for tunnel water speed are 4.0m/s, 4.5m/s, and 5.0m/s. The tunnel diameter can be calculated from the tunnel water speed. The choices for tunnel/turbine combination are 3 tunnels 3 turbines, 2 tunnels 4 turbines, and 2 tunnels 6 turbines. The important engineering parameter choices can be shown in Figure 4-6:

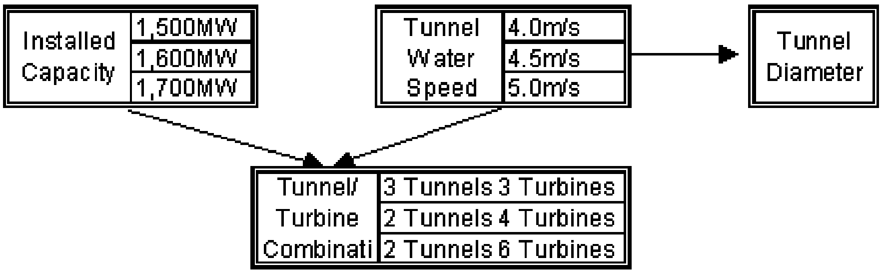


Figure 4-6: Project B Tunnel Parameters

Project B would have 2 stages, each stage has an investment of 3.691 Billion RMB, has an average power generating capacity of 11.578 TWh/yr, 2 tunnels and 4 turbines, each turbine has an installed capacity of 400MW

4.4.4. Project C

Project C hydropower station would be located 2 km downstream to the connection of Yalongjiang River mainstream and its tributary Xianshuihe River. Because Project C is in a remote area, so the cost of flooding of the reservoir is virtually negligible.

The considered design options see Table 4-6.

Project C hydropower station has adjustable capability over year. The establishment of Project C will add considerable power generating capacity to downstream stations. See Table 4-7: Project C Adding Capacity to Downstream Stations.

The streamflow data for Project C is provided in Table 4-8.

Table 4-6: Project C Design Alternatives

		Alternative 1	**Alternative 2**
Normal Water Storage Level	m	2840	2880
Dead Water Level	m	2760	2800
Reservoir Capacity	billion m^3	7.68	12.03
Adjustable Capacity	billion m^3	5.28	7.49
Installed Capacity	mW	2500	3000

(Source: Sichuan Hydrology and Hydropower Institute)

Table 4-7: Project C Adding Capacity to Downstream Stations

		Alternative 1	**Alternative 2**
Increased Dry Season Power Generating Capacity	mW	3109	2841
Increased Yearly Power Generation	TkWh	8.906	10.642

(Source: Sichuan Hydrology and Hydropower Institute)

Table 4-8: Streamflow for Project C

Unit: m^3/s	**Average**	**Qp**		
		p = 10%	p = 50%	p = 90%
Yearly	657	829	649	495
Dry season (Dec - May)	283	342	281	227

(Source: Sichuan Hydrology and Hydropower Institute)

The study on the Yalongjiang River Basin will be divided into 2 steps: the first step is to value Project A using real options method with consideration of the market uncertainties; the second step is to study the River Basin as a whole using real options method with consideration of both market and technical uncertainties.

Chapter 5 Valuing Project A

The key part of this chapter applies binomial options pricing model to study a case on Yalongjiang River basin development, more specifically, a deferral option of Project A. To study the proc/cons and applicability of real options method in the valuation for Project A, the NPV, IRR, NPV with simulation, IRR with simulation, and decision tree options valuation are compared with the real options method.

5.1. Traditional NPV

Project A is scheduled to start generating power in the mid of the 11th year, and to produce at full capacity in the 13th year. It is projected that the installed capacity will be 1,258 MW in the 11th year, 2516 MW in the 12th, and 3564 MW in the 13th. According to the historical data, an average waterflow per year can be derived. The production is to be 5.94 TWh in the 11th year, 11.88 TWh in the 12th, and 16.83 TWh a year thereafter. Based on the guidelines China is now using to calculate energy price, the price for the electricity is 0.25 RMB/KWh. The revenue is the annual production times the price, and the time frame used is 60 years with no residual value. 60 years is the expected life of the project, and any variation of the life to 70 years or 50 years will not affect the result a lot. It is not a big effort to study a time frame as long as 60 years with an Excel spreadsheet. The investment is taken to be 14.6 Billion RMB as in year 0. The actual investment happens each year during the construction. Discounting the investment each year back to year 0 using the interest rate of 5.72% and adding all of them up, we get the equivalence of total investment as of 14.6 Billion RMB in year 0.

The NPV analysis is as Table 5-1:

Table 5-1 Project A NPV Analysis

Year	0	1	…	10	11	12	13	…	60
Quantity (in TWh)		0	0	0	5.94	11.88	16.83	16.83	16.83
Price (in RMB/KWh)		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Revenue (in B RMB)		0	0	0	1.485	2.97	4.2075	4.2075	4.2075
Investment (in B RMB)	14.6								
Cash Flow	-14.6	0	0	0	1.485	2.97	4.2075	4.2075	4.2075

The NPV is 7.02 Billion RMB using a discount rate of 8%. With such an analysis, because the NPV is greater than 0, Project A should be carried out immediately. All the analysis is a point estimate of value and the corresponding strategy is a go or no-go decision without a third choice, such as “wait and see”.

Note in the above net present value analysis, there are three very important assumptions:

> 1, the power plant will produce to full capacity, and all the electricity produced can be sold.
> 2, the price is fixed and will not change in 60 years.
> 3, here an 8% discount rate is used, the same as the normal discount rate used in the China Development Bank.

These three assumptions are hard to defend:

> 1. How can a plant always produce at full capacity and sell all the electricity produced for a period of 60 years? It is not only a simplified case, but also the most optimistic case and apparently not realistic. For example, Ertan only produced at half of its capacity for its first two years. Also, all the quantity of electricity produced is based on the average annual waterflow; the actual waterflow fluctuates every year.
> 2, it seems unreasonable to assume that the price for electricity does not change over 60 years. Even in the case the power supply is allocated by government, the

price is decided by some government plans, it is still unimaginable that the price would not change.

3, the choice of discount rate is always a problem when evaluating public projects, there is no concrete logic or proof for a specific discount rate chosen, and leaves this topic to a game of politics. Here the discount rate applied is 8%, but the evidence why it should be 8% was not and cannot be provided.

Although there are apparently unrealistic assumptions behind the NPV method, the method is still ubiquitous. The reason is the computation difficulty of more refined models, and the NPV is much better than nothing. However, with the development of computer technology, more refined models can be easily set up and calculated.

5.2. Traditional Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) for Project A can also be calculated. It is 10.05%. IRR provides a better measure than NPV because it avoids the problem of choice of discount rate, and makes it possible to compare the project with the expected return or capital cost to decide what to do. Applying the traditional IRR valuation, the conclusion is that as long as the capital cost is less than 10.05%, the best strategy is to build the dam immediately. Like the traditional NPV method, there are only go or no-go decisions, no third choice.

5.3. NPV with Simulation

In the Project A cash flow simulation model, the key uncertainties affecting quantity and price are decomposed and analyzed, thereby establishing the function between the cash flow and the uncertainties. Then the uncertain factors are simulated to get thousands of realizations of the cash flows over 60 years. For each realization over the 60 years, a NPV or IRR is calculated. With the samples of thousands of NPV, the expected NPV can be calculated.

A generalized framework of engineering systems analysis with focus on uncertainty can be seen as Figure 5-1:

Engineering design needs to take into account both the technical uncertainty and the market uncertainty. People often design engineering systems assuming the technical parameters are deterministic, which is often not the case. For example, if a reservoir and hydropower plant design is based on the waterflow data of a typical year, the design would miss an important element, i.e. the uncertainty of waterflow and thus the uncertain amount of electricity generated. Though market uncertainty is more recognized, ironically, the market analysis is still dominated by deterministic NPV projections.

Another tendency is that, for a big engineering system, engineering features are taken care of by engineers, and marketing side is taken care of by marketing people. Although a great lot of literature emphasizes the importance of integrating engineering and marketing, the technical and marketing sides of an engineering system are taken care of by two functions with totally different kind of people and thinking. Consequently, the engineering systems are analyzed separately. Engineering people optimize the system given technical constraints, while marketing people optimize sales given market conditions. The result is that the two parts are near optimization given constraints for the specific part respectively, but the whole system is suboptimal. So it is important to take the engineering system optimization into more holistic settings, considering technical and marketing in an integrated model.

In Figure 5-1, the engineering systems model with uncertainties can be divided into two sub-models: the first one is a technical sub-model, which analyzes the technical constraints; the second one is a market sub-model, which analyzes the market uncertainties. The key difference of this model compared to many previous models is that it explicitly integrates the technical and market sub-models.

Applying the above framework specifically to the problem of the Yalongjiang River basin development, the model in Figure 5-1 can be redrawn as Figure 5-2:

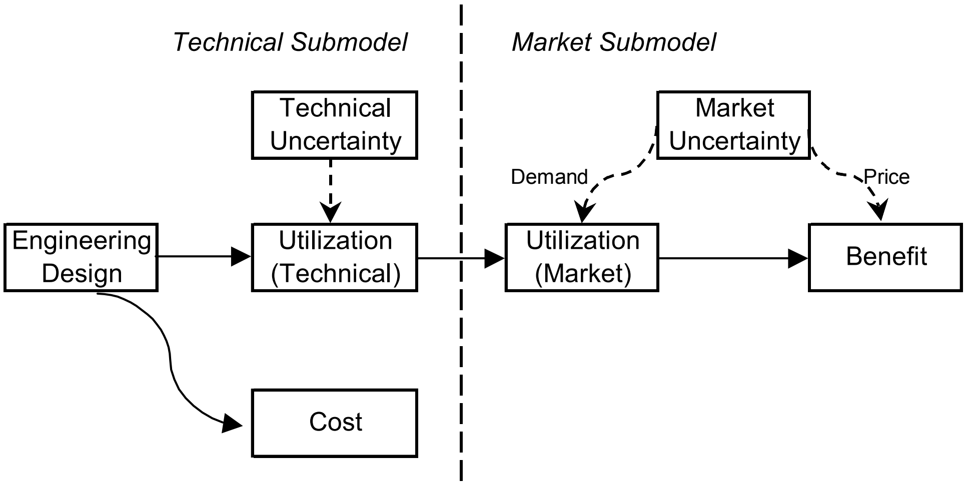


Figure 5-1 Engineering Systems Model with Uncertainties

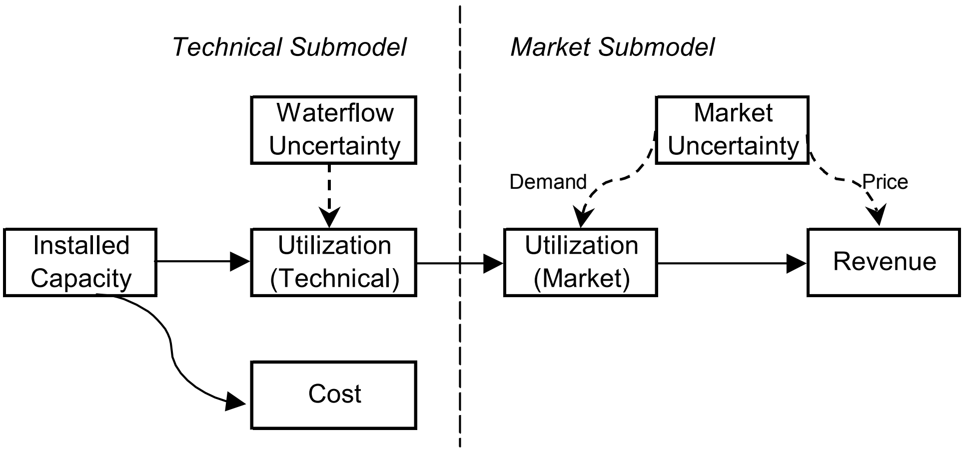


Figure 5-2 Yalongjiang River Basin Model with Uncertainties

5.3.1. Technical Sub-Model

The main purpose of the Yalongjiang River basin development is power generation, so installed capacity is one of the most important engineering parameters. The uncertain waterflow each year makes the average utilization of the capacity less than 100%. In the years with a lot of water, water has to be wasted; while in dry years, the capacity cannot be fully realized.

To some extent, this situation is like holding a stock and being short a call option on that stock. If at the expiration day, the stock price is greater the exercise price, then the option will be exercised, and the payoff is the exercise price; if at the expiration day, the stock price is less than the exercise price, the option will not be exercised, the payoff is the price of the stock then. The payoff chart is as Figure 5-3.

The relationship of power generated and waterflow is similar, as in Figure 5-4.

