

REAL OPTIONS EVALUATION OF FINANCIAL INVESTMENT IN FLEXIBLE  
MANUFACTURING SYSTEMS IN THE AUTOMOTIVE INDUSTRY

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REAL OPTIONS EVALUATION OF FINANCIAL INVESTMENT IN FLEXIBLE  
MANUFACTURING SYSTEMS IN THE AUTOMOTIVE INDUSTRY

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## VITA

Duoxing Zhang, son of Haoru Zhang and Fengkui Li, was born on September 26, 1962 in Zhenyuan, Gansu Province, People's Republic of China. He graduated with the degrees of Bachelor of Engineering (Railway Engineering), and Master of Engineering (Bridge and Structural Engineering) from Lanzhou Railway College in Gansu Province, China, in July 1983, and July 1986 respectively. He graduated from China Academy of Railway Science in Beijing, China, and received the degree of Doctor of Philosophy in Engineering in December 1990.

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DISSERTATION ABSTRACT

REAL OPTIONS EVALUATION OF FINANCIAL INVESTMENT IN FLEXIBLE  
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Applying financial option pricing theory to real world investment evaluation practice, real option analysis is quickly emerging as a new approach to economic evaluation and selection of strategic investment alternatives in non-financial industries.

The objective of this research is to apply real options theory to evaluate financial investments in flexible manufacturing systems in the automotive industry and help to identify future growth opportunities both in national and international markets. Models were developed to capture the strategic value of management and operational flexibility for capital investments in a flexible manufacturing system.

Financial option pricing models were reviewed with the analogy between financial option pricing and real option analysis discussed in order to establish the real options analysis framework.

An evaluation model was also developed to account for foreign exchange risk for financial investments in foreign countries. Real options analysis was applied to evaluate investments in flexible manufacturing systems in the automotive industry for both the economy of scope and the economy of scale. Advantages and concerns related to the application of real options analysis are discussed with brief comments on future research needs.

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## CHAPTER 1

### INTRODUCTION

The automotive industry represents the largest contribution to the world economy in terms of growth in Gross Domestic Production, growth in employment and job creation, as well as economic growth in other related industries according to Cooney and Yacobucci in their research in 2005 for the United States congress, which indicated that total employment in the automotive industry has increased since 1990 while employment in overall domestic manufacturing has significantly declined. The development of the automotive industry creates a strong demand for production materials such as steel, aluminum, high performance plastics and composite material, electronics and related products, telecommunications, as well as gasoline and diesel fuel from the oil industry.

The North American automotive industry has always been a major contributor of economic growth and employment (McAlinden and Hill 2003). Automobile manufacturers, along with millions of material and component suppliers, have been one of the most important power houses to drive the economic growth. Due to the wide use of motor vehicles as the most common means of transportation, the United States has been leading the world in motor vehicle ownership as a percentage of total population. For

decades the automotive industry in the United States has been the largest in the world in terms of market size, scale and scope of research, development, and production activities.

According to the statistics from the Alliance of Automobile Manufacturers (McAlinden et al 2003), motor vehicles and parts has contributed \$ 444.7 billion or 3.36% to the total Gross Domestic Production in the United States in 2006, representing the single largest contributor in the general manufacturing industry. Total direct employment in the automotive industry is about 1,338,700 workers, while the total employment dependent on the automotive industry is about 6,638,100 with a total wages and benefits of \$ 335 billion.

In an increasingly competitive global market of the twenty first century, the automotive industry is lead by major manufacturers, General Motors, Ford Motor Company, Toyota, Honda, Volkswagen, Chrysler, BMW Group, and quite a few others. All of these companies operate in a global competitive marketplace, with research, development and production operations in all major markets around the world. It is well recognized that the globalization of the automotive industry, has greatly accelerated since the 1990's due to the fast market expansion of the leading automobile manufacturers in North America, Europe, and Japan, combined with fast growth of the world economy, especially in emerging markets.

Increasing global trade and economic integration, fast development of global transportation and communications industry, have promoted the growth in world economy with both cooperation and competition. While American and European auto manufacturers have successfully expanded their operations and sales in all major markets



around the world, Japanese automakers have enhanced their competitive positions in research and development, new model production and sales, as well as more aggressive development and marketing of fuel efficient automobiles. In the years ahead, there will continue to be great potentials for growth and development as well as challenges and opportunities for the American automotive industry. Some of the major challenges and opportunities are: fast paced research and development of new products, especially new technologies and products with improved fuel economy; rebuilding of a strong, long term, strategic alliance between motor vehicle manufacturers and suppliers; more effective investment in research and production capability for market responsiveness and cost effectiveness; and continued global business positioning for competitive advantage in both traditional markets and emerging markets.

In the following two sections major challenges and opportunities facing the automotive industry will be discussed, and the advantages of the application of flexible manufacturing systems in the automotive industry will be commented.

## **1.1 Challenges and Opportunities Facing the Automotive Industry**

### **1.1.1 A More Competitive Business Environment in the Age of Globalization**

More than any other factors, globalization has changed the business landscape in the twenty first century world economy. The automotive industry, with its global operation and global sales to consumers in different countries, is bound to be affected by globalization.

After a full century of development, most of the leading manufacturers in the automotive industry are now located in North America, Western Europe, and Japan, with world wide operations in most countries. Since the three most advanced regions, North America, Western Europe, and Japan, are the mature automotive markets, with low expected sales growth and more or less an over capacity problem, major vehicle manufacturers have been looking for global expansion and growth opportunities in emerging markets: Latin America, North and South Asia, China, India, Eastern Europe, and Russia.

For the automotive industry, globalization is a natural business development of major auto manufacturers in the United States, West Europe, and Japan, as they expanded their operations from their home country to foreign countries to serve customers in foreign markets. As early as in the middle of last century, following the world economic recovery from World War Two, Ford and General Motors played pioneering roles in globalizing automotive technology and manufacturing with new plants in Europe and later in Japan. With the optimistic perception of political and economic trends in the 1950s, Ford Motor Company led the global expansion of the American automotive industry in the 1960s, and established Ford Europe in 1967, 20 years before the formation of the European Economic Community, now the European Union. The company established its North American Automotive Operations in 1971, consolidating U.S., Canadian, and Mexican operations more than two decades ahead of the North American Free Trade Agreement. The global operation of General Motors Corporation has an even longer history, dating back to 1911, when General Motors Export Company was founded

to sell cars and trucks in international markets worldwide. In 1923 General Motors International opened in Copenhagen to build and market Chevrolet cars. The acquisition of Adam Opel AG in Germany in 1929 marked the start of a significant General Motors global operation which has since added value to the company. In the later 1990s, General Motors, Ford Motor Company, and Chrysler, started investment in China, which marked the most recent wave of global expansion. Similar developments towards globalization can be observed for major automobile manufacturers in Europe, Japan, and South Korea.

With the latest development toward globalization in a larger scale, all major automotive companies are truly operating globally. The continued growth of the world economy and fast economic development in the emerging markets, have accelerated the globalization process. While companies and industries continue to benefit from global operation and global sales, business environment around the world has become much more competitive. Cost effectiveness from operations in foreign markets can be reduced by competitive entries. The rising standard of living and cost of material and labor in the hosting countries could reduce the operational profit. New technology and competitive product offerings have to consider the effect of globalization with fast information sharing by customers in different countries. Consumers in the emerging markets are demanding the same level of technology and service available to consumers in the advanced and mature markets. Product development, design, and manufacturing have to take into consideration the possible platform production and information sharing between different operations in different countries. Culture differences, local labor issues, quality material supply, operational risk, and foreign exchange risk have to be considered and

well managed in order for any investment in foreign countries to be successful in the competitive global economy. In spite of the challenges posed by globalization, it also provides huge potentials for global business expansion and integration, successful companies in the automotive industry will be able to manage these challenges and explore the opportunities arising from globalization.