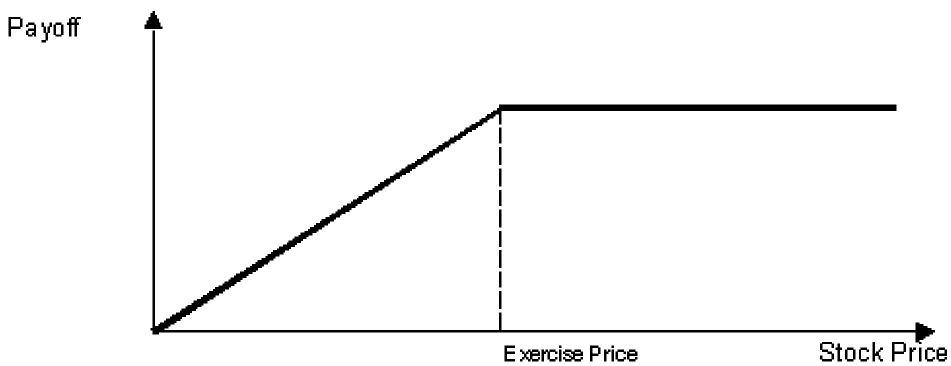


Figure 5-3 Payoff Diagram of Longing a Stock and Shorting a call

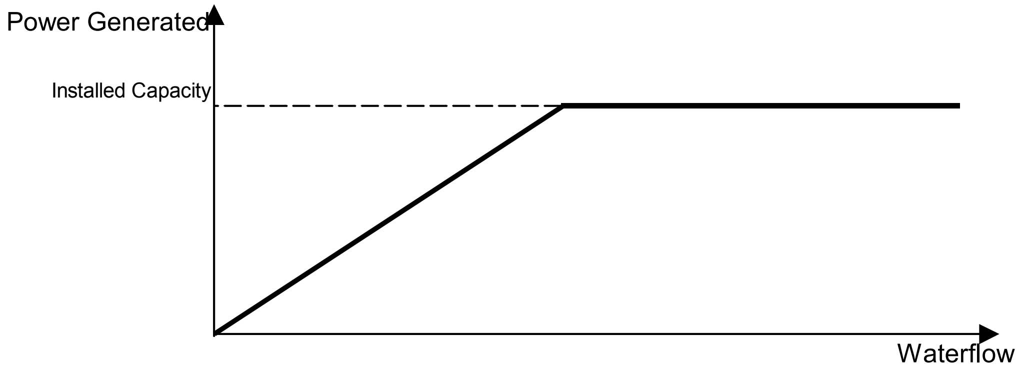


Figure 5-4 Power Generation and Waterflow

Given the waterflow distribution, the distribution of the utilization of a specific installed capacity can be obtained. The maximum utilization is 100%, which means the maximum amount of electricity produced is the installed capacity, additional water has to be wasted; the utilization can be less than 100%, when it is dry season or dry year, there is not enough water for the hydropower plant to run whole capacity. With the distribution of the utilization, the actual power generating capacity can be simulated. As a first approximation in this thesis, the technical utilization is taken to be full, or 100%.

5.3.2. Market Sub-Model

The revenue from selling electricity is determined by the amount sold and its price. The amount sold is determined by the demand and supply of the market. The demand of electricity is highly correlated with the GDP growth, and is taken in this thesis to grow at the same speed as GDP. The supply of electricity can be divided into thermal, hydro, and nuclear power. A key assumption in the first simple model is that the market for energy is complete, which means that the market always first buys the cheapest power, if the cheapest power is used up, then it turns to the next cheapest power, and so on. Because there is no nuclear power in Sichuan, the types of power we are considering are hydro and thermal. The marginal cost of producing hydropower is cheaper than that of thermal, so the market uses hydropower first. After no more hydro capacity available, the market turns to the thermal power, as in Figure 5-5:

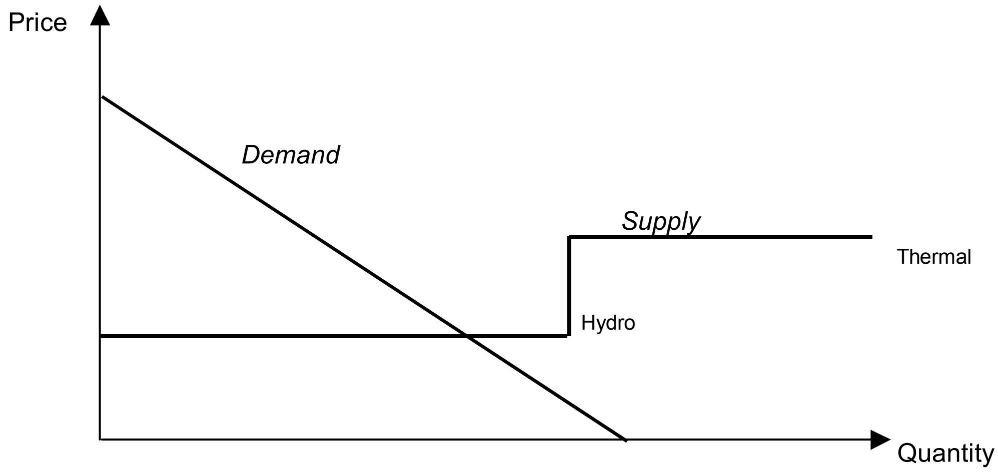


Figure 5-5 Assumed Power Supply and Demand Curve in Sichuan

Uncertainties

Demand

It is assumed that the demand of electricity is highly correlated with the local GDP growth. In the model, the demand is growing at the GDP growth rate beginning from the demand for 2000, i.e., 52.123 TkWh. In order to model the GDP growth stochastically, a simple mean reverting model is used. Its mathematical expression is as Equation 5-1:

$$dr = \eta(\bar{r} - r)dt + \sigma dz \qquad \textbf{\textit{Equation 5-1}}$$

where r is the GDP growth rate, η is the reversion parameter signifying the strength of the reverting process, $\bar{r}$ is the long-run mean of GDP growth rate, σ is the volatility, and dz is a basic Wiener process with a drift rate of zero and a variance of 1.0.

This mean reverting model points out the trend that when a country is developing at a high speed, the probability that it grows even faster is smaller than the chance that the growth rate decreases; when a country's economy is stagnating and slower than the long-run mean, the chance of regaining growth is bigger than growing even slower. For the long run, the growth of an economy tends to converge to an average, while the n+1 year's growth rate is related to the growth rate for year n. This is a simple yet acceptable model for the first model for the Yalongjiang river basin development.

This thesis uses some plausible numbers for the parameters for a first try. As a next step, the history of economy growth of Japan, Korea, or other countries may be studied to help getting such parameters, based on the assumption that the current China economy will be similar to some other countries when their economies took off.

Supply

This thesis assumes the power plants compete in a complete market. Because hydropower is cheaper than thermal, so the market will first use hydropower, and then use thermal for the amount of power needed more than that can be supplied by hydro. If the hydropower supply is greater than the total market demands, each hydropower company is producing

its hydro capacity X (total demand / total hydro capacity)

Total exploitable hydropower resources in Sichuan are 290 TkWh, assuming all exploitable resources will be developed in 30 years. The growth of hydropower supply is staged. Each time a planned new hydropower station is put into use, the total supply is increased. The growth begins on the basis of the power production in 2000 of 39.61 TkWh.

Price

The price of electricity is a highly uncertain in China right now. This is because China is going to reform its energy market to allow free competition. Currently, the energy in China is still mainly under the old planned system, and exhibits a lot of inefficiency. For example, the Ertan Hydro Power failed to sell even half of its capacity for the first year after it was put in use. This put Ertan in a very awkward position. Because of their huge loans for building the project, one year's additional interest of the principal when they just begin to operate seems too big a burden for them to recove. The World Bank ranked the project unsatisfactory because their financial difficulties, though all the other aspects of the project are very good, from engineering to environmental to reallocation of residents. The key reason of this impasse is because local electricity authorities refused to use the hydropower from Ertan though it is much cheaper. They used electricity generated by many small thermal power plants whose price is much higher. The thermal plants also cause serious environmental problems because they burn coal. The reason is simply because the local electrical power authorities have direct or indirect investments in those newly built thermal power plants. They also have to repay loans.

Given the highly complex economical, social and political surroundings in China, it is hard to predict the price of power after the energy market reforms. Current price data are all but unusable because they are highly distorted, and there will be a system discontinuity after the reforms that make everything different. The fact that the marginal cost of hydropower is low makes the price of the electricity even harder to predict.

The parameters for analysis are based on expert estimates. I talked with two Chinese experts on China energy market in the China Development Bank to get their low, most likely, and high estimate of the electricity price for 3 years later[1]. The experts reached the high price estimate of 0.315RMB/kWh and low 0.18RMB/kWh both with 95% confidence. The experts estimate the electricity price will drop 0.33% per year.

The two experts in the China Development Bank believe that the major energy market reforms are done by 2007. Please refer to a report on China energy market on the China official media, *People's Daily*, as Appendix II. It is assumed that the energy price will then be mostly subject to the inflation factor and more predictable. In the model established, all terms are in real money, and inflation does not need to be considered explicitly.

5.3.3. Simulation

Having established the model, it is possible to simulate the NPV using a software package called Crystal Ball. The procedure is to:

- identify the basic factors that influencing a specific outcome,
- determine their distributions,
- draw a set of samples for each of the factors according to its distribution,
- get the value of the outcome that we are interested in with each set of samples,
- repeat this a great number of times to get correspondingly number of samples for the outcome of interest (in this case, the NPV). The distribution of the samples converges to the actual distribution with probability one.

The process is called Monte-Carlo simulation.

[1] The purpose of this thesis is to study the methodology of real options, not to offer real decision support. So the accuracy of the parameters is not explored further. However, for particular applications, several ways to estimate the parameters need to be used concurrently to crosscheck the validity of the estimates.

For example, if O is a function of random variables X_1 and X_2, or

$$O = f(X_1, X_2)$$ **Equation 5-2**

If X_1 follows a normal distribution and X_2 follows a triangular distribution, a set of samples for X_1 and X_2, say X_{11} and X_{21}, is randomly drawn according to the distribution of the two random variables, i.e., normal and triangle distribution. Then X_{11} and X_{21} are put into the function to get

$$O_1 = f(X_{11}, X_{21})$$

Repeat this process to draw another set of samples for X_1 and X_2 to calculate O_2. Repeat it a large number, say 10,000, times. Then the distribution of O_1, O_2, …, O_{10000} is obtained. Mathematically, it converges to the true distribution of O with probability one, and different statistics on these 10000 values can be obtained to see how close it is to the true distribution.

In this hydropower case, a model is established to describe the uncertainties (with certain distributions) and the function between the uncertain variables and the subject of interest (NPV in this case). Then the model is simulated for a great number of times, say 2000. It is like that the project is implemented for 2000 times, 2000 NPVs corresponding to the 2000 times are obtained, and thus the distribution of the NPV is obtained. Now the expected value of the NPV is easy to calculate. For Project A, Monte-Carlo simulation is applied to the spreadsheet with the tool of Crystal Ball. The distribution is as Figure 5-6.

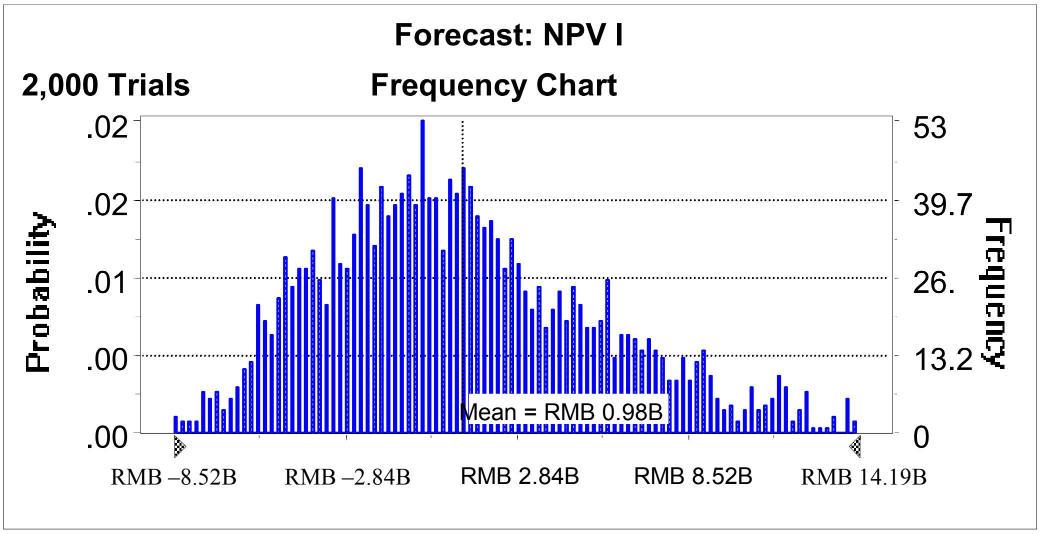


Figure 5-6 Distribution of NPV for Project A

The expected value of the NPV is 0.98 Billion RMB. It is distinct from the traditional NPV result of 7.02 B RMB. This is a notable result, and signifying some important limitation of the traditional NPV method:

1. The logic of traditional NPV method obtains the expected values of the important factors and plugs them into Equation 5-2 to get

$$O = f(E(X_1), E(X_2)).$$

Specifically, in the NPV calculation above, X_1 is the quantity of electricity sold, and X_2 is the price with which the electricity to be sold, and O is the NPV. $E(X_1)$ is taken to be the capacity of the hydropower plant, or 16.83 TWh/year[1], and $E[X_2]$ is the expected price for which the electricity is sold, taken to be 0.25 RMB in the calculation for traditional NPV. With $E(X_1)$ and $E[X_2]$, the value of traditional NPV is calculated to be 7.02 B RMB.

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[1] During the first two years when the plant just put into use, the capacity is assumed to be 1/3 of the total capacity for the first year, and 2/3 of the total capacity for the second year.

In most cases, however,

$$E[f(X)] \neq f[E(X)]\,.$$

The only case that the equality is guaranteed is when the *f(X)* is a linear function of all uncertainties. Savage [2000] had a discussion on this issue what he called "flaw of averages", which states "plans based on the assumption that average conditions will occur are usually wrong".

2. What makes things even worse is that it is usually hard to identify the expected value of uncertainties. People tend to take values that are easy to get as the expected values, partly because the expected values are hard to find out. For example, in the traditional NPV calculation above, the value plugged in to calculate the NPV is not even the expected quantity of electricity produced, but the maximum of quantity can be sold (the capacity of the power plant, which is an upper limit of the quantity that the amount of electricity can be produced, and any real produciton of electricity can only be less or equal than this amount). It is the most convenient value to get, but it is not the right value. Though the price of the electricity is actually the expected value, the above calculation for traditional NPV sues the formula:

$$O = f(Max(X_1), E(X_2))$$

So the value is seriously distorted, and too much optimistic. As found using the simulation technology, the expected NPV for project A is only 0.98 B RMA, while the traditional NPV calculation renders a value as high as 7.02 B RMB. This is not an uncommon practice in the application of NPV methodology.

5.4. IRR with simulation

The distribution of the IRR can also be obtained using the Project A cash flow simulation model. Because IRR is better than NPV in the sense that it avoids the tough problem of choice of discount rate, the distribution of the IRR can also deliver a lot of information useful for decision-making. See the result of the IRR simulation as Figure 5-7:

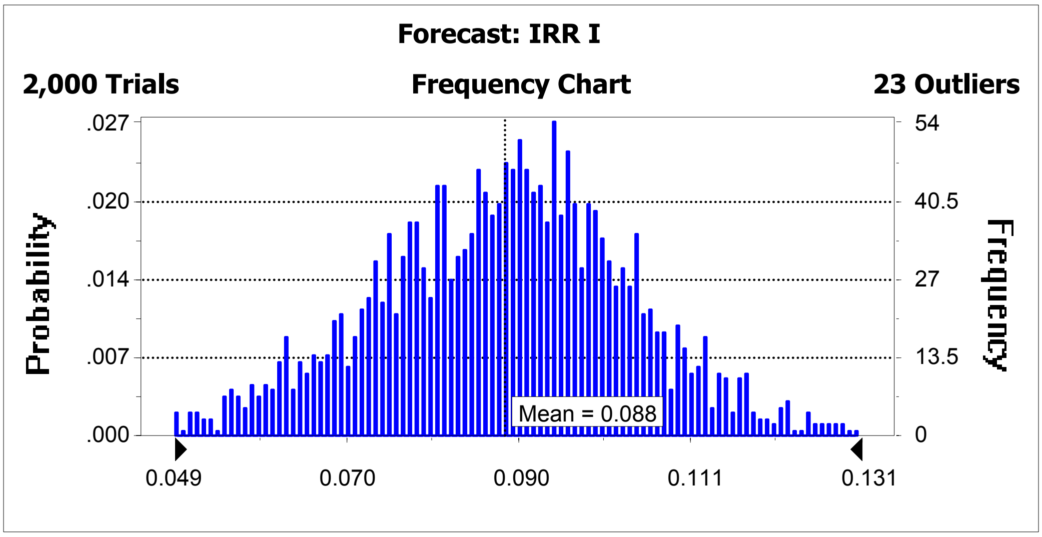


Figure 5-7 Distribution of IRR for Project A

Notice that the average IRR presented in Figure 5-7 as 8.8%. When it is interpreted as the expected IRR, there is complexity underneath this issue because of the nonlinearity of IRR. The interpretation of the IRR simulation result should be based on the figure as a whole, such as the range of the IRR, and average, and both tails.

This figure will render much more information than traditional IRR. And the same principle of “flaw of averages” as NPV applies to IRR calculation. In general:

$$IRR(E[X_1], E[X_2]) \neq E[IRR(X_1, X_2)]$$

Where X_1 and X_2 are random variables.

The traditional IRR is 10.05%, while the average of simulated IRR is 8.8%. One of the reasons for this is that the quantity of electricity sold used for the calculation of traditional IRR is the maximum value, not the expected value as identified in section 5.2. .

5.5. Real Options Analysis

This section compares two possible variants of real options analysis (ROA). The first uses the electricity price as underlying and the second uses the NPV of the project as the underlying.

5.5.1. A General Binomial Tree Framework for ROA

The general framework is the same for ROA with NPV or electricity price as underlying. This section introduces the general binomial tree framework for ROA, and the following sections will study the real options value with either underlying.

Event tree

Firstly, a binomial tree needs to be built based on some underlying describing the market uncertainty. After building the binomial tree, a series of scenarios are developed with probabilities, and what happens in each scenario can be analyzed. So a binomial tree can be thought as an event tree in essence. To get such an event tree describing the market uncertainty, one way is to lay out the scenarios of different NPVs, another way is to present the evolution of the electricity price.

Analysis of each scenario

Given the scenarios of underlying evolution, the expected payoff of each option can be established. As Figure 5-8, a project with option 1, option 2 … option n[1] is valued. Given the underlying value M, payoffs for each of those options can be calculated. The hold value is calculated by discounted the expected value of next phase of the binomial tree.

M

Payoff for option 1

Payoff for option 2

Payoff for option 3

…

Hold value

Figure 5-8 Analysis of a scenario on the event tree

In the case of analyzing the deferral option for Project A, there is only one option. Only the exercise value and hold value are entered into Figure 5-8.

Roll back

After establishing the options values for each scenario, the tree can be rolled back to get the value of the option. The value for each scenario is

Max (payoff for option 1, payoff for option 2, …, payoff for option n, the hold value)

[1] If n > 1, it is a compound option.

Beginning from rightmost scenarios, the up probability p_u and down probability p_d are applied to roll back to get the hold value for any scenario. Note the discount rate used must be risk adjusted. The way to risk adjust the discount rate is to simulate the IRR and get the standard deviation of the IRR. Note that different discount rates need to be applied to different cash flows with distinct risk properties.

After rolling back the leftmost scenario, not only the value of options but also a contingency strategy can be developed.

5.5.2. ROA with electricity price as underlying

The first step for a ROA with electricity price as underlying for Project A was to estimate the drift rate *r* and the volatility σ. For the options on stocks, the drift rate *r* is the risk-free interest rate as shown in Section 3.4. Risk-neutral Valuation. If the underlying is electricity price, however, the drift rate cannot use the risk free rate, it should be the expected change of electricity price per period of time.

Estimation of drift rate r and volatility σ for electricity price

The key uncertainties under the valuation of the Project A are the market features of demand and price. Assuming that the market is complete, people will first use all the hydro capacity and then turn to thermal. Given that in Sichuan, total power consumption was 55.638TWh in 2000. Among the total consumption, 66.3% is hydropower, so a first simple assumption is that, in the future, the total hydropower supply will always less than or equal to the total electricity demand of Sichuan given the growth scheme of supply of hydropower described in section 5.3.2. Therefore, all the power produced by a hydro plant will be able to find a buyer.

Then price becomes the only market uncertainty in this analysis. Because China is undergoing aggressive energy market reform, the price of electricity in the future is highly uncertain. Projecting what happens in 3 years, the experts [China Development Bank, 2002] give the optimistic price estimate of 0.315 RMB/kWh and pessimistic 0.18RMB/kWh, both with 95% confidence. And the experts estimate the electricity price drops 1%. Therefore, the drift rate *r* of electricity price is –0.33% per year.

Defining the volatility of electricity price σ_e can be defined as the standard deviation of $\ln({}^{P_1}\!/\!_{P_0})$ in one year, where P_1 is the electricity at year 1 and P_0 is the electricity price at year 0. The standard deviation for 3 years is $\sqrt{3}\sigma_e$. And the 95%confidence means 2 σ_e range. So

$$\sqrt{3}\sigma_e = \frac{\ln(\frac{0.315}{0.25\times(1-1\%)})}{2}$$

or

$$\sigma_e = 6.96\%$$

Risk-adjusted discount rate

The underlying of this binomial model is electricity price, and the drift rate of –0.33% is the actual rate not in a “risk-neutral world”, in other words, the expected growth rate is not the risk-free interest rate. The scenarios established by the binomial tree are not in a risk-neutral world, but the real world. Since the scenarios are in the real world, risk-adjusted discount rate rather than risk-free rate applies. The discount rate adjusted to the specific risk profile of the project needs to be determined.

The key development that makes it possible to find out a risk adjusted discount rate for a specific project is the power of computers to simulate complex systems more readily and easily. After simulating, the measure of the risk of the project, or σ^2, can be obtained. Modern finance theory can help get the corresponding market expected rate of return for efficient assets with such σ^2, which should be the upper bound of risk adjusted discount rate.

Previously, the choice of discount rate is always a controversy. The root of this problem is that people did not have a way to decide the discount rate from the intrinsic characteristics of a project, and had to turn to some extrinsic sources to decide the discount rate that does not have a convincing logic for a specific project. For example, US Office of Management and Budget has regulations regarding the discount rate should be used. Actually, finance theory states the discount rate can be decided by three parameters, that is r_f, the risk-free rate, σ, the measure of risk, and p_σ, the market price for risk. The r_f and p_σ are readily observable in the financial market. Unlike stocks or many other financial instruments, σ is hard to get for many public projects because no corresponding stock is traded in the market, and the σ cannot be derived from other stocks or projects because of the uniqueness of every project. However, the measure of risk of a project can be obtained with simulation.

[Capital market line and CAPM]

According to Luenberger [1998], the capital market line as Figure 5-9 in shows the relation between the expected rate of return and the risk of return for efficient assets or portfolio of assets. M in Figure 5-9 represents the market portfolio, or the summation of all assets on the market.

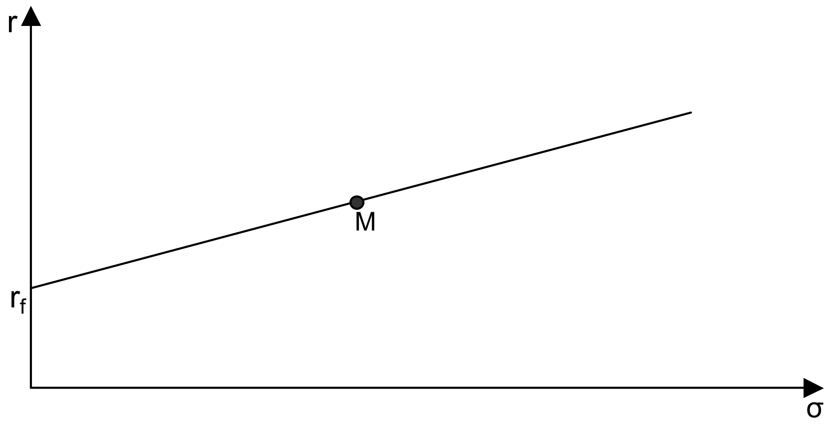


Figure 5-9 Capital Market Line

The relationship in Figure 5-9 can be described by a straight line in mathematical terms:

$$r = r_f + \frac{r_M - r_f}{\sigma_M}\sigma \qquad \textbf{\textit{Equation 5-3}}$$

where r_M and σ_M are the expected value and the standard deviation of the market rate of return of the market portfolio, r and σ is the expected value and the standard deviation of the market rate of return of an efficient asset that earns the highest possible expected rate of return given a specific risk profile.

The slope of the capital market line is $p_\sigma = (r_M - r_f)/\sigma_M$, and this value is frequently called the price of risk. So the capital market line can be also written as:

$$r = r_f + p_\sigma \cdot \sigma \qquad \textbf{\textit{Equation 5-4}}$$

Note the capital market line does not show how the expected rate of return of an individual asset relates to its individual risk, such as Project A in this thesis. The relation is expressed by the capital asset pricing model (CAPM) as:

$$r_i = r_f + \beta_i (r_M - r_f)$$ ***Equation 5-5***

$$\beta_i = \frac{\sigma_{iM}}{\sigma_M^2}$$ ***Equation 5-6***

where r_i is the expected return of asset i, and σ_{iM} is the covariance of the rate of returns between asset i and the market portfolio.

The empirical problem for valuation of Project A is, however, that it is virtually impossible to find out the σ_{iM} that describes the covariance of the rate of return of Project A and that of China finance market. The CAPM model is not applicable in this case.

The capital budget line, however, defines the efficient boundary of the feasible set of the expected rate of return and the standard deviation of rate of return for any individual asset. This means that any point on the capital market line is the highest possible expected rate of return of the given the standard deviation of the rate of return of the assets or portfolios of assets.

So if the capital market line is used, the upper bound of the risk-adjusted discount rate can be found. As an approximation, this thesis adopts the upper bound as the risk-adjusted discount. Since the upper bound of the discount rate is used, the valuation is lower than the actual value. It is good in the sense of being conservative, meanwhile.