### **1.1.2 Increasing Fuel Cost, Environmental Concerns, and the Application of Advanced Manufacturing Technology**

In the process of globalization and business growth from around the world, technology advancement has played a key role in order for vehicle manufacturers to improve production efficiency, reduce cost, speed up new model development, and be more responsive to changing market demand.

With the recent increase of fuel cost, alternative fuel and hybrid technologies become key issues of public interest. Rising fuel cost and environmental concerns also helped to speed up research and development for alternative fuel and hybrid technology in the automotive industry. These technologies are urgently needed in order to reduce greenhouse gas emission for environmental protection, and to reduce the dependence on foreign oil. With research and development work led by the automotive industry and independent research institutions, alternative fuel and hybrid technology vehicles are perceived by both the general public and the industry as one of the directions for future development. Alternative fuels under research and development include ethanol, natural gas, propane, hydrogen, bio-diesel, electricity, and methanol fuels. These fuels are being

tested and used worldwide in a variety of vehicle applications. However major barriers, especially the economics related with alternative fuel manufacturing and distribution, research and testing with test fleets, new engine design and modification for alternative fuel, and the construction of necessary infrastructure currently prevent the widespread use of these fuels and technologies. In spite of these barriers, the potential social and environmental benefits are huge, nations around the world, especially the United States, Germany and other European nations, and Japan, are committed to alternative fuel research and development. Economic and other incentives are provided to support alternative fuel research, development, and commercialization. Vehicle manufacturers need to actively engage in research and development for future alternative fuel vehicles that will have wide commercial applications and significant market potential.

Hybrid gasoline/electric (and diesel/electric) vehicles are becoming increasingly popular in the United States and other countries. Hybrids combine a gasoline (or diesel) engine with an electrical motor system to improve fuel efficiency. If their use becomes more widespread, they could help improve the overall efficiency of the vehicle fleet and could help reduce oil consumption and greenhouse gas emission. Since hybrid vehicles could provide better fuel efficiency without significant changes to engine design and virtually no change to existing fueling infrastructure, they have gained public acceptance and increasing sales with good profitability. Now many auto manufacturers, including Ford, General Motors, Honda, Nissan, and Toyota are offering hybrid passenger cars and sport utility vehicles for sale to the public. Other hybrid vehicle models and classes are expected in the near future. Rising fuel cost and economic pressure on consumers will

surly help to increase the demand for vehicles with alternative fuel and hybrid technology. Continued research and development in hybrid technology and production of more hybrid vehicles remain a challenge as well as a great opportunity for the automotive industry. Companies with the capability to provide consumers with such technology and products will have a better competitive edge.

Advanced manufacturing systems applying computer aided design (CAD), computer aided engineering (CAE) and computer aided manufacturing (CAM) technologies will continue to be the cornerstones for automotive manufacturers as they strive for fast development of new products and quick response to global market demand. A flexible manufacturing system is one of the most commonly applied manufacturing systems in the automotive industry.

A flexible manufacturing system (FMS) is a form of flexible automation and production in which a set of CNC machine tools are interconnected by an automated material-handling system, and all functions and movements of the system are controlled by a central computer. An FMS is distinguished from an automated production line by its ability to process more than one type of products, and the ability to expand in response to changing market demand. With high speed CNC machines and an inter-connected automatic material handling system, a flexible manufacturing system can be built for medium and large quantity production, and can be shifted to different types of products relatively easily with a change of manufacturing software and quick modification of tools and fixtures.

In the age of globalization and changing market dynamics, a well designed flexible manufacturing system will be a key successful factor for a manufacturing company in the automotive industry.

### **1.1.3 Strategic Positioning for Global Business Growth in Major Markets**

Business expansion from developed countries to developing countries has been in progress since World War Two. The rapid advances of information technology, the accession of more countries to the World Trade Organization, increasing global connectivity in travel, communication, international trade, integration and economic cooperation, have promoted globalization in recent years. The emergence of worldwide production and consumer markets and broader access to a range of goods and services to consumers around the world provided a solid basis for globalization. As the largest manufacturing industry in many developed countries, automotive industry has experienced fast paced globalization in the last twenty years. With advanced technology, long time experience in product design and manufacturing, a strong financial position and valuable expertise in international business management, world leading manufacturers in West Europe and United States have successfully expanded their business operations to other countries, such as Brazil, Mexico, China, India, and East European countries. The strategic positioning of product development and manufacturing facilities in the emerging countries allow the investing companies to better serve the local markets with a cost advantage, while the economic benefits from such global investment can be used to support even more advanced technology development and production restructuring in the

home markets. This successful global business strategy has been followed in one way or the other by major auto manufacturers from Europe, United States, Japan, and South Korea.

As have been widely recognized, investment and cooperation are essential in securing shares of major international markets, which in turn will help the investing company gain sales and earnings from all markets in the world, and thus build a globally integrated and balanced business strategy. The profit generated from international operations could be used to better meet the competitive challenges in the home market, and put the company in a more competitive position in the world markets.

## **1.2 Flexible Manufacturing Systems for Market Responsiveness and Competitive Advantage**

The changing customer demand, a more competitive business environment in the domestic and international markets, global business expansion, and the application of new technologies in production design and manufacturing in recent years have brought about a change in manufacturing systems in the automotive industry from mass production systems to flexible production. Flexible manufacturing systems played a key role in this transformation of production system design and configuration in the automotive industry.



### **1.2.1 Flexible Manufacturing Systems and Their Application in the Automotive Industry**

A traditional flexible manufacturing system (FMS) is an arrangement of machines interconnected by a part transport system. In the early days of application in the manufacturing industry, flexible manufacturing systems were often applied in the design and configuration of job shops where different types of parts and components can be processed in a small batch size. The key benefit from an early flexible manufacturing system is the capability to process more than one type of part with the same set of machines and equipment. Those systems were ideal for part suppliers serving many customers with low to medium quantity but large part variety.

With the development of computer science and its application in the industry, advanced processing control technologies, such as Programmable Logical Control (PLC) and Computer Numerical Control (CNC) were developed and applied in the manufacturing industry since the 1970s up to the present time. The need for high volume production with higher productivity and efficiency, as well as the need for the capability to produce different parts without major retooling cost, have promoted the design of much more efficient flexible manufacturing systems with automatic control and material handling capability. These modern flexible manufacturing systems were used in major manufacturing plants in the automotive industry and other industries around the world. They were well designed for medium and high volume production with large batch size, with the flexibility to change quickly from one type of product to another (Upton 1992).

With flexible manufacturing systems, manufacturers could easily change the type of product to be produced by the selection of a different part processing control program integrated with the CNC machines and the material handling system, and modify tool settings accordingly in a relatively short period of time. And the system could be set up for high volume production of another type of product quickly. The capability of fast change over to produce different types of products at high production rates offered by flexible manufacturing systems, created a strategic advantage in reducing production cost, extended effective service life time of the production system, better investment effectiveness for long term production, and quick response to market demand. These advantages offered by flexible manufacturing systems are of strategic value to manufacturing companies in the automotive industry, where high volume production of quality products and quick change over for the manufacturing of different products in response to changes in market demand are key factors of success.

Because of the cost benefits and operational advantages generated with flexible manufacturing systems, companies in the automotive industry, including original vehicle manufacturers and part and component suppliers, have embraced the flexible manufacturing concept and have successfully implemented flexible manufacturing systems in their production facilities in the United States and in their overseas operations. Due to the competitiveness of the automotive industry and the large population of motor vehicle ownership in the United States and in other countries around the world, production systems in the automotive industry have to be designed and managed in such a way that allows for high volume production with high efficiency, yet makes it possible

for a quick change of product type in response to changes in market demand without incurring too much retooling cost. Well designed and managed flexible manufacturing systems, could be better solutions for production in the automotive industry than dedicated production lines. Companies which successfully implemented flexible manufacturing strategy are able to achieve the long term benefits from high volume production for the economy of scale and wide variety of production for the economy of scope. Companies doing well in both aspects will have a better perspective for sustained business growth and success in the long run.