[The standard deviation]

After building up Project A cash flow simulation model, it is assumed that the life of the project is 60 years. The Internal Rate of Return (IRR) can be calculated from each path of the simulated cash flows for 60 years. Assuming the value for the project at year 1 is V_1, and the invest is I, invested at year 0, CF_i is the cash flow for year i, and the IRR is r. So

$$-I+\sum_{i=1}^{60}\frac{CF_i}{(1+r)^i}=0$$

while

$$V_1=CF_1+\sum_{j=2}^{60}\frac{CF_j}{(1+r)^{j-1}}$$

so

$$-I+\frac{V_1}{1+r}=0$$

which means

$$V_1=I(1+r)$$

Applying Crystal Ball to the model of Project A, and simulated the IRR as Figure 5-7. The standard deviation in Figure 5-7 is 0.0115. Notice because this standard deviation of the IRR of Project A, or σ_v is averaged out for 60 years, so it is

$$\sigma_v/\sqrt{60}=0.0115$$

so the standard deviation of IRR

$$\sigma_v=0.0115\times\sqrt{60}=0.089$$

[The risk-adjusted discount rate]

What is the risk free rate in this analysis? Examining the China Treasury Bill as August 2002, the longest is 20 years with an annual rate of 4.26%. Because the life span of the project is 60 years, longer than 20 years, risk free rate is a little bigger than 4.26%. This thesis uses 4.5%. According to the website about China finance market at www.genius.com.cn/data/, the expected value and standard deviation of the market rate of return are approximately 18% and 30%. So the market price of risk

$$p_\sigma = \frac{r_m - r_f}{\sigma_m} = \frac{18\% - 4.5\%}{30\%} = 0.45$$

All the parameters chosen here are only for illustration. A better examination to determine the parameters is needed when real decision is made based on this model.

Substituting r_f, p_σ, and σ into Equation 5-4, the discount rate used for Project A is

$$r = r_f + p_\sigma \cdot {\sigma_v}^2 = 0.045 + 0.45 \cdot 0.089 = 0.086$$

The risk-adjusted discount rate r represents the intrinsic risk profile of the project.

Binomial Tree

The time period of the tree is 12 years with per stage of 3 years. The decision of starting the construction is likely to be made in the coming 10 years, though the life span of the hydropower project considered is 60 years. If a stage of 1 year used, there will be 10 stages. 10 stages are too many for this thesis, whose main purpose is to illustrate the method. So the stage is taken to be 3 years.

With *r* and σ specified, according to Equation 3-13 to 3-15, the various parameters for per stage are as follow:

$$u = e^{\sqrt{3}\sigma_e} = 1.128$$
$$d = \frac{1}{u} = 0.886$$
$$p_u = \frac{e^r - d}{u - d} = 42.87\%$$
$$p_d = 1 - p_u = 57.13\%$$

Then the electricity price movement is established as the binomial tree in Figure 5-10:

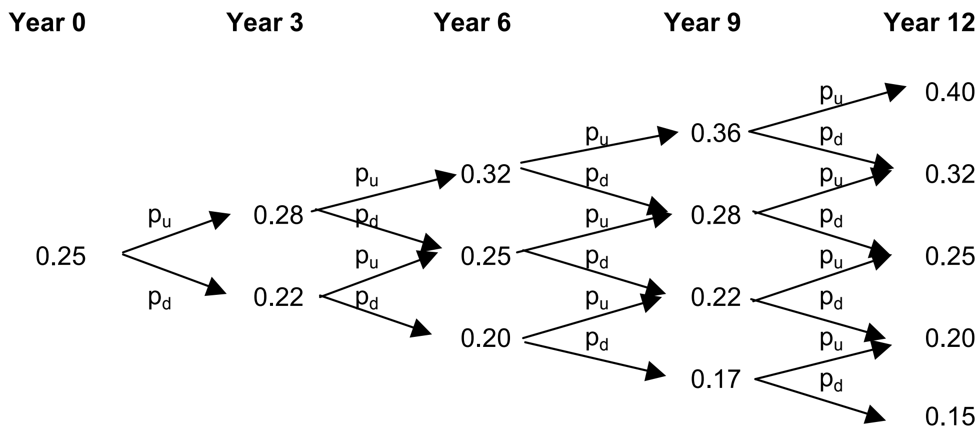


Figure 5-10 Electricity Price Movement

Note that this event tree gives different scenarios of the evolution of the market. For each scenario, the exercise value and deferral value can be calculated.

The exercise value is just the expected NPV of starting Project A given the specific price in the scenario. Given the starting price of electricity in a specific scenario, the Project A cash flow simulation model can be used to get the expected value in this scenario. For example, for the scenario in which the electricity price is 0.22RMB/kWh, 0.22 is put as the starting price of electricity in the Project A cash flow simulation model, and the expected NPV of the project is –0.68 B RMB. See Figure 5-11.

The deferral value is the expected value if the option is not exercised. The deferral value is

$$\frac{(\text{value in up state 3 years later})\cdot p_u + (\text{value in down state 3 years later})\cdot p_d}{(1+\text{discount rate})^3}$$

The risk-adjusted discount rate for Project A should be 8.6%.

The value of the project with deferral options at any point of time is the maximum of the exercise value and the deferral value.

The binomial tree developed for this Project A deferral options is shown in Figure 5-11.

The value for the deferral option is 1.25 – 0.98 = 0.27 billion RMB. 1.25 billion RMB is the value of Project A with deferral options. And 0.98 billion RMB is the value of the project without deferral options, in other words, the value of the project if it has to begin right now.

The tree in Figure 5-11 allows people to get important insights into the strategy of this project. Given the high volatility of price due to the pending energy market reforms, the best strategy is to wait until the price of electricity is mostly resolved. If the price is high then beginning building the plant, if it is low then still wait.

	Year 0	Year 3	Year 6	Year 9	Year 12
Price	0.25	0.28	0.32	0.36	0.40
Exercise (B RMB)	0.98	3.24	5.41	8.04	10.85
Deferal	1.25	2.24	3.02	6.04	0.00
Value	1.25	3.24	5.41	8.04	10.85
Exercise?	no	yes	yes	yes	yes
Price		0.22	0.25	0.28	0.32
Exercise (B RMB)		-0.68	0.97	3.24	5.41
Deferal		0.37	0.90	2.24	0.00
Value		0.37	0.97	3.24	5.41
Exercise?		no	yes	yes	yes
Price			0.20	0.22	0.25
Exercise (B RMB)			-2.09	-0.68	0.97
Deferal			0.11	0.32	0.00
Value			0.11	0.32	0.97
Exercise?			no	no	yes
Price				0.17	0.20
Exercise (B RMB)				-4.02	-2.09
Deferal				0.00	0.00
Value				0.00	0.00
Exercise?				no	no
Price					0.15
Exercise (B RMB)					-5.23
Deferal					0.00
Value					0.00
Exercise?					no

Figure 5-11 Binomial Tree for ROA with electricity price as underlying

Sensitivity Analysis

The option value of 0.27 Billion RMB is 27.6% of the value of the project that is taken to be as the NPV with simulation of 0.98 Billion RMB. The option value should be compared to the NPV with simulation rather than the cost of the project of 14.6 Billion RMB, because the option value is based on the value of the project that is revenue net cost. On each node of the binomial tree as Figure 5-11, the exercise value of the option is the NPV with simulation, given the specific value of underlying electricity price.

The key element deciding the value of the option is the volatility. Besides the volatility of 6.96% as the guess of the experts, a sensitivity study on various values of volatility and drift date must be done. The result is shown in Table 5-2. The first value in each cell is the option value, and the second value is the percentage of the option value to the total investment.

Table 5-2 Sensitivity Analysis to Option Value

(Option Value in Billion RMB
percentage of total investment)

Drift rate	**Volatility**					
	6.96%	10%	15%	20%	25%	30%
-0.01/yr	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*
-0.0033/yr	0.27 1.85%	0.45 3.08%	0.97 6.64%	1.55 10.62%	2.13 14.59%	2.59 17.74%
0.005/yr	0	0	0.45 3.08%	0.64 4.38%	0.88 6.03%	1.87 12.81%
0.01/yr	0	0	0	0.24 1.64%	0.59 4.04%	0.90 6.16%
0.02/yr	0	0	0	0	0	0
0.08/yr	0	0	0	0	0	0
0.09/yr	N/A**	15.74 107.81%	15.93 109.11%	16.29 111.58%	17.98 123.15%	20.20 138.36%
0.10/yr	N/A**	N/A**	60.19 412.26%	63.86 437.40%	64.96 444.93%	66.46 455.21%

* because the NPV with simulation is less than 0, there is no option for waiting or not. The only choice is to wait, not carry on the project. It is the area of “Option Value not Defined (II)” in Figure 5-12.

** for the binomial tree formula used, the volatility has to be greater than the drift rate. Otherwise, no option value can be calculated. It is the area of “Option Value not Defined (I)” in Figure 5-12.

The option values given different combination of volatility and drift rate can be sketched as in Figure 5-12 . For high drift rate and low volatility, the option value is not applicable because the binomial model requires that volatility greater than drift rate. In the middle of the diagram, the option value is 0. The option has a positive value both when the drift rate is big[1] and small. An intuitive explanation is that an option has value either to avoid downside risks when drift rate is low or to wait for even better chance when drift rate is high. Option has value when situation is problematic or promising. The latter observation is a little counterintuitive without an options analysis. Without an options analysis, the decision was often to go immediately when it looks promising while overlooking the chance that things could be better by waiting.

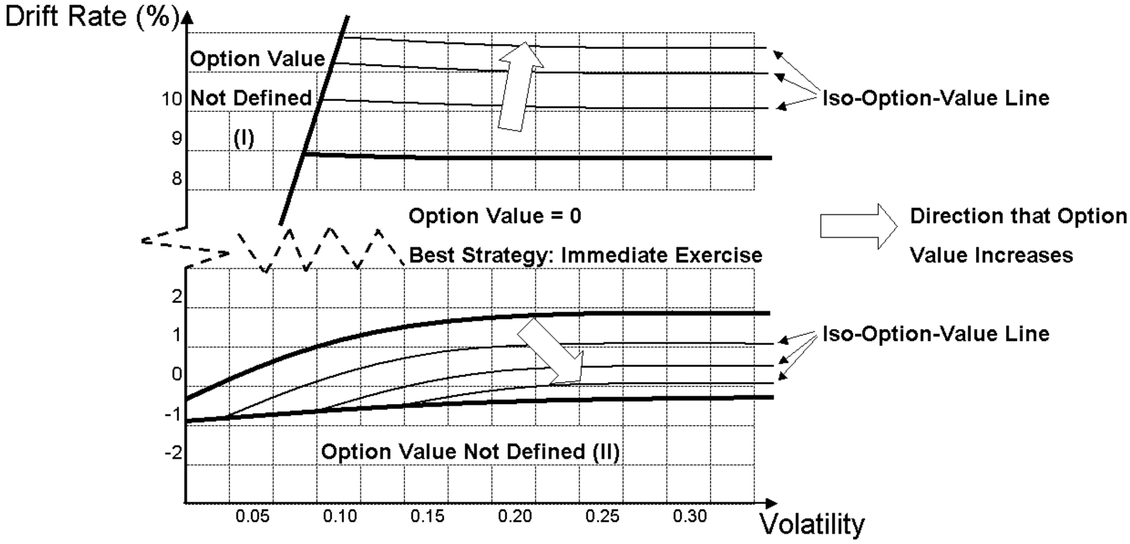


Figure 5-12 Option Value as Function of Volatility and Drift Rate

[1] Although a drift rate as high as 8% per year is not reasonable for a hydropower case in this thesis, the sensitivity to high drift rates is done, nevertheless. This is to illustrate a general insight gained by options analysis.

5.5.3. ROA with NPV as underlying

For the ROA with NPV as underlying, the underlying asset of the analysis is the value of the project, or the NPV of the project without flexibility. As calculated above, the expected value of the NPV with simulation is 0.98 B RMB. Because the investment is 14.6 B RMB, so the expected revenue of the project is 14.6 + 0.98 = 15.58 B RMB. The underlying has an initial value of 15.58 B RMB, and the exercise price of the option is the investment, or 14.6 B RMB.

The next step is the get the volatility. Remember the IRR for the project has been simulated as Figure 5-7, and the standard deviation of the IRR is 1.15% (the mean is 8.8%). The IRR is the average IRR over a lifetime of the project of 60 years. So the standard deviation of 1.15% is equal to $\sigma/\sqrt{60}$. Therefore,

$$\sigma_v = 8.9\%$$ [1]

With σ obtained, the up factor and down factor for a 3-year period are as follow:

$$u = e^{\sqrt{3}\sigma_v} = 1.167$$
$$d = 1/u = 0.857$$

Here the risk free rate r_f is taken to be 13.5% because the time interval is 3 years, and the risk free rate is 4.5% per year. Therefore, the risk neutral probabilities

[1] Note the volatility should be the standard deviation of logarithm of IRR. However, since the standard deviation of IRR is very close to the standard deviation of logarithm of IRR because both are very small. So the volatility is approximately taken to be the standard deviation of IRR.

$$p_u = \frac{e^{r_f} - d}{u - d} = 0.928$$
$$p_d = 1 - p_u = 0.072$$

With the information about the initial value of 15.58 B (net revenue without flexibility), the exercise price as of the investment of 14.6 B, the parameters of u, d, p_u, and p_d, the binomial tree is established as Figure 5-13.

The project value with option is 2.83 B RMB, so the value of option is 2.83 – 0.98 = 1.85 B RMB.

Applying such ROA with NPV as underlying, though we get the value of the option, there are several problems:

1, the underlying is the NPV of the project, and the exercise conditions is not clear because the NPV of the project is not readily observable. The NPV itself at any point is not determined. People can only get the expected value of NPV at a specific node. For a financial option, at any time, the underlying asset of stock price is readily observable and determined. If the exercise condition is not clear, then it is unknown whether the hypothetical exercise in the binomial tree is practical. So the value of the option is questionable if the options are not exercisable themselves.

2, the binomial tree as in Figure 5-13 assumes that on each node the underlying is a determined and observable measure, such as stock or other commodity price. But the NPV is not determined at any point of time. It has a distribution. In other words, it has variance or risk, so just applying a risk free rate to discount is not enough (though it is correct for the case where the underlying are determined, for example using stock price as the underlying where, at the time people exercise the stock option, the stock price is determined). Because systematically applying a small discount rate (risk-free rate) than necessary, the valuation tends to be too big.

	Year 0	Year 3	Year 6	Year 9	Year 12
Project Value	15.58	18.18	21.21	24.75	28.88
Exercise (B RMB)	0.98	3.58	6.61	10.15	14.28
Deferal	2.83	4.33	6.17	9.39	0.00
Option Value	2.83	4.33	6.61	10.15	14.28
Exercise?	no	no	yes	yes	yes
Project Value		13.35	15.58	18.18	21.21
Exercise (B RMB)		-1.25	0.98	3.58	6.61
Deferal		1.75	2.72	4.24	0.00
Option Value		1.75	2.72	4.24	6.61
Exercise?		no	no	no	yes
Project Value			11.44	13.35	15.58
Exercise (B RMB)			-3.16	-1.25	0.98
Deferal			0.39	0.62	0.00
Option Value			0.39	0.62	0.98
Exercise?			no	no	yes
Project Value				9.81	11.44
Exercise (B RMB)				-4.79	-3.16
Deferal				0.00	0.00
Option Value				0.00	0.00
Exercise?				no	no
Project Value					8.41
Exercise (B RMB)					-6.19
Deferal					0.00
Option Value					0.00
Exercise?					no

Figure 5-13 Binomial Tree for ROA with NPV as underlying

3, because the underlying is unobservable, so using the ROA with NPV as underlying will not render a clear-cut strategy like the ROA with electricity price as underlying or decision tree analysis do.

5.6. Decision Tree Analysis

Another way to obtain the value of the Project A is through decision tree analysis. The analysis assumes as before that there is a decision every three years. For any considered year, that is, years 0, 3, 6, and 9, there are three possible price schemes, high, medium, and low. For any year there is a decision, the structure of the tree is as Figure 5-14:

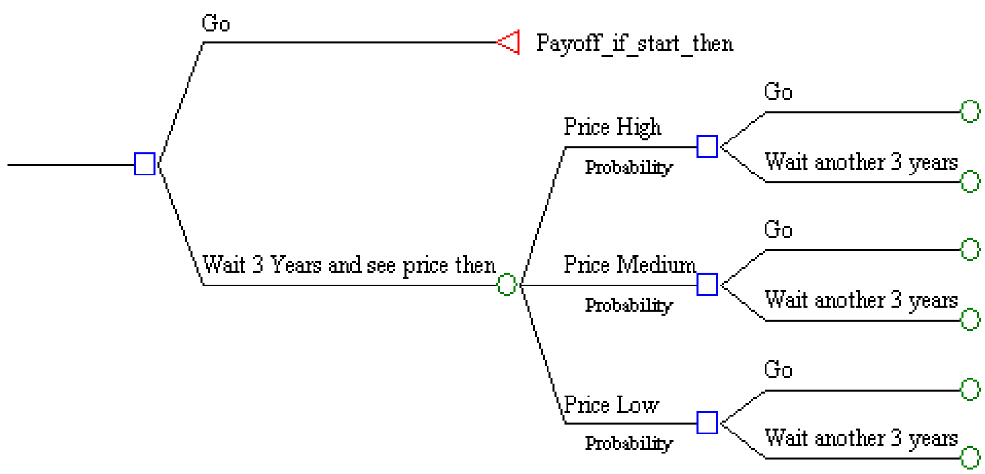


Figure 5-14 Basic Structure of the Decision Tree

“Go” in the decision tree means to invest.

5.6.1. Scenarios on Condition Branches:

The probability and price and determined by a Binomial tree with a drift rate of –0.33% per year and an electricity price volatility of 6.96% per year. The decision tree has three branches for each node, corresponding price high, medium and low, while the binomial tree extends two branches per period. To deal with this mismatch, the binomial tree used to calculate parameters for the decision tree has a length of period of 1.5 year. This binomial tree is different from the binomial trees in Figure 5-11 or Figure 5-13. The data for years 0, 3, 6, and 9 are kept and the data for years 1.5, 4.5, and 7.5 are discarded.

Therefore, evolution from year 0 to year 3 has three paths (branches) and suits the use of the decision tree. For example, see Table 5-3:

Table 5-3 Using Binomial Tree to Get Probability for Decision Tree

0 year	Prob.	1.5 years	Prob.	3 years	Prob.
0.25	1	0.27	0.449	0.30	0.202
		0.23	0.551	0.25	0.495
				0.21	0.303

For the price move form year 0, or present, to year 1.5, there are two possibilities, either moves up by a factor of u, or moves down by a factor of d. where

$$u = e^{\sqrt{1.5}\cdot\sigma} = 1.089$$
$$d = \frac{1}{u} = 0.919$$

The probability of moving up is

$$p_u = \frac{e^{-0.005} - d}{u - d}$$

-0.005 is the drift rate of electricity price per 1.5 year. So:

$$p_u = 44.9\%$$
$$p_d = 1 - p_u = 55.1\%$$

Refer to Table 5-3, at year 3, the high branch has a price of $u^2 \cdot 0.25 = 0.30$ with a probability of $p_u^2 = 20.2\%$; the medium branch has a price of $u \cdot d \cdot 0.25 = 0.25$ with a probability of $2p_u p_d = 49.5\%$; the low branch has a price of $d^2 \cdot 0.25 = 0.21$ with a probability of $p_d^2 = 30.3\%$.

Applying the same techniques, all the price scenarios in this tree and the associated probability are obtained.

5.6.2. Payoffs

In this analysis, the Project A cash flow simulation model is used to get all the payoffs. For each of the price scenario, the price is input into the model as the initial price at year 0 to get the expected NPV of the project under such a price scheme. For example, at year 3, the high price branch is price of 0.30 RMB with a possibility of 20.2%, the price of 0.30 RMB is set as the initial price, and the expect NPV for this case is 4.29 B RMB. It should be discounted to present value and use the present value as the payoff. For the payoffs at year n, it needs to be discounted for n years. The choice of discount rate problem presents again. It is hard to find solid grounds for any discount rate used. Here, the discount rate of 8% is used, as in the traditional NPV analysis.

With the structure of the tree, scenarios of price and probability, and payoffs, the software of TreeAge is used to build the tree as Figure 5-15 .

5.6.3. Result

Roll back the decision tree to get the value of the decision tree is 1.20 B RMB. Compared the expected NPV with simulation (actually it is a case without flexibility) of 0.98 B RMB, the value of the deferral option is the difference between the value from decision tree and value from NPV with simulation, or 0.22 B RMB.

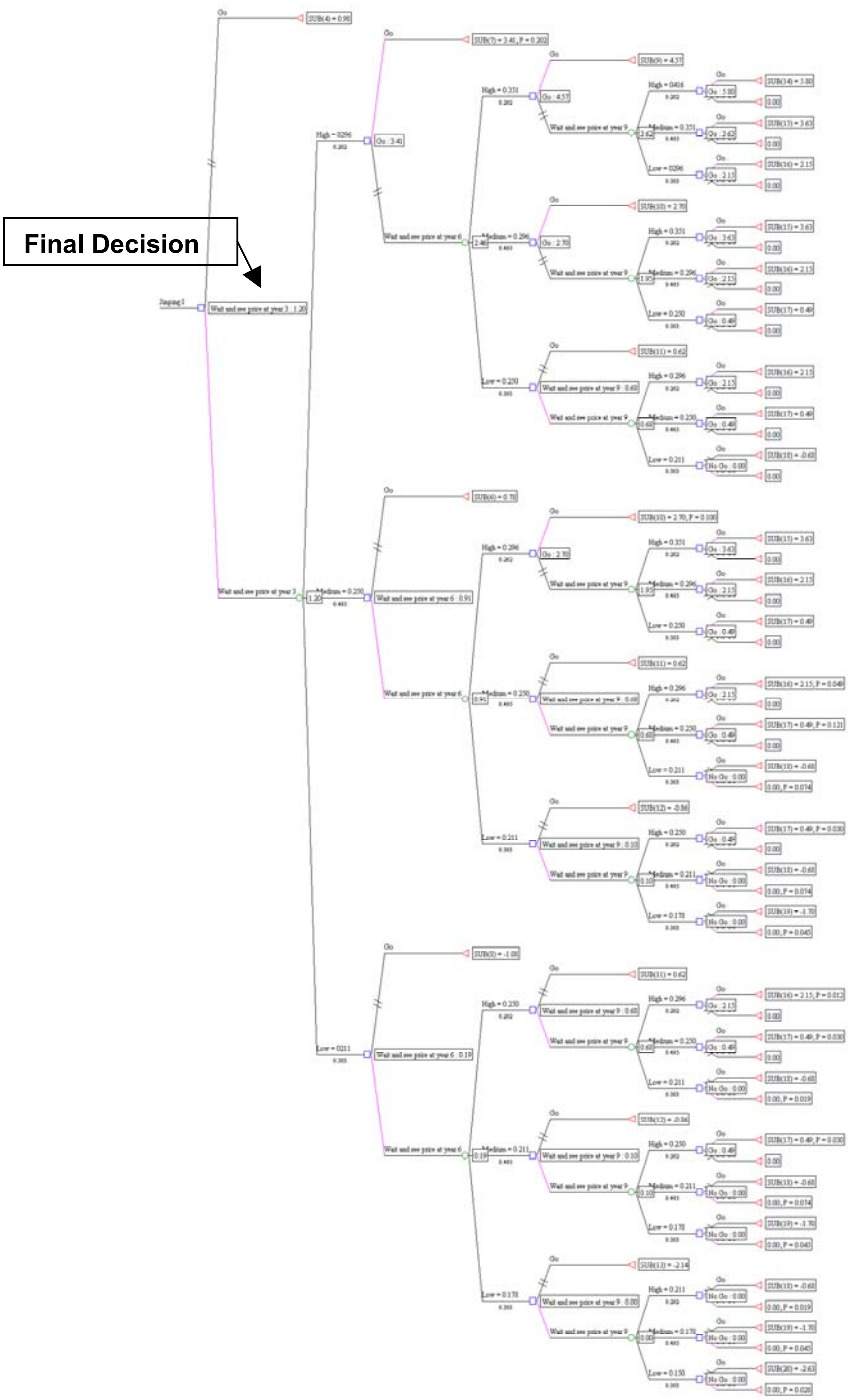


Figure 5-15 Decision Tree Analysis

5.6.4. Shortcomings of Such an Analysis

1. The decision tree can be very bushy, for the tree we built that considering 9 years 4 periods, it has totally $((2\times3+1)\times3+1)\times3+1=67$ branches. If 12 years 5 periods are analyzed, $67\times3+1=202$ branches are needed.

A tree of 202 branches needs a big effort to build and needs to be very careful otherwise the establishment of such a tree will involve a big cost of debugging. One of the problems with such a tree is that people do not have other mechanism to crosscheck if the tree is built correctly; because there is no means to cross-check, people has to examine each node and branch carefully. It is a tedious and tiring task, very easy to make mistakes. Because the number of branches of a decision tree is increasing exponentially, A bushy tree is one of the most salient problems of the decision tree analysis method.

A binomial tree can analyze the same problem of 9 years 4 periods with 4 braches, or 12 years 5 periods with a tree of 5 braches. Binomial tree is a very smart tool to make many scenarios recombined.

2. Another problem facing this decision tree analysis methodology is the problem of choice of discount rate. And explained, the choice of 8% as discount rate here is not easy to justify objectively.
3. The tree is so bushy that any sensitivity analysis is not simple, for example, if people are going to get the sensitivity analysis for the discount rate. A big portion of the tree needs to be redone, and it is not a trivial task. Even if with a tool like TreeAge that people can link the tree to a spreadsheet, it is still a significant task to build this linkage and do sensitivity analysis.