### **1.2.2 Essential Components of a Flexible Manufacturing System**

The key components of a flexible manufacturing system include:

(1) Processing machines arranged in line with the part processing sequence. These machines are usually CNC machines that perform processing operations on certain parts and components. Other types of automated workstations such as inspection machines may also be included in a flexible manufacturing system.

(2) An automated material-handling system, such as an overhead automatic loading and unloading system combined with conveyors for complete transport of parts and components throughout the flexible manufacturing system. The material handling system is also electronically inter-connected with all the machines for electronic information exchange for part loading and unloading.

(3) A central computer system that is responsible for the inter connection and information exchange between each machine and the material handling system,

coordinating the movement of the grippers in the automatic material handling system for timely loading and unloading of work parts. Part machining or processing programs are pre-loaded into each machine in the flexible manufacturing system for production of different types of parts.

### **1.2.3 Advantages and Disadvantages of a Flexible Manufacturing System**

The main advantages of a flexible manufacturing system are the short change-over time for production of different types of products, and the capability of medium to high volume production to achieve the benefit from cost effective high volume production.

In a flexible manufacturing system, a family of different type of products can be produced according to their demand. The advantages of a flexible manufacturing system may include:

#### **(1) Flexibility to Accommodate Changing Market Demand**

A flexible manufacturing system is designed to produce a variety of products using the same set of machines, thereby reducing total investment in manufacturing facilities as compared to the total investment otherwise required for several dedicated production lines. The higher the degree of flexibility of the manufacturing system, the shorter the change over time, the lower the retooling and reconfiguration cost will be in order to produce a different type of product. In the highly competitive automotive industry, changes in customer preference, changes in the general economic condition, such as rising interest rates or rising fuel costs in particular, could change the market

demand for different types of vehicles. Recent fuel price increases since 2005 have promoted the demand for smaller and hybrid vehicles, automobile manufacturers and part suppliers would be better off if they have more capability in flexible manufacturing. This will allow management to switch production activity from large vehicles to smaller models and hybrid models. The revenue lost in reduced sales of large cars and sport utility vehicles, can be balanced out with increased sales of smaller models and hybrid vehicles. A challenge could be turned into an opportunity.

(2) Production with Better Research and Development Capability to Promote Cooperation between Original Vehicle Manufacturers and Suppliers

For both original vehicle manufacturer and part suppliers in particular, the flexibility to produce new products on existing machines in the same flexible manufacturing system or manufacturing cell is especially valuable in terms of new product research and development. Suppliers with flexible manufacturing capabilities are better qualified and more competitive in terms of cooperative research and development of new products with their customers. The cooperative partnership between auto manufacturers and part suppliers are beneficial for the long term growth and success of both parties.

(3) Production for High Volume and High Profitability

Due to technology advancement in the manufacturing process, in computer aided design and engineering, in automatic material handling systems, as well as in the machine tool industry, most of the modern flexible manufacturing systems are built with machines with high processing speed, short cycle time, and high processing accuracy, combined

with automatic material handling system and appropriate operation and maintenance, these flexible manufacturing systems have the capacity of running high volume production once a new type of part is set up. This capability of high volume production has made flexible manufacturing systems valuable to the automotive industry and other industries where the economy of scale is important for the success of the business, since revenue and profit depend on sales of a large quantity of products.

(4) Quick New Product Launch and Short Time to Market

An important advantage of a flexible manufacturing system is its capability to convert quickly from making an existing line of products to producing a new product. This capability is apparently important in today's competitive global business environment, where products are constantly being modified or redesigned to fit customer needs. Freshly designed new products need to be produced and tested internally before going into high production for the consumer market. The capability of flexible manufacturing in terms of variety of products to be produced offers a great deal of competitive advantage to automobile manufacturers and suppliers alike.

(5) Reduced Labor Cost

Due to the large reduction in number of operators required in order to run the production line designed as a flexible manufacturing system, great savings in labour cost can be achieved. On the other hand the one or two operators, who will be running the manufacturing system with an automatic process control panel, will need to be more knowledgeable about the whole manufacturing system, as compared to knowing just one or two machines. Even though additional training of the operator may cost more than the

training cost of an operator for a single machine, the total labor cost savings will far outweigh the additional training cost for the flexible manufacturing system.

*The main disadvantages or challenges related to a flexible manufacturing system are as follows:*

(1) Large Initial Investment

To achieve a higher degree of manufacturing flexibility with a relatively high volume of production, an efficient flexible manufacturing system has to be designed and implemented with CNC machines and processing stations. These machines and work stations must have a fairly large range of processing capabilities which can be adjusted according to different production requirements. Also they must be able to be interconnected with the automatic material handling system for automatic production. The investment required for such CNC machines and the material handling system in order to set up a flexible manufacturing system will be larger than the investment required for a simple, dedicated production line, or a production line or production cell without automation.

(2) Substantial Technical Planning and Design Requirements

Because an automated flexible manufacturing system requires sophisticated machines and an automatic material handling system, substantial technical planning and design work is required. Process and plant design engineers will need to work together with machine and equipment suppliers to finalize the flexible manufacturing system design. Companies with adequate technical capabilities and technical personnel resource

tend to do a better job in planning and design of a flexible manufacturing system. For companies less competitive in technical and personnel resources, the task to design a flexible manufacturing system could be a challenge.

### (3) Extensive Training on Operational and Maintenance Team

In order to operate a flexible manufacturing system successfully for its intended objective, and fully achieve its potential in production efficiency and flexibility, all the operation and maintenance personnel has to be well trained to understand the function and operation requirement of the system. Operators must have the capability to monitor the operation of all machines and the material handling system, physically and electronically through the central control computer, and they must be able to understand each process in the system, and be able to modify processing parameters related with each machine and the material handling system. The maintenance team must be able to carry out mechanical, hydraulic, electrical, and electronic maintenance for all machines and the material handling system. Part programming capabilities are required for both operators and maintenance staff. All these technical requirements can only be meet with a motivated, technically capable workforce with constant training and learning on the job. Once such a competitive workforce is in place, it will be a very valuable asset to the long term success of the manufacturing company.

## **1.3 Research Objective and Plan of Study**

According to many examples of real world application, flexible manufacturing systems can provide significant long term benefits to a manufacturer. Unfortunately, the



investment required for a flexible manufacturing system is often considerably higher than the investment required for a dedicated, simple machining system. The flexibility to switch production from one type of product to another, and the capability to expand manufacturing capacity for higher volume of production, as well as many other technical requirements for production flexibility, will require additional capital investment at the time of such expansion in the scope of production and or in the scale of production.

Financial evaluation of investment in flexible manufacturing systems has been one of the major topics of interest in manufacturing and production management as well as in engineering economics. The primary objective and the unique contribution of this research is to evaluate financial investment in flexible manufacturing systems in a real options framework. Major aspects of the economic evaluation are specifically considered in relation to the challenges posed by market demand uncertainty and the relatively large investment requirement for flexible manufacturing in the automotive industry. Models will be developed to account for the risk associated with investment in flexible manufacturing capability, as well as foreign exchange risk involved in financial investment in flexible manufacturing systems in the automotive industry in international markets. While traditional discounted cash flow evaluation techniques, such as the widely accepted net present value (NPV) evaluation may provide an relatively accurate estimate of the economic contribution from an investment project with a fixed path of action, real options analysis, as a complementary approach to investment analysis, is better suited for investment evaluation with a higher degree of uncertainty and more flexibility in making phased investment decisions according to market development. In

this research real options analysis of financial investments in flexible manufacturing systems will be carried out and compared with traditional discounted cash flow evaluation. Appropriate recommendations will be given for the application of each of these methods for investment evaluation.

Chapter 2 will present a review of the relevant literature addressing flexible manufacturing system and its application in the industry, with emphasis on the automotive industry. Different methods of economic evaluation of financial investment in flexible manufacturing systems will be reviewed and compared. The need for real options thinking in strategic investment planning, and the application of a real options approach to the investment evaluation in flexible manufacturing systems will be discussed.

Chapter 3 will provide an overview of real options analysis. The analogy from financial options to real options will be discussed in this chapter. The framework for real options evaluation of financial investment in real assets will be established in analogy with financial options pricing theory. Estimates of key parameters in real options evaluation will be discussed briefly with comments on some of the concerns and difficulties. The development of the financial option pricing model is presented in the Appendix at the end of the dissertation.

The economic benefits of a flexible manufacturing system will be described in Chapter 4. Potential economic benefits of a flexible manufacturing system, pending future market development, will be estimated with real options analysis; while realized economic benefits from a flexible manufacturing system will be reflected by the increase

in revenue and reduction in cost, captured by an operation cash flow model developed in this chapter.

Model development for real options evaluation of financial investment in foreign countries will be presented in Chapter 5. Strategies of foreign exchange risk management for financial investment in foreign markets will be discussed, and a model for considering foreign exchange risk in real options evaluation will be developed.

One of the critical parameters in real options analysis is the volatility of investment project value. A unique model is developed in Chapter 6 to estimate the volatility of future project value for investment in flexible manufacturing systems, with special consideration given to the operational flexibility in capability expansion.

Chapter 7 will describe a typical example of the application of real options evaluation for investment in a flexible manufacturing system in an automotive part manufacturing plant in a foreign country, where foreign exchange risk will be considered in real options evaluation. The results of real options analysis will be compared with traditional discounted cash flow evaluation, to indicate that real options evaluation is a complementary approach to traditional models of evaluation, and real options analysis is particularly appropriate for the evaluation of investment with a high degree of uncertainty.

Chapter 8 will present an application of real options evaluation of a flexible manufacturing system for the production of automotive electronics. The benefit of the economy of scale offered by a flexible manufacturing system will be evaluated with a real options model to expand production capacity in response to increased market

demand. Concluding remarks and comments on future research needs will be presented in Chapter 9.

## CHAPTER 2

### LITERATURE REVIEW

#### **2.1 Introduction**

Every year corporations in various industries around the world are making large investments in research and development, in new product design, as well as in production and operation facilities in both home markets and international markets in order to provide better service to customers and stay competitive in their industries.

With increasing technology advancement and global economic cooperation and competition, more than ever before, economic evaluation of investment project in the manufacturing industry becomes more and more important in the management decision making process. Careful investment evaluation, market research, and competitive advantage assessment have therefore become indispensable steps to reach a well informed, strategically correct investment decision.

In the automotive industry, where globalization has long been a reality for more than a century, competition at home and abroad has intensified in recent years. Leading manufacturers in the automotive industry invest large amount of funds each year in research and new vehicle technology development in order to have a competitive edge in new product development. Financial investments are also made to upgrade or build new

manufacturing facilities for the production of existing and new models of different types of vehicles for different market segments. Both original vehicle manufacturers and part and component suppliers are making investments to expand their production capability in both home and international markets. Because of their apparent advantage to switch from production of one type of product to another, to expand production capacity, as well as to benefit from longer service life, modern flexible manufacturing systems have gained wider application in the automotive industry as well as in other manufacturing industries. Due to the relatively large initial investment and the need to plan for phased expansion or reconfiguration investments, traditional discounted cash flow (DCF) techniques of economic evaluation may not be able to fully capture the benefit from flexible manufacturing systems. Real options analysis, on the other hand may provide a better framework for the economic evaluation of financial investment in such systems.

A brief literature review will be provided in this chapter to understand the current state of research activities in flexible manufacturing systems and their applications; methods of economic evaluation of investment in flexible manufacturing systems; and the application of the real options approach in the evaluation of investments in flexible manufacturing systems.

## **2.2 Flexible Manufacturing Systems in the Automotive Industry**

The dramatic improvement in quality and productivity by some of the Japanese automobile manufactures in the last ten to fifteen years has in large part been contributed to the successful implementation of advanced manufacturing technology and lean

production principles in the design, production, and management activities in those companies (Mansfield 1993, Kaighobadi 1994). In addition to their book about the lean manufacturing and Toyota production system, Womack, Jones, and Roos in their famous 1990 book, *The Machine That Changed the World*, provided a comprehensive description of the entire lean system and the promising future of its application in the automotive industry, where it would replace mass production as a better manufacturing strategy. Flexible manufacturing systems, identified as one of the advanced manufacturing technologies (Kaighobadi et al 1994) with wide applications, when well designed in line with lean manufacturing principles and automation capability, could enable flexible production of various types of products in relatively high volume in order to meet the need for the economy of scale in the automotive industry, allowing companies to stay competitive and responsive to changing market demand with the efficiency of high volume production and a relatively wide scope of supply. According to a review by Kaighobadi and Venkatesh, the number of flexible manufacturing system installations has increased sharply from 1980s to 1990s, many of them are related with production activities in the automotive industry. It is well recognized that the success of a flexible manufacturing system largely depends on the degree of commitment of the top management and the technical and operational team in the plant where the flexible manufacturing system is installed (see also Small 2006). Contrary to common belief that the application of flexible manufacturing systems is limited only to large corporations with huge financial resource, successful cases of flexible manufacturing systems installation were reported with small firms as well. Edwin Mansfield (1993) provided a

sound review of the wide application of flexible manufacturing systems in Japan, Europe, and United States. By 1987 based on available data from 175 major firms in the automotive industry, aerospace industry, machinery, and electronic equipment industries, Japanese companies had the highest rate of application of flexible manufacturing systems in their production activities. Aerospace and automotive industries were the leading industries embracing flexible manufacturing technology. Computer-controlled manufacturing programming (Upton 1992, Milling 1997, Kaighobadi et al 1994) has been identified as a key technical component for information exchange and automatic control of flexible manufacturing systems.

Early examples of the application of flexible manufacturing systems in the automotive industry and other industries include: General Motors Pontiac Division, Saturn plant, Cadillac Livonia engine plant, General Motors Buick City, and locomotive plant in Pennsylvania; Ford Motor Company Sterling Heights transmission and chassis-axle plant; Chrysler Toronto plant; Hughes aircraft plant in California, Pratt and Whitney plant in Georgia. With the global expansion of the major automotive companies from the United States, Europe, Japan, and South Korea, more production facilities are built with flexible manufacturing systems in countries of the emerging markets.

### **2.3 Methods of Investment Evaluation for Flexible Manufacturing Systems**

With the increasing trend of the application of flexible manufacturing systems in the automotive industry and other industries, corporate executives and plant managers have come to a better understanding of the benefits of product flexibility and long term



manufacturing efficiency offered by flexible manufacturing systems. Due to the relative large financial investment required and the technical complexity involved in design and implementation of a flexible manufacturing system, and due to the need for financial accountability in every investment project, companies that intended to implement flexible manufacturing systems have to perform a careful economic evaluation of financial investments in such manufacturing systems in order to make sure that while strategically beneficial with advanced technology, product offering flexibility, and production efficiency, flexible manufacturing systems do provide positive economic value to the investing company. In other words, strategically beneficial projects have to be economically successful in order to justify the required investment and increase the value of the company. Since the early 1990s, a large number of academic research and business analysis papers have been published on investment evaluation of flexible manufacturing systems (Chen and Small 1996, Burcher and Lee 2000, Ajah and Herder 2005).