5.7. Summary of Results

With all the above analyses using different methods, the following results for the Project A are obtained as Table 5-4:

Table 5-4 Summary of Results

in Billion RMB, $1 = 8 RMB

	NPV	NPV w/Simulation	IRR	IRR w/Simulation	DTA	ROA	
						NPV as Underlying	Electricity Price as Underlying
Value	7.02*	0.98*	10.05%	8.80%	1.20*	2.83	1.25
Option Value	N/A	N/A	N/A	N/A	0.22	1.85	0.27
Decision	Go	Go	Go	Go	Wait	Wait	Wait

* the discount rate is chosen to be 8%

Using traditional NPV method and NPV with simulation, the project value without flexibility is studied. As analyzed above, the NPV with simulation gives a more accurate answer for the value of the project. Then decision tree analysis and real options analysis (using NPV and electricity price as underlying, respectively) are used to obtain the value of the project with flexibility (the deferral options). The difference between the project value with flexibility and the value without the project flexibility is the deferral options value. The base case for the value of the project without flexibility is the NPV with simulation or 0.98 B RMB.

Among the three methodology valuating the flexibility: DTA result has the problem of using an unjustified number of 8% as the discount rate, so it is less accurate than the real options analysis. Between the two Real options models used, the ROA with NPV as underlying has a very vague exercise condition; actually the options are not exercised in the way it describes because the NPV is not readily observable. Moreover, it systematically overvalues the options because the risk-free discount rate is not enough for an additional risk component because, at any time, the underlying NPV is not a determined value.

The conclusion is that the ROA with electricity pricing as underlying gives the most accurate valuation as 0.27 B RMB, and it gives a strategy to develop the project, a contingency plan regarding what to do under different scenario. Given the high volatility of price due to the pending energy market reforms, the best strategy is to wait until the price of electricity is mostly resolved. If the price is high then beginning building the plant, if it is low then still wait.

Chapter 6 Policy Implications – Options Thinking in Practice

Before studying how to apply options thinking in practice, we have to first make sure that policy makers would use it. This means that options analysis has to make a substantial improvement over previous analysis tools. Two substantial improvements must be presented to and understood by policy makers before the efforts to apply options thinking. The two improvements from options thinking are value of options (better mean) and/or change of distribution (desirable distribution)

Better mean. It is often the case[1], once options are imbedded in the systems planning process, there is an improvement in the value of the project. The value is substantial when uncertainty is higher, which is measured by a higher volatility. For the case of Yalongjiang River studied in this thesis, when the volatility is 30% and drift rate is –0.33% per year, the value of a deferral option is 17.74% of the total investment, or 2.59 Billion RMB (refer to Table 5-2). According to Alvarado and Rajaraman (2000), the US electricity price volatility has been 21.8%. It is reasonable that volatility in China is higher than that in the US, given many uncertainties in the current China energy market, such as the pending energy market reform. 30% is a more reasonable guess of volatility than 6.96% provided by the experts in the China Development Bank. The value of option cannot be neglected in the planning of the projects on Yalongjiang River.

Desirable distribution. With options on hand, the distribution of the value of a project is changed. Some extreme values are avoided for the downside, and/or some more favorable upside potential is obtained. Smaller downside risk is very important for many

[1] Under circumstances, people may use an option decreasing the mean actually, e.g. insurance. See following paragraph.

policy makers. The more risk averse a policy maker, the more important a smaller downside risk is. For some cases, even if the mean of the value of a project is smaller than the another project, the project may be still be preferred by policy makers because of a smaller downside risk. An options analysis will provide a plan with a smaller downside and/or bigger upside.

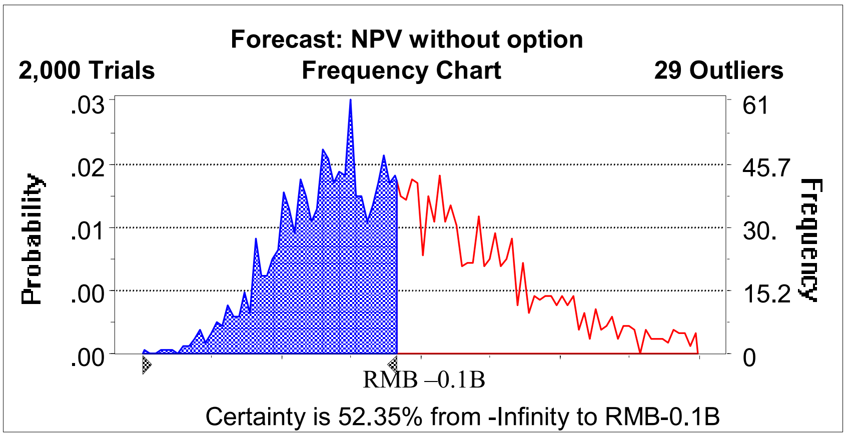


Figure 6-1 Distribution of NPV without options (Drift = -0.33%/yr, σ = 6.96%)

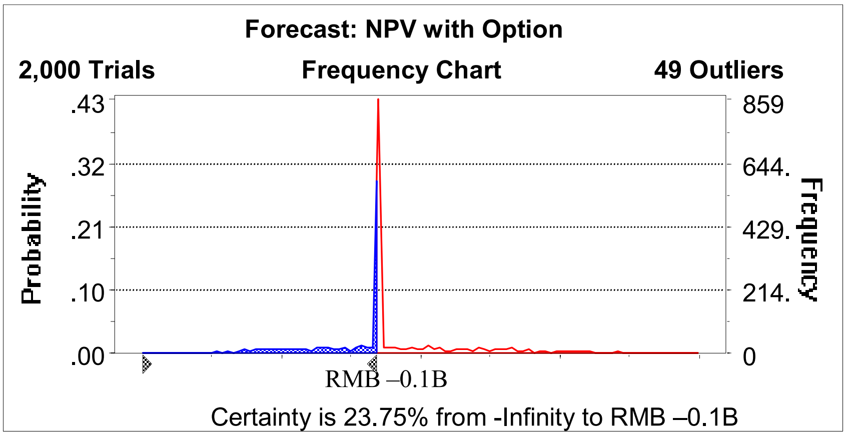


Figure 6-2 Distribution of NPV with options (Drift = -0.33%/yr, σ = 6.96%)

For example, Figure 6-1 shows the distribution of NPV of Project A without a deferral option, the probability that the project will have an NPV less than 0.1B RMB is 52.35%.

Figure 6-2 shows the distribution of NPV of Project A with the deferral option. It has a big spike because many values concentrate around 0.1 B RMB for the case that the project is abandoned at year 3. When comparing Figure 6-1 and Figure 6-2, notice the change of scale for the y-axis. With the option, the probability that the project will have a NPV less than –0.1B RMB is 23.75%. Much smaller. Although for the case studied here with –0.33% drift rate and 6.96% volatility, the value of the option is only 0.27B RMB, or 1.85% of the total investment, the deferral option may help the project decrease the chance of losing more than 0.1B RMB by 28.6%. This significant risk avoidance may justify the use of the deferral option though the option value is negligible.

After convincing policy makers of the significance of options thinking, some application tactics is very important in making real impact of the options thinking. Meanwhile, we should be aware that options analysis is not a panacea, sometimes it works, sometime it does not. So it is important to understand the uncertainty reality and choice of appropriate methodology.

6.1. Making Real Impact of the Options Thinking

The author of this thesis spent 4 months in the China Development Bank in Beijing to help the bank study the real options method and implement the real options thinking in their project evaluation process. The China Development Bank is the major investor of China public projects in energy, transportation, and other public areas where other investors are unwilling or unable to invest.

To use options thinking in a developing country like China, there are more difficulties than using the methodology in a developed country like the US. In the US, there are still many problems need to be solved before real options method can be applied maturely and widely. The major difficulties of the real options method in developing countries are how to make decision-makers understand the method and obtain the quality data necessary for options valuation models.

The options methodology develops a proactive and analytical view of uncertainty and flexibility. Despite the difficulties mentioned above, it has a good possibility to make real impact in a developing country such as China. Besides the methodology itself, the organizational tactics and skills to make people accept new ideas are also among the keys to make real impact of the method.

This section discusses the two aspects of promoting the real options method in China, and more generally, in developing countries. The first aspect is the intrinsic difficulties in promoting real options method in developing countries, and the second is the organizational wisdom to advocate new thinking.

6.1.1. Intrinsic Difficulties in Promoting Real Options methodology in Developing Countries

First of all, it should be stressed the real options methods have big room to grow in developing countries, despite the difficulties discussed in this section. In other words, these difficulties do not make the method inapplicable in developing countries.

Understanding the method

The options theories and models always seem arcane to people, the partial differential equations… the dynamic processes… people usually think options are the work of rocket scientists.

In developing countries, what makes things even worse is that financial options are not traded in local financial markets. This is because the trade of options is very easy to foster fraudulence in a weak legal system. For example, China once allowed the trade of Chinese treasury note options. Soon after the beginning of the trade, a scandal broke out and a broker's firm lost more RMB 10 billion overnight. And after that, financial options have not been allowed to trade on China financial markets. So Chinese people do not know what options are intuitively like people in developed countries.

If a person does not establish an understanding of financial options, he/she will find it very hard to develop the idea of what the real options are and to have confidence in the method. For example, in the China Development Bank where I worked, a manager heard that the real options method overvalues projects, then he had deep misunderstanding of the method because the real options method was a black box for him. He could not appreciate that the real option valuation will overvalue a project only when it is misused.

After all, a manager is not going use a method if he/she does not understand it.

Data

Options analysis needs a lot of historical data to do objective analysis. In developed countries, the abundant historical data on financial market provides the power of options analysis - there is little subjective element in the analysis, and the magic of market tells all. However, in developing countries, there is no complete financial market, and consequently, the data is incomplete. Even with some data, the financial market is decided by too much government interference so the information is highly distorted. China is such an example. So even if there is data, people must be very cautious when using it. Also, because China has been undergoing tremendous reform for a long time, there has been several major system changes in the past 10 years. The state changes imply that the available data do not reflect the current situation.

A way to circumvent the data problem is to use simulation to obtain important parameters such as the volatility. In this way, the model risk is huge because the model includes of subjective assumptions of the model-makers.

Although the difficulties in helping managers understand the methodology and the availability of data problems, the real options method will be able to spread fast in developing countries because of its insights into uncertainty and flexibility. The thinking is invaluable, nevertheless.

6.1.2. My Strategy in making real impact of options thinking “in” hydropower projects on Yalongjiang River

The first step to think about making real impact with options thinking is to understand the institutions that have the most influence over the implementation of real options “in” hydropower projects in Yalongjiang River Basin. To the best of my knowledge, the most influential institutions are:

- Ertan Hydroelectric Development Corporation (EHDC)
- China Development Bank (CDB)
- Sichuan Hydrology and Hydropower Institute (SHHI)
- Sichuan Trust and Investment Corporation (STIC)
- Ministry of Water Resources (MWR)
- China State Power (CSP)

<u>Ertan Hydroelectric Development Corporation (EHDC)</u>

This corporation is now in charge of the development of Yalongjiang River Basin. It is the entity that developed the first hydropower project, Ertan Hydropower Station, on

Yalongjiang River. EHDC is eagerly pushing further projects on the river. It is natural for any institution to seek more projects to enhance its control of resources and influence. Moreover, the first project of Ertan has been losing money, and EDHC is in serious debt. They would like to have further projects to alleviate their hard times.

There is competition between Yalongjiang River and Daduhe River, another tributary of Yangtze River in Sichuan that also has good natural conditions to develop hydro projects. Given the limited funding and other resources, a new project approved by the state government on Daduhe River will greatly delay the development of Yalongjiang River Basin.

EHDC is the most active player in pushing hydropower projects on the Yalongjiang River. They would accept anything that is beneficial to the success of new projects on Yalongjiang, in finance or in engineering. The idea of incorporating of flexibility into the design of projects is definitely to their benefit.

China Development Bank (CDB)

The Bank is a major funding source for new projects in the Yalongjiang River Basin. Since EHDC is already deep in the red, they have to get substantial support of loans from CDB.

In the China loan market, CDB faces serious competition from other banks in China. Currently, CDB is having difficulties in finding good customers to lend money. They have money but lack good projects. Also, since the previous centralized system of energy and hydrology in China, CDB and EHDC have very close ties. Many influential managers in CDB have worked in EHDC before. A big percentage of senior managers in EDHC are from CDB. And a number of managers in CDB are looking forward to the opportunity to work as senior management in EHDC one day. They have personal interest in pushing the projects. So a group of managers in CDB are enthusiastically pushing the projects.

However, as they are mainly concerned about finance, engineering flexibility is apart from their interest.

Given the current financial situation of EDHC and the astronomical amount of investment of hydro projects, the risk is too big for CDB. So CDB is hesitating to invest more in Yalongjiang River Basin. They are hoping other financial institutions will share the risk. One of the possible institutions to share the risk with CDB is the Sichuan Trust and Investment Corporation (STIC).

Sichuan Trust and Investment Corporation (STIC)

STIC is a local investment company that participated in the financing of the first dam on Yalongjiang River, Ertan. Both CDB and EHDC want STIC to provide part of the funding for the new projects. However, STIC are not in a good financial situation partly because of the financial failure of Ertan for several years. STIC is not big enough as CDB to suffer the loss. They are not enthusiastic on the projects, let alone interested in the engineering aspect.