In an early survey of capital budget methods, Schall, Sundem and Geijsbeek Jr. presented their findings in 1978 in *The Journal of Finance*. Out of the 189 responses from large corporations in the United States, 86% of the companies used the Internal Rate of Return (IRR) or Accounting Rate of Return (ARR) in capital budgeting practice, 74% of the responding companies used the Payback Period (PBK) to compare investment projects, while 56% of the companies applied Net Present Value (NPV) analysis in capital budgeting. Of all the companies responding to the question of risk consideration in capital budgeting, 90% raised the required rate of return or the discount rate in NPV calculation to account for added project risk.

John Graham and Campbell Harvey reported in a more recent survey in 2001 of 4440 companies about corporate capital budgeting and capital structure. Out of the 392 companies that responded, the survey found that most respondents cited net present value (NPV) and internal rate of return (IRR) as their most frequently used capital budgeting techniques; with 74.9% of CFOs always or almost always using NPV, and 75.7% always or almost always using IRR. However, large companies were significantly more likely to use NPV than were small firms. Other than NPV and IRR, hurdle rates and payback period was the most frequently used capital budgeting technique by 56% of the companies. After IRR, NPV, hurdle rates, payback period, and sensitivity analysis, real options analysis was used in capital budgeting by 27% of the companies, this reflected a significantly increasing application of real options analysis in corporate investment evaluation since the last survey in 1978 by Schall and others, in which non of the responding companies indicated the use of real options evaluation in capital budgeting.

Even though real options analysis is a fairly new capital budgeting technique, over a quarter of the companies participated in the 2001 survey reported using it in their investment evaluation. It is believed that the increasing application of real options analysis in corporate investment evaluation since the later 1970s reflected the following facts:

(1) With the wide application of financial option pricing theory and increasingly large volume of trading activities in financial options on stock and stock indexes, interest rates, foreign exchange, as well as real metals and other commodities, the research on the

application of financial options theory to value options on real assets, has advanced in the last 30 years since Myers (1984) first coined the term “Real Options”.

(2) In a much more competitive global market environment, investment decisions often have to be made in a more complex financial and operational environment with a lot of uncertainty. While based on sound financial principles of the time value of money and corporate cost of capital, traditional discounted cash flow analysis, such as NPV, IRR, and Discounted Payback Period analysis, can not fully account for the risks and flexible opportunities associated with the uncertainty in financial investment in various industrial projects. Additional complementary methods of economic evaluation of financial investment in real assets must be developed and applied appropriately to offer insights into the strategic value in some of the long term industrial investment projects.

More detailed comments and discussions about the application of real options analysis in financial investment in the automotive industry and other industries will be given in the next section.

## **2.4 Real Options Evaluation of Investment in Flexible Manufacturing Systems**

The effective allocation of capital resources for the best interest of long term strategic growth and profitability is the key objective of capital budgeting for companies in the manufacturing industry. With the global operation and global competition of the automotive industry, both vehicle manufacturers and part suppliers are striving to stay competitive and profitable for sustained business growth. Manufacturing facilities must

be built to meet current and future production requirements in product variety and quantity, automated flexible manufacturing systems could fit well into those requirements.

Over the last few decades many financial analysis and economic evaluation methods have been developed and successfully applied to guide the capital budgeting and investment evaluation process in various industries. Some of the most widely accepted and practiced methods of economic evaluation of industrial investments are based on Discounted Cash Flow (DCF) evaluation, such as net present value (NPV) and internal rate of return (IRR) analysis. Recent research and advances in Real Option Analysis (Park and Son 1988; Nembhard, Shi, and Park 2000; Herath and Park 2000; McGrath 2000; Miller and Park 2002, 2004) has added an important complementary approach to economic evaluation of financial investment in various industries.

For many years discounted cash flow analysis has offered straightforward evaluation of investment performance in terms of project net present value, project internal rate of return, discounted payback period, and profitability index. In applying discounted cash flow analysis, the risk associated with capital investment projects in the industry, both public and private, could be reflected by the application of capital asset pricing model (CAPM) and the weighted average cost of capital (WACC) model, with special adjustment for investment projects with particular concerns of higher risk to determine an appropriate discount rate. It is also widely recognized that discounted cash flow analysis is based on a static project setting with fixed investment timing and fixed set of expected investment outlays and cash inflows.

As Slagmulder and Bruggeman (1992) and many others pointed out, traditional accounting and investment justification techniques may lead to myopic investment behavior, and inevitably creates a bias against strategic investment in new technology which could involve higher degrees of uncertainty and management flexibility. Discounted cash flow calculations can not capture the full range of strategic benefits offered by a flexible manufacturing system, such as higher quality, quick response to changing market condition, and the option to expand production capacity or add new products. New methods of evaluation have to be developed for the justification of investment in flexible manufacturing systems.

In a comprehensive review of different investment evaluation methods, Frank Lefley (1996) pointed out that although considerable potentials can be offered by new technology to deal with strategic challenges facing manufacturers today, it is still difficult to fully evaluate the strategic benefits brought by the application of advanced technology in the manufacturing process, such as the benefits associated with flexible manufacturing systems. Lefley also stressed the importance of a shared vision to balanced needs of technology advancement and financial performance by top management, financial accounting officers, plant managers and design engineers. In his review of the models of economic evaluation of capital investment in flexible manufacturing systems, the Kaplan Model, a traditional NPV plus the value of strategic benefits was recommended. In the early years when real options analysis was not widely applied in capital investment evaluation, strategic benefits were often evaluated in terms of qualitative advantages such as technology advancement, market competitiveness, and long term business objectives.

Michael Small (2006) proposed a portfolio analysis to justify investment in advanced manufacturing technology.

Complementary to traditional discounted cash flow evaluation, real options analysis, on the other hand, provides a new view and new approach to capital budgeting and financial evaluation, which combined financial options pricing theory and discounted cash flow method to assess the benefit and risks associated with real world industrial investments. Of particular importance is the capability of real options analysis to capture the value of management and operational flexibility in many investment projects, such as investment in flexible manufacturing systems. With the advancement in real options analysis in recent years, it is possible to analyze the strategic benefits of a flexible manufacturing system in financial terms. The added strategic value created by a flexible manufacturing system will help corporate executives and financial managers to get a better understanding of the true value offered by such systems, and to be confident in financial investment in flexible manufacturing systems, knowing that such systems will add economic value and strategic competitiveness to the company.

CHAPTER 3  
OVERVIEW OF REAL OPTIONS ANALYSIS: FROM FINANCIAL  
OPTIONS TO REAL OPTIONS

Financial analysis and economic evaluation of industrial investment has been one of the major topics in the field of engineering economics. Appropriate evaluation of financial investment in different types of business activities and projects is an important aspect of corporate finance and capital budgeting, which is aimed at the appropriate allocation of a limited capital resource to a well planned and optimized portfolio of long term and short term investment projects, in such a way that the market value of the company and the wealth of the shareholders will be maximized. Financially sound and successful performance of major investment projects will lead to the success of the investing corporation, with enhanced business competitiveness and increased shareholder value; on the other hand, it will be very difficult to run a successful business with many failed investment projects. The financial success of any business depends on the success of different operations and projects the business has invested in.

During the last few decades, the world has experienced increasing technology advancement with increasing international trade and economic involvement. Globalization has affected every industry in almost every country. Large corporations and

small businesses around the world are making development plans in a global context. Tremendous business opportunities have become available for virtually all businesses in all industries. At the same time, a dynamic global market competitive landscape with changing customer demand has brought up serious risk issues to be addressed by corporate financial managers and executives. Even within a domestic or regional market, competitive pressure, diversified market demand and customer preference, factors related with regional and global economic environment, will require companies in any industry to perform a sound financial evaluation of the estimated risk and return from all possible business opportunities before investment decisions can be made. Across different industries companies are striving to apply advanced technology to pursue new business opportunities while increasing flexibility and market responsiveness, with a common objective of higher productivity, reduced business risk and operation cost, improved profitability, and enhanced overall competitive position in the industries they serve.

Sound economic evaluation of financial investment in different projects will help to define the best strategy for the allocation of limited capital resource so that both current and future operational objectives are met, with long term business competitiveness improved and shareholder value increased. Based on the principles of the time value of money and with the objective to maximize shareholder value, traditional discounted cash flow (DCF) analysis has served the needs of corporate capital budgeting for decades. In the last ten to twenty years, with the increasing trend of globalization and international economic cooperation in trade and foreign direct investment, corporations in many industries are facing a wide range of investment and business opportunities both in



their home country and in foreign countries. The diversified investment opportunities coming with globalization and technology advancement provided unprecedented opportunities for growth and prosperity, and at the same time posed greater risk to financial investments and business management in general. Investments in many industries are often faced with more uncertainty and risk.

Developed from the financial option pricing theory, real options analysis of financial investment in real assets in various industries has emerged as an alternative method of economic evaluation of financial investment in real industry projects. Complementary to the traditional discounted cash flow evaluation, real options analysis tends to provide a better appreciation of the flexibility in making strategic investment decisions with different operational choices, and strives to evaluate the benefits from such strategic investment opportunities in financial terms. In the last ten to fifteen years, real options analysis has been applied to evaluate financial investments in many different industries, such as new drug research and development in the pharmaceutical industry, system design and infrastructure construction in the information technology industry, oil and natural gas exploration in the petroleum industry, land development in the real estate industry, maintenance, overhaul, and repair services in the aerospace industry (Miller and Park 2004), as well as flexible production planning in power generation and the energy industry. This chapter will give an overview of the basic financial options pricing theory, as well as the application of financial option pricing theory in real world investment evaluations involving investment in real assets. The basic framework for real options analysis will be described along with key valuation factors.

### **3.1 Financial Options Pricing Theory and Its Applications**

With the world economic recovery and development since World War Two, corporate finance theory has made many advances to allow financial executives and business managers understand how capital markets work and how financial and real assets may be evaluated with consideration of risk related to such assets. Many economic evaluation techniques have been derived from finance theory, with discounted cash flow analysis, being the most widely accepted method of economic evaluation for financial investments in different industries.

In the 1970s, another influential advance in economy and finance theory was made with the development of the financial options pricing model. Robert Merton (1973, 1998) was the first to publish his research expanding the mathematical understanding of the options pricing and created the term "Black-Scholes" options pricing model, in recognition of the earlier landmark work by Fischer Black and Myron Scholes. In his work on rational option pricing in 1973, Merton gave a full description of the structure of financial call and put options, and derived a mathematical formula for the pricing of financial options. The fundamental insight of Black-Scholes financial option pricing model is that an option can be implicitly priced with observable variables of the underlying stock if the stock is publicly traded.

Since the publication of Black-Scholes model in the 1970s, trading activities of financial options, including options on stock, options on foreign exchange, options on commodity, options on interest rate and other financial derivatives have increased

tremendously, allowing corporations and individual investors to hedge and manage investment risks in financial markets.

A detailed review and discussion of the general assumptions and the development of the Black-Scholes financial option pricing model, which will be applied for real options analysis of financial investments in flexible manufacturing systems in the later chapters of this research, is presented in Appendix A at the end of this chapter.

### **3.2 From Financial Options to Real Options: The Applications of Option Pricing Theory to Industrial Investment Evaluation**

With the development of financial options pricing theory since 1970s, and in particular after Robert Morton and Myron Scholes received the 1997 Nobel Price in Economics Science for their work on option pricing, trade in financial options have continued to increase at all major financial exchanges around the world, allowing investors to hedge and manage financial risks associated with their investments.

The unique characteristic of financial options comes from its capability to provide investors with an opportunity to take full advantage of an upward market movement while limit their risk in case of a downward market movement. The successful application of financial options in the management of economic risk associated with financial assets, lead to the analogy of real world investment in the non-financial industries to investment in financial markets. Since the concept of “real options” was created in 1977 by Stewart C. Myers of Massachusetts Institute of Technology (see also Myers 1984), real options analysis has been developed and applied to evaluate

investment in real assets in many industries, such as new drug research and development in the pharmaceutical industry. Complementary to the traditional discounted cash flow evaluation, real options analysis offers a new perspective to corporate investment in different industries. One of the benefits of real options analysis is that strategic investment can be viewed as phased investments, where one phase of the total investment may lead to future investment and growth opportunities if the market development is favorable; if the market development turns out to be unfavorable, the investing corporation could still continue with the original operation serving the current needs of its customers while looking for better investment opportunities in the future, or choose to terminate the current operation if the market for current products is diminishing. The application of real options evaluation could provide a better insight into future opportunities of business growth, and justify financial investment in real world projects that will have a long term impact on the sustained growth and profitability of corporations in many industries.

Real option analysis recognizes that in a world of economic globalization and international business cooperation, the business environment in any industry will be dynamic, competitive, and uncertain. Financial managers and top executives in a wide variety of industries have to identify and evaluate major opportunities in different lines of business as well as in different regions of the world market, in order to make investment decisions that will increase the value for the shareholder in the long term. It should be noted that in the development of financial option pricing theory (see Appendix at the end

of the dissertation), a number of assumptions were made in order to obtain the Black-Scholes model.

### **3.3 Evaluation of Investment Projects in a Real Options Framework**

In a competitive business environment, companies in most industries are fully aware of the fact that profitable investment opportunities are few and far between, limited capital assets have to be allocated to a limited number of projects according to long term business strategies. Prudent business planning and careful investment evaluation of feasible investment alternatives become indispensable steps to reach well informed and strategically correct investment decisions. Real options analysis provides a complementary approach to discounted cash flow evaluation. In fact the discounted cash flow concept played an important role in estimating current project value, before the real options model could be applied to value an investment project with different phases. A clear framework of real options evaluation will be described in this section with key evaluation parameters discussed and compared with that in financial options pricing.

Although the concept of real options was created thirty years ago, significant application of real options analysis in corporate capital budgeting started in the late 1980s and early 1990s, when real options analysis theory had been better developed, and more competitive international and domestic business environment required more strategic thinking and long term business planning, and when technology advancement in many industries opened up new business opportunities with higher degrees of uncertainties. Rapid changes in technology and market demand require corporations to be responsive to

changing market conditions and to be flexible in product offerings and business operations in general. Real options analysis, combined with traditional discounted cash flow models, offers an important alternative approach to investment evaluation in many industries. Typical examples of successful application of real options analysis to investment evaluation include investment projects in: new drug research and development in the pharmaceutical industry; electrical power generation with different fuel options and different scales of production; patent and license valuation in oil and natural gas exploration and development; mining for precious metals and other mineral resources; land development in the real estate industry; research, development, and infrastructure construction in telecommunication and information technology industries; inventory control, logistics, and outsourcing decisions; and flexible production systems in the manufacturing industry.

In the perspective of real options analysis, financial investment projects in various industries can be classified and analyzed as real call options and real put options.

### **3.3.1 Industrial Investment Projects as Real Call Options**

Industrial investment projects that could be classified as “real call options” may include but are not limited to the following investment scenarios:

(1) ***Delay Options:*** The Investor may choose not to invest immediately in a certain project, but instead to hold the investment project for a limited period of time while the investment opportunity is still open. The investor may take the time to analyze the risks and benefits associated with the project under consideration, uncertainty in market demand and competitive dynamics, and look for other competing investment

opportunities. Real option analysis in such scenarios will give the investor some indication of the value in the decision making flexibility to postpone the investment to a future time.