Sichuan Hydrology and Hydropower Institute (SHHI)

This is a research institute. They have been responsible for the hydrology research and engineering design for the Yalongjiang River Basin development. They are genuinely interested in any new methodologies. Furthermore, because it is likely that they have to bid for projects in the future given the rapid reform in China (there are other research institutions in Sichuan and China and they can be tough competitors). They are more than willing to incorporate new methodology in their design responsively if they are sure it works.

Ministry of Water Resources (MWR)

This Ministry is responsible for controlling and coordinating all water resources development in China. They are interested in more strategic issues, though they would like to see the technological advances in engineering.

China State Power (CSP)

CSP has been the monopolist of China energy market. Now it is dissolving into several separate companies according to the plan of China energy market reform. CSP is concerned about the problem of overcapacity in Sichuan because the grid to transport electricity from Sichuan to Eastern provinces has not been built yet. Whether to build the grid itself is a problem given the huge costs to do so. CSP is not particularly interested in the design issues of hydropower projects.

Target institutions to "sell" real options methodology

The two institutions that might be most willing to accept the results of an analysis of real options "in" a project are:

- Ertan Hydroelectric Development Corporation (EHDC)
- Sichuan Hydrology and Hydropower Institute (SHHI)

Ertan Hydroelectric Development Corporation (EHDC)

As analyzed above, EHDC is the most active player in pushing hydropower projects on the Yalongjiang River. They would accept anything that is beneficial to the success of new projects on Yalongjiang River.

The engineering department might be the most willing part of EHDC to accept the results of an analysis of real options "in" a project. Their perspective is pretty short-term. They want to begin construction of whatever project as soon as possible, and the long-term sequencing and scheduling is not their particular interest.

They may be interested in the real options analysis on tunnel design and selection of installed capacity. The previous design principle is to minimize total cost. With real options analysis, we should replace the decision principle with the one of maximizing net revenue given the uncertainty of electricity price.

To deal with an options analysis for tunnel design and selection of installed capacity, it might be hard to analyze the China electricity market with the poor data available and huge uncertainties, while the other part of the analysis can be done relatively easy if there is a cost model. We also need hydrologic information. Then we can do simulation to get the expected value of net revenue.

In order to successfully present the method to EHDC building on their existing understanding, I would stress the inadequacy of previous decision principle of minimizing the total cost that misses market uncertainty (implicitly assuming that the plant can produce full capacity all the time). For the difficulty of a credible model for China energy market, I would ask EHDC to develop a probabilistic model on China energy market and we use their model to do the rest of analysis.

Sichuan Hydrology and Hydropower Institute (SHHI)

As a research institution and eager to keep their current design projects, SHHI may be willing to learn and would incorporate new methodology in their design responsively. And they have a longer and strategic view of the river basin development.

The department that might be most willing to accept the results of an analysis of a real option "in" a project is the strategic planning department. They are interested in the strategic plan of developing the river basin, including selecting project location and size, sequencing, and scheduling.

It should be possible to develop a deeper understanding than what current methods can offer on selecting project location/size and sequencing, using the current available data, the knowledge on river basin development optimization, and methodology of real options.

To deal with such a real options analysis, I do not see insurmountable difficulties for now. Although the model of instantaneous behavior for China energy market is hard to develop, the long-term equilibrium that the energy with the lowest cost will be consumed first provides a good basis for solution of the problem.

In order to successfully present the method to SHHI building on their existing understanding, I would show the optimization model first and then add the real options part as an modification. Chinese people are unfamiliar with options concept and need time to understand. By showing real options part as a modification to current methods of optimization, it might be easier to present the real options methodology. Meanwhile, I would stress the inadequacy of deterministic analysis all the time.

My strategy

In terms of making the most effective contribution to the efficient implementation of options thinking “in” hydropower projects, I would target my work toward the strategic planning section in the Sichuan Hydrology and Hydropower Institution, aiming to influence the engineering systems planning part of the process of getting real options in hydropower projects.

With the development of decision science, finance science, and computer technology, it is now possible to adequately address the issue of building flexibility into systems design. The water resource systems design and planning has been developed to maturity, and finance science has developed a systematic theory on uncertainty with options theory as the most significant contribution. It is now time to explore design large systems with full awareness of uncertainty.

As a student in Engineering Systems Division (ESD) at MIT, I am more interested in systems level analysis and planning rather than more detailed design of a specific system. ESD people has the special expertise to be distinguished form finance people who do not establish engineering models, while develop a general model for engineers with more technical knowledge to develop the model with more details.

My background and gained knowledge is adequate in the areas of options and optimization (both at the application level, I would not pretend to have strong theoretical capability). Detailed engineering design is not my strength.

The most possible research direction to have the most influence over real options "in" project is to work on the projects selection, sequencing, and scheduling using optimization techniques and real options, and present the work to Sichuan Hydrology and Hydropower Institute.

The general contribution of the work would be providing a general model that water resources engineers can build on with more details and other large engineering systems can also use the model for their specific systems. See Figure 6-3.

	River Basin Development	**Satellite Systems**	. . .
General	***Our Position***		
More Details			

Figure 6-3 Contribution of my work

6.1.3. Organizational Wisdom to Advocate New Thinking

In this section, the author's personal experience in specific settings is introduced. Readers please judge if it works in the specific organization and specific country you are working in.

During the work in the China Development Bank, I realized the tremendous difficulties in promoting new thinking, especially in some big institutions that are featured of rigidity of bureaucracy and highly risk-aversion. After working in the bank for months, I figured out some tactics to quicken the process of adoption of new ideas. Although any good ideas will be used in the end, the process is very slow and painful. For example, it takes 20 years for people to use the NPV method widely. However, a smart way will make the process faster.

People don't like changes. They would like to follow the old way that they are familiar with. Because of the efforts and pains to, unless people do not face threats or other pressures, they won't take the efforts to change. Change is difficult and we must be patient and know how to make things happen tactically.

After working in the China Development Bank. I understand the following 4 elements are the keys for the success of letting people accept the options thinking. They are

- support from the top management;
- identify the needs of the organization;
- from simple to complex;
- perfect communication with grass-root people in the organization.

The support from the top management is key to success. Basically, in most big organizations, one of the most important motivations of people is promotion. If the top management would like to promote something, people will have enough motivation to take the endeavor to study the new ideas. When I did the real options study and promotion in the China Development Bank, one of the top managers gave me full support on the project.

Another important tactic is to identify the needs of the organization, and firstly show them that the method can be used to deal with the questions that they are most interested in. In the bank, I understand that a bank does not care too much about the value of a project, because what they can get at most is the principle plus interest. If the project earns more, or has more upside, it has nothing to do with the bank. On the other hand, the bank bears the risk of losing the big chunk of the principal (while the interest they can earn is only a small part compared the principal). So they are more interested in the risk management rather than valuation. So when I presented the real options to the Bank during the first several weeks, I did not mention many classical benefits of the options valuation, such as valuation of the flexibility. Instead, I used simple simulation showing the idea of right not obligation of options can be designed into a contract and reduce the default risk. By focusing on the needs of the bank rather than the traditional stressed benefits of real options, people in the Bank are getting interested in the method and understand the method gradually.

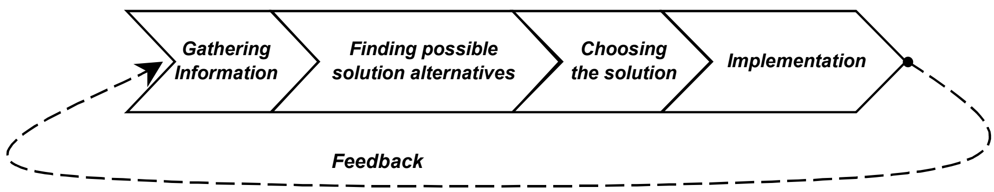
The real options method is not a simple method, though it looks transparent to experts who are studying the method everyday. It does take a while for those have never heard about it to understand the method. So it is important to show the thinking and method from simple to complex step by step. In the bank, when I showed [people there how to valuate the options, firstly I did not show them the profound options valuation formula or even binomial tree. I just showed them the idea of cut probability density function to valuate an options which is much more intuitive with the presentation of a software like Crystal ball.

A perfect communication with the bank people is the key to success, especially the grass-root people. Their trust in me is one of the necessary conditions to success. In the bank, I had to do a successful case to show the method workable. Though I know the real options method, I do not know the intricacy of project evaluation. For example, I did a project valuation on a hydropower project study, but I am not an expert on the China hydropower industry. So my real options analysis might have made no sense to the experts in the bank who have studied the industry for decades. So I have to make sure that my reports were collaborated with experts in the bank. In the bank, I made two very good friends, one is an expert in China energy industry and another is the people who the bank designated to cooperate with me. With friendly and perfect communication with these two grass-root people, I was able to understand the bank faster and avoid many stupid mistakes.

Please see a journal I took about for my work in the Bank about how I analyzed the situation to do a successful job in the Bank.

Despite the support from the top management, one of the key of a successful consulting project, there are two major difficulties to persuade people to try the method: firstly, there are no options traded in China financial market, the concept of options seems too arcade for most Chinese people; secondly, the China Development Bank (CDB) is a typical state-owned enterprise, slow in accepting new things. How to influence CDB to try and use real options?

I applied my process to make decision to analyze the situation and decide the way to make impact in CDB. The process is as the following figure:



Gathering Information:

On one hand, I understood the key trait of the Bank is risk aversion; their primary interest is the default possibility rather than the profitability of the debtor. Options are highly risky but yielding a fatty premium, so I cannot talk about the options in a traditional sense and need to customize the useful part of the theory and methodology for the bank. On the other hand, I tried to understand what every people I worked with in the bank needs and their relationships with each other. Though relationship is like a maze in a China state-owned company, so complex that I cannot understand in months, I tried my best to be careful. Also I identified two people in the Bank were really highly motivated for the project. One is a chief of a section who was eager to show himself before the top manager who was pushing the project forward, another is a young man just graduated from graduate school whose thesis is on real options.

Possible solution alternatives:

I identified several possible solution alternatives:

1, focus on communication to management to overcome the obstacles in the learning process of the CDB people;

2, gradually involve the CDB people in the method. More specifically, by adapting the real options method to work for the issues they are caring about most, to show the power of the method and let them involved in the development of the application of the method to the bank;

3, let the top management push the project;

4, win over the young people in the bank first, let them spread the method, and finally make the method a common practice.

Choose the alternative:

Alternative 1, it was not practical in CDB in a short period I worked there, given the facts that there are no financial options in China, and the theory is not straightforward.

Alternative 2, it was a good approach. As a first step, I could deal with a basic problem of quantifying default risk (the subject that the Bank are most interested in) in a new way.

Though it is not a traditional real options method meant to be, I gradually unfold the real options when working with CDB people on quantifying default risks.
Alternative 3, it was not so good at the time I was working in the CDB. I understood the attention that the top manager could put on the project at the time is small given that time one other Vice Governor was sick.
Alternative 4, it was a good idea because young people are more willing to learn new things and faster in learning. If they use the method, at least partly in their work by themselves, the method will be spread out finally. Although it is a little slow, it is one of the best ways to influence the Bank in the long run.

Implementation:

I worked together with the 2 CDB people who are highly motivated for the project in the bank. By attacking the problem of quantifying the default risk, I was gradually presenting the real options concept. I managed to persuade the division head to accept the real options method.

I had 3 lectures for around 100 young people in the Bank, and arouse the interest of them in the method. A number of them contacted me later, and I guided them to learn about the approach.

Though it is a challenge to make real impact in real business, I have been pretty successful in presenting the method to CDB. I finished two case reports and one general report for the Bank, and they are satisfied with the preliminary results and inviting me to come back again in February 2003 to promote the method further.

6.2. Uncertain Reality and Appropriate Method

The nature is inherently unknown. People can handle the situation with known risks, but people just cannot deal with the situations where the uncertain factor is unknown, or the uncertain factor is known but the distribution of the uncertain factor is unknown. Anticipatable risk should be managed, but other system risks have to be left there. When people have to enter into the domains that are ultimately unknown, they need to invest in information to the best capacity possible. If you have done what you can do and still fail in the end, nothing to blame.

Several common quantitative tools for policy evaluation are listed below:

- DCF[1]
- Decision tree analysis
- Real Options

A useful classification of uncertainty helps people to understand the environment better, and identify the best quantitative tools for policy evaluation to deal with the specific uncertainty. And most importantly, people need to understand that the right decision and method do not necessarily lead to a happy outcome.

Suppose the outcome, denoted Π, is a function of N influence parameters:

$$\Pi = \Pi(w_1, w_2, ..., w_N)$$

Usually, the project payoff Π cannot be predicted with certainty.

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[1] Discounted cash flow method.

Complexity: Many of the parameters are not random, and they could be under the influence of the decision-makers – for example, engineering designs. Interdependencies among influence parameters may make the optimization a significant task. Thus, complexity is the centerpiece of much of deterministic analysis tools, such as the NPV method and Linear Programming. Complexity increases with the number of nonseparable variables in Π. There is no uncertainty involved in complexity, actually. Another example of complexity is scheduling classes in a big university.