**(2) *Patent and License Evaluation:*** The investor has to decide whether to pay to enter into an agreement for production, marketing and selling of a certain product applying patent technology; or to pay and enter into a license agreement to have the right to produce and sell a product for a certain period of time; or have access and permission to use a piece of land for commercial exploration or mining during a period of time stated in the license agreement. The objective of real option analysis in such cases is to give a fair indication of the present value of the patent or license agreement to the investor should such an agreement be reached. The investor would compare the fair value of the agreement with the cost to enter into such an agreement, and thereby make the investment decision.

**(3) *Growth Options:*** In a growth option scenario, the investor is planning to invest in an initial small scale project, if all internal and external events are favorable after the initial project is undertaken, the investor will continue to invest in a larger scale project. The real option analysis in this case helps the investor to value the flexibility to invest in larger scale projects if events are favorable. The possible loss on the initial small scale project is viewed as the premium paid for the growth option at a late time. The growth option approach can be applied to evaluate industrial investment projects in phased production, as well as production or entire business expansion from local, to regional and global markets.

(4) **Research and Development:** Many companies in the pharmaceutical industry and other technology intensive industries, such as information technology and telecommunication industries, have to invest heavily in technology advancement in order to maintain a leading position and profitability. In many cases, investment in research and development pave the way for successful production and operation profitability in the future, therefore cost of research and development is viewed as a premium for a real call option to invest in future production and sales.

### **3.3.2 Industrial Investment Projects as Real Put Options**

Similarly, put option theory can be applied to analyze investment alternatives in the real world where certain projects fail to meet initial expectations for financial return due to changes in internal and external conditions, as well as changes in the market competitiveness of the investing firm or the products related with the investment project. In such cases, the investor has the option to do one of the following:

- (1) Abandon or sell off the project and related assets.
- (2) Switch the investment project to produce other types of products or services which are more competitive and more profitable.
- (3) Scale down the investment project and phase off the products that are no longer competitive.

In all the scenarios described above, Black-Scholes model or Binominal lattice model can be applied to solve for the value of the real put option, with all necessary



parameters be estimated from the real world project that has to be sold off, switched to other applications, or scaled down. The value of the real put option obtained in such analysis process will give an indication of the real present value of the investment options or alternatives to abandon, switch, or scale down certain projects that are not as successful as expected. The investor would compare these option values against the financial consequences of continuing the original project, and choose an appropriate course of action.

### **3.4 Essential Parameters in Financial Options and Real Options Evaluation**

The fundamental difference between financial option analysis and real option analysis is that financial option analysis involves underlying financial assets, such as stocks and foreign currencies, which are publicly traded in the open market and have a higher degree of liquidity, while real option analysis involves underlying assets that are real assets, and in most cases those real assets, such as investment projects, are not traded in the open market and have a relatively very low degree of liquidity. The implications of such difference in financial option pricing and real option evaluation will be discussed in Chapter 9.

In applying financial option theory to real option analysis of different investment opportunities, the first and the most important step is to analyze the investment project, and estimate its key economic values and evaluation parameters, so that the investment project can be fit correctly into the real options analysis framework. Table 3.1 shows the structural analogy between the properties of financial options and that of real options.

**Table 3.1 Properties of Financial Options and Real options**

<i>Financial Options</i>	<i>Real Options</i>
Call option on stock	= Opportunity to undertake a future investment project
Call option price, $c$	= Current value of the future investment opportunity, $c$
Put option on stock	= Opportunity to abandon a project in the future
Put option price, $p$	= Current value to abandon a project in the future, $p$
Current stock price, $S_0$	= Present value of future project cash flows, $V_0$
Strike price, $X$	= Investment required for future project, $I$
Time to expiration, $T$	= Time to make future investment decision, $T$
Risk free interest rate, $r$	= Risk free interest rate, $r$
Stock dividend yield, $q$	= Percentage cost to keep the investment opportunity, $q$
Stock return volatility, $\sigma$	= Future cash flow volatility if the investment is made, $\sigma$

With the analogous relationship between stock options and the corresponding real options established in Table 1, we can set up any industrial investment project in the framework of real option valuation, and use the Black-Scholes model or the Binominal lattice model to estimate the current value of the opportunity to invest in a certain project in the future, or sale a real asset in the future.

## CHAPTER 4

### ECONOMIC BENEFITS FROM FLEXIBLE MANUFACTURING SYSTEMS

#### **4.1 Flexible Manufacturing Systems with High Production Capacity for the Automotive Industry**

A flexible manufacturing system is formed with a group of highly automated machines with computer numerical control, known as CNC machines. These machines are usually arranged in a machining cell, or production line setting according to the actual product processing sequence. As we discussed in Chapter 1, a flexible manufacturing systems includes three key components: a group of CNC machines and automatic online inspection stations if required, an automatic material handling system for part loading and unloading, and a central control system to coordinate part flow through the manufacturing system.

In general there are many different types of flexible manufacturing systems depending on the specific application and level of automation. It is commonly understood that flexible manufacturing systems can be classified into two categories according to their plane layout: Flexible manufacturing cells and flexible manufacturing systems. A flexible manufacturing cell (FMC) consists of one to several CNC machines and machining centers with an automated or manual material handling systems, such as

conveyors, robots, or automated guided vehicles (AGVs). While flexible manufacturing cells are designed for production with large variety in part types and part families at relatively low to medium volume of production, a flexible manufacturing system (FMS) is normally designed for high volume production of a limited variety of part families, within each part family there could be several different part types. Because of the capability of high volume production and quick response to changing market demand for the manufacturing of new types of products, flexible manufacturing systems are best suited for manufacturing activities in the automotive industry where market responsiveness and the ability to run large volume of production are the primary factors of operation profitability and long term business success. Table 4.1 gives a brief summary of different types of flexible manufacturing systems, including flexible manufacturing cells.

**Table 4.1 Different Types of Flexible Manufacturing Systems**

Type of manufacturing System	Level of Flexibility	No. of parts in Product Family	Average lot Size
Dedicated Transfer Lines	Low	1-2	7,000 and up
<b>High Production FMS</b>	<b>Medium</b>	<b>3-10</b>	<b>1,000-10,000</b>
Sequential or Random FMS	Medium	4-50	50-2,000
Manufacturing Cells	Medium	30-500	20-500
Stand-alone NC Machines	High	200 and up	1-50

*Source:* Mehdi Kaighobadi and Kurapati Venkatesh, "Flexible Manufacturing Systems: An Overview", International Journal of Operations & Production Management, Vol. 14, No. 4, 1994

Starting from the 1970s, flexible manufacturing systems have been widely used by large corporations in the automotive industry for efficient production of parts and

components. With the capability to run a high volume of production while offering required flexibility in product variety and the flexibility for capacity increase with further investment when necessary, high production flexible manufacturing systems are most suitable for production of parts and components in the automotive industry, where both market responsive manufacturing and high volume production are required to stay competitive with sustained operation profit and financial success. The model developed in this study is mainly for the evaluation of high production flexible manufacturing systems. It has been the common understanding (Kaplan 1986, Lefley 1996, Small 2006) that both strategic assessment and economic evaluation are necessary to capture the primary benefits offered by such systems.

#### **4.2 Strategic Assessment and Economic Evaluation of Financial Investment in Flexible Manufacturing Systems**

With the new wave of globalization and increasing competition in both home market and international markets, business leaders in many industries including the automotive industry have to carefully evaluate different strategies for sustained business operation and financial success. Manufacturing process improvement has been a key task in corporate strategic planning in many manufacturing companies. With the capability of high volume, high quality production, and the flexibility to change from the production of one type of product to another in response to changing market development, flexible manufacturing systems have been introduced in the production systems in many large corporations around the world.

Despite the apparent advantages offered by a flexible manufacturing system in production cost savings, quality improvement, quick response to meet changing customers demands for new products, and the strong production capability support to the investing company for a sustained competitive edge, the economic valuation or investment justification for such manufacturing systems has been a relatively difficult task due to the large initial investment required to set up a flexible manufacturing platform, and the subsequent investment required to expand the flexible manufacturing system for production of additional family of products, or to expand the total production capacity for higher volume of production of the same family of products.

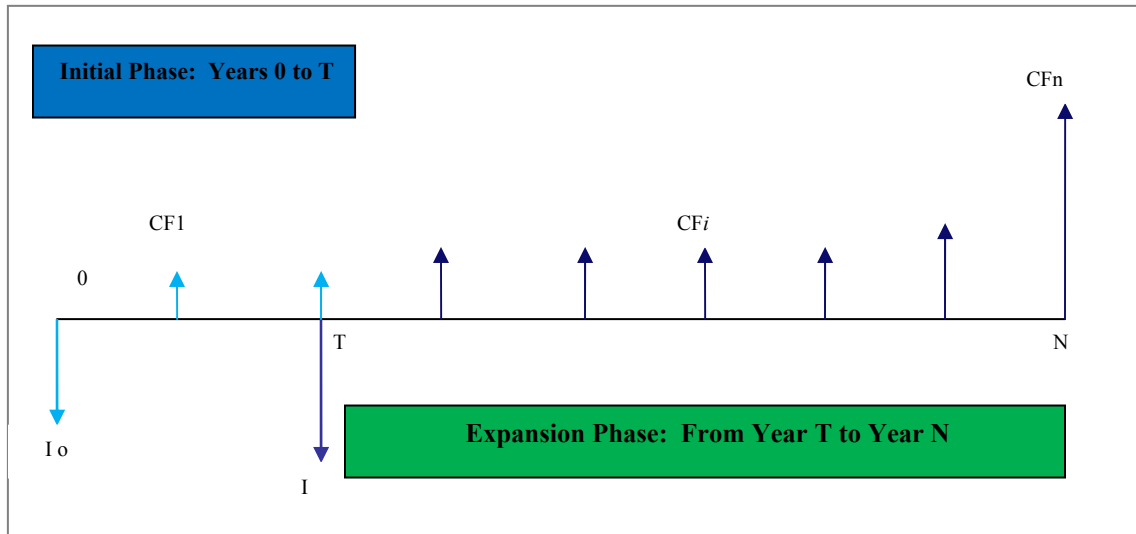
To appropriately evaluate financial investment in flexible manufacturing systems, it is the common understanding of the academic research community and corporate executives that both strategic assessment and economic evaluation have to be considered in order to justify investment in flexible manufacturing systems, so that sound investment and operational decisions can be made for the common objective of long term business success.

The purpose of a strategic assessment of financial investments in flexible manufacturing systems is to ensure that such investment is consistent with corporate long term development and growth objective. The main strategic benefits provided by a well designed and implemented flexible manufacturing system are improved market competitiveness, technology leadership in the industry, and long term economic benefits in revenue increases and cost reductions as compared to one or several dedicated production lines to reach the same long term production objectives.

As far as detailed economic evaluation is concerned, traditional DCF analysis is unable to capture the full benefit of flexibility with respect to economic environment uncertainty. Real options analysis, on the other hand, offered a complementary approach to traditional models of economic evaluation, such as net present value evaluation. In real options analysis, the whole investment project, including its initial base production phase and the later expansion phase, are put into the perspective of a real options framework. The initial investment serves as a condition for future expansion contingent on market development. In other words the initial investment is viewed as a premium to purchase a real option for future manufacturing capability expansion for either a wider scope of production or for a large scale of production. In most cases of flexible manufacturing system implementation, the initial investment not only serves as a real option premium for future investment and expansion opportunity, it also serves the purpose of setting up the initial manufacturing platform for immediate production of the base phase products according to current market demand, generating cash inflows in the initial phase.

#### **4.3 Real Options Framework for Expansion Project Evaluation**

In order to carry out a real options evaluation, the project value in different phases have to be calculated in terms of net present value, which is the base value for real options evaluation. Suppose the initial investment and implementation of a flexible manufacturing system completed at time zero, and the initial phase of production started at the same time.



**Figure 4.1 Phased Project Investment and Cash Flow Schedule**

With real options analysis, the initial investment  $I_0$  combined with the net present value of any positive cash flows during the initial phase of production, is viewed as an option premium to secure the opportunity for future investment  $I$  to be made at time  $T$ , for the benefit generated in the expansion phase from year  $T$  to year  $N$ . The benefit from the expansion period is evaluated by the net present value at time zero of all cash flows in the expansion phase, normally referred to as  $V_0$  in real options valuation.

Expansion phase project value  $V_0$  together with expansion investment  $I$ , time from now to expansion decision  $T$ , risk free interest rate  $r$ , and the volatility of return on project value  $\sigma$ , will determine the real option value of the investment project in the expansion phase,  $c$ . The total project value, including the initial investment phase and the expansion phase will be given by the strategic project net present value, or, SNPV:



$$\text{SNPV} = \text{NPV}_0 + c \quad (4.1)$$

Where  $\text{NPV}_0$  is the initial investment  $I_0$  combined with the net present value of any positive cash flows during the initial phase of production. The decision rule for the whole investment project will be, if

$$\text{SNPV} \geq 0 \quad (4.2)$$

The investment project should be approved and pursued; otherwise the investment project should be rejected or further information for reconsideration will have to be collected.

#### **4.4 Project Annual Cash Flow Generated by a Flexible Manufacturing System**

In order to appropriately account for the economic benefits provided by a flexible manufacturing system, key competitive advantages have to be considered in quantitative terms of added value in operation revenue and reduced cost of production.

##### **4.4.1 The Benefits of a Market Responsive Flexible Manufacturing System**

Assume the flexible manufacturing system is capable of producing several types of products within the same product family; when there is an expected market demand for a different family of products, or for a significantly higher volume of production for products in the same product family, additional investment will be required for a new set of machine fixtures, tooling, and setup requirement, or additional machines at bottle neck processes, as well as a new set of product processing software. It is further assumed that during the initial phase of base family production, market research and new product development is already carried out in close cooperation with customers who may require an additional family of products, or increased volume of current family of products.

Communications and cooperation with machine and automation suppliers are also necessary in technical and financial planning for the project expansion, so that when the time comes to make additional expansion investment for either increased scope of supply to produce a new family of products, or for increased scale of supply with higher volume output of the same family of products. In case of a temporary shortage in production capacity the investing company will choose to manufacture products with high profitability. In case of an expected future significant increase in either the types of products or the volume of products, an expansion investment may be initiated.

With the capability to quickly switch from manufacturing of one type of product to another in the same product family with limited setup cost, a flexible manufacturing system is able to capture the market opportunity created by changing market demand, thereby capturing the added value in revenue which may have been foregone in case of a dedicated production line. This added value to total operation revenue reflects the value of market responsiveness provided by a flexible manufacturing system.

Because of the technology advancement in machining capability, online automatic measuring and monitoring technology for quality control, and the use of automatic material handling system in highly efficient flexible manufacturing systems, some of the cost components considered important ten or twenty years ago, such as waiting cost, idle cost, quality appraisal and failure prevention cost, have been either eliminated or reduced to a minimal so that they can be included in fixed or variable costs of production. The automatic material handling system also helped to reduce the number of operators required to run the manufacturing system as compared to the number of operators

required in a dedicated transfer line with similar production capacity. The implementation of an efficient flexible manufacturing system will help to reduce overhead cost due to reduced floor space requirement, reduced consumption of electricity, heating and cooling capacity, as well as other shared resources.

#### **4.4.2 Annual Operation Cash Flow from a Flexible Manufacturing System**

In order to appropriately evaluate investment in flexible manufacturing systems, it is suggested