Risk: Some influence parameters are not deterministic but dynamic. There is payoff variation of Π associated with those parameters. There are two kinds of situation: the distributions of those influence parameters are known or unknown. If the distribution is known, and the influence parameter is market-traded assets, the standard real options approaches apply, such as the Black-Scholes formula, binomial tree, and simulation methods. If the distribution is known, and the influence parameters are not marketed traded, people may use the decision tree analysis and binomial tree to design contingent plan and value the project. However, if the influence parameter is known while the distribution is unknown, a decision tree analysis with the probability as an unknown parameter is an appropriate method. Sensitivity analysis with the unknown parameter can be done to get important insights into the problem.

Ambiguity: The decision-makers may not be aware of some the influence parameters at all. The decision-makers explicitly ignore the payoff impact of those influence parameters, but implicitly takes “default” value for those influence parameters. The past is extrapolated subject to changes in known parameters in the category of complexity and risk. For any real decision, it is very hard to avoid ambiguity, or in other words, not to miss any influence diameter. This is the key reason why forecast is almost certainly to be wrong. For the case in an ambiguous environment, the best method is to invest in information carefully, learning by trial and error. It is like entering a room without light to find a way out,. After bumping onto the table, the pain tells you that there is a table… In such situation, people should avoid betting too much and do not put all the eggs in a single basket.

The above analysis of uncertainty types can be summarized in Table 6-1.

Table 6-1 Uncertain Reality and Appropriate Method

	Complexity	**Risk**			**Ambiguity**
		Distribution Known		**Distribution Unknown**	
		underlyingmarket traded	**underlying not market traded**		
Methods	Deterministic Valuation (NPV, LP, etc)	Financial Options valuation formula	DTA	DTA (with probability as an unknown to do sensitivity analysis)	Trial and error
		Binomial Tree	Simulation		
		Simulation			
Examples	Scheduling classes in a university	Energy Project valuation with underlying of energy price	River basin development with waterflow distribution known	Whether China energy market will be market allocation or government allocation regime	New technology aimed at unkonwn market

With the understanding of uncertainty types, policy-makers can

- decide when different analysis techniques are most suitable, when to use real options method, when to apply decision tree analysis, and when the mathematical programming method is the best.;
- understand that there are cases where the analysis techniques do not help much if a lot ambiguity exists, and the best strategy is to carefully learn by trial and error, and do not make life-or-death bet;
- because of the ambiguity is ubiquitous in real life, sometimes the policy is optimized given the information available. The result may not be happy, however. In such case, policy-makers should not blame the methodology and gather more lessons for future decisions.

Chapter 7 Conclusions

7.1. ROA with electricity pricing as underlying is appropriate for Project A

The recommended methodology for the Project A is a ROA with electricity pricing as underlying. Compared to Ramirez's study on the Columbian Bogota water supply expansion plan [Ramirez, 2002] where she concluded that real options method is imprecise and complicates the process of identifying an optimal strategy, the Project A case is different from that of Ramirez's case because of the following observations:

1. The subject of deficit cost that Ramirez was studying is not a market observable monetary value. She had to change a lot of non-monetary values into a monetary value. It is not only hard to justify the monetary value assigned convincingly, but also hard to find data. Moreover, the deficit cost does not look like following a geometric Brownian motion.

2. She was using the ROA with NPV as underlying, but what this thesis suggests to use is the ROA with electricity pricing as underlying. The differences between the two methods please see Table 7-1. She did not recommend a the ROA with NPV as underlying for Bogota water supply expansion plan; though this thesis does not recommend a ROA with NPV as underlying for Project A either, it recommends a ROA with electricity pricing as underlying. If people have to choose between decision tree analysis and ROA with NPV as underlying Project A, the DTA analysis would be suggested.

Table 7-1 Comparison of the two ROA methods studied in this Thesis

	ROA with NPV as underlying	**ROA with electricity price as underlying**
Intuitive to Managers?	Very unintuitive	Medium
Identifying strategy?	No	Yes
Data?	Very hard to justify convincingly when underlying is not traded on market	Easier to obtain than ROA with NPV as underlying *
Key issue	Justify Brownian Motion (Weiner Process) of the underlying**	Justify the stochastic process of the effective market.

* The three ways to get the volatility for the effective market is historical data, Delphi method, and simulation.

** I believe this is why Ramirez [2002] got a ROA result way different from DTA. The deficit cost she put into the RO model is not following the Brownian motion model.

Ramirez's three key arguments for the real options method might not be valid for Project A, though reasonable in her Bogota case:

- Data not available. On the electricity market, data on electricity price is abundant. For the deficit cost that Ramirez was studying, the data is harder to obtain.
- Not intuitive for manager. The ROA with NPV as underlying that Ramirez was using is hard to explain to mangers because the vague and hard-to-define underlying value of the project. The ROA with electricity pricing as underlying for Project A is using electricity price as underlying. The event tree built to display the different scenarios of electricity price is much more transparent to mangers.
- Cannot identify the optimal strategy. The ROA with electricity pricing as underlying solves this problem well and offers an optimal contingent strategy,

while the ROA with NPV as underlying based on a vague underlying of the value of the project is hard to provide a clear optimal strategy.

7.2. Comparison of Methods

The methods used in this thesis can be divided into two categories: the first are point valuation methods, including NPV, NPV with simulation, IRR, and IRR with simulation; and the second are dynamic analysis methods, including decision tree analysis, ROA with electricity price as underlying, and ROA with NPV as underlying.

The point valuation methods provide a point measurement of the project such as NPV or IRR. They are simple yet power tools to decide the acceptance of projects or compare between projects, but they do not take into account the flexible decisions people can make after the project begins. In a word, the point valuation methods miss the value of flexibility, and they cannot provide a contingency strategy for projects. If resources permit, a dynamic analysis method is preferred to a point valuation method.

This paragraph compares the four point valuation methods. Traditional NPV method is the simplest model that gives a primitive financial evaluation. NPV with simulation is a better method than traditional NPV method because 1, $E[f(X)] \neq f[E(X)]$ and 2, the expected value of the inputs for the traditional NPV method is not easy to observe. And both NPV methods have the problem of choice of discount rate. IRR method and IRR with simulation method overcome the dilemma of choice of discount rate. The difference between IRR method and IRR with simulation method is similar to the difference between NPV method and NPV with simulation method.

This paragraph compares the three dynamic analysis models. Table 7-2 shows the pros and cons about the decision tree analysis, ROA with NPV as underlying, and ROA with electricity pricing as underlying is established.

Table 7-2 Comparison between Methods

	Decision Tree Analysis	ROA with NPV as underlying	ROA with electricity price as underlying
Pros	- Can readily identify optimal strategy. - Intuitive to managers	- Better dealing with discount rate problem by using risk-neutral discount rate	- Readily identify optimal strategy - Better dealing with discount rate problem by using risk-neutral discount rate
Cons	- Very easy to become extremely bushy - Problem with choice of discount rate - Hard to do sensitivity analysis - Hard to assign convincing probability if lack of data.	- Data is not readily available because the underlying value (NPV) is not traded on market - Need to justify the assumptions for Options valuation, such as Brownian motion and no arbitrage. - Can not readily identify the optimal strategy - Not intuitive for managers	- Need to decide the stochastic process of the electricity price - Data is sometimes not readily available

7.3. Future Work

As the next step following this thesis, engineering options will be explored in the development of Yalongjiang River Basin. In the process of applying options thinking in engineering projects evaluation, 3 key components are identified. They are identifying options, modeling, and obtaining insights into the project.

7.3.1. Identifying Options

The possible engineering options built into the design include the road building as growth options and the tunnel design for Project B project as scaling options.

Roads as growth options. For the projects in the Yalongjiang River Basin, people will have to build roads into the remote sites of dams. These cost a lot. Traditionally, people decide the design of the dam and the specifications for roads almost the same time; actually, people can, at the time the roads are finished, decide the height of the dams given the conditions of the energy market then. In real options literature, it can be regarded as growth options, or early investments to get information. Incorporating growth options, important engineering decisions regarding roads and dams are different from traditional way of designing.

Tunnel design as scaling options. The Project B project would dig tunnel(s) to shortcut a part of Yalongjiang River to gain significant head. People can build one big tunnel, two small tunnels, or three smaller tunnels. Traditionally, the decision rule is based on hydraulics. But if decision-makers take into account the market uncertainty and financing uncertainty, they may get the additional value of three tunnels over two tunnels or two tunnels over one tunnel because of the options to postpone building additional tunnels if the market is unfavorable and the financing is very expensive. This value can be significant and reverse the decisions based only on hydraulics considerations.

7.3.2. Modeling

The modeling has two parts: traditional models and real options models.

Traditional Models

Although options thinking is added into the framework of systems design, the foundation of systems design is nevertheless traditional model, such as engineering technical models and mathematical programming models.

The researcher has all the pieces for the technical cost models because he has built a financial analysis model for the China Development Bank in summer 2002 that has a very important part of cost analysis. The mathematical programming screening models in river basin planning needs more work. The objective function is to maximize the profit from power sales, because the Yalongjiang River Basin development is mainly for hydroelectric power, and all the other considerations are secondary.

Real Options Models

The first question for a real options model is what the underlying[1] is. *Effective market* is introduced as underlying. Effective market is effective demand multiplies price. It is in terms of money. If the effective demand for the company is bigger than the capacity of the company, then the company will produce to its maximum; if the effective demand for the company is smaller than the capacity of the company, the company can only produce up to the effective demand.

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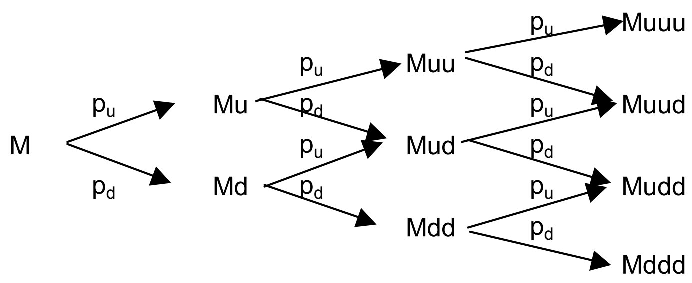
[1] In this study, a generalized concept of underlying is used. An underlying is the agent that determines the value of a project or an investment. An underlying can be assets, but it also can be other agents such as market size or utility price.

A binomial tree is one of the most easy-to-use options valuation models. It is a scenario analysis in essence, because a binomial tree can be thought as an event tree that establishes different scenario on each node. See a binomial tree as Figure 7-1.



(where M denotes the effective market value)

Figure 7-1 A binomial Tree

On each node of the binomial tree in Figure 7-1, the project is analyzed based on the traditional models developed, i.e., the mathematical programming screening models and technical cost models. Under each scenario specified by the node, the exercise value given a specific option exercised is obtained by the traditional models. For example, at a specific node, traditional models calculate the project value if the deferral option is exercised at this node.

A simulation model of the internal rate of return (IRR) of the project is developed to get the lifetime risk profiles of the project, more specifically, the standard deviation of the IRR. The standard deviation of the IRR, or σ, is the measure of the average risk per year of the project with the design. With this σ, a risk-adjusted discount rate is obtained.

Having the exercise values, risk-adjusted discount rate, the move-up probability (p_u), and move-down probability (p_d), the binomial tree is rolled back from the rightmost side to get the option value.

7.3.3. Obtaining Insights

With the binomial tree established, important strategic and operational insights into the project are developed. Overall, the thesis helps provide a preliminary methodology to incorporate options thinking into river basin development and engineering systems analysis.

Appendix I Ito's Lemma

Ito's lemma was discovered by a mathematician, K. Ito, in 1951. Suppose that the value of a variable *x* follows an Ito process:

$$dx = a(x,t)dt + b(x,t)dz$$

where *dz* is a Wiener process. A function G(x,t) follows the process

$$dG = (\frac{\partial G}{\partial x}a + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial x^2}b^2)dt + \frac{\partial G}{\partial x}bdz$$

where the *dz* is the same Wiener process. Thus, G also follows an Ito process.

Appendix II China Steps Up Reform of Electric Power System

- China will intensify reforms to break up the State-monopoly of the electricity supply system in order to cut costs and raise efficiency.

The reform will include restructuring State-owned assets, implementing a new pricing mechanism and bettering the regulation of the electricity industry, Xie Songlin, vice-president of the State Power Corporation, said Wednesday at the Annual Meeting of the Asian Development Bank (ADB) in Shanghai.

At present, the State Power Corporation owns 46 percent of the country's total electricity generation assets, and 90 percent of the total electricity supply assets. The reform will divide most of the electricity generation sector from the corporation and set up five independent national power plants, according to Xie.

After the restructuring, a national power network corporation will be established, and five regional subsidiaries will be affiliated to the national corporation in North, Northeast, Northwest, East and Central China. A separate power network company for south China will be set up, said Xie. He added that a more appropriate electric pricing system will come into being in the foreseeable future.

Since the founding of the State Power Corporation five years ago, the sales volume of electricity has increased 26 percent, and the net profit has grown 40 percent, according to Xie. In 2001, the corporation ranked the 77th among the world’s top 500 companies.

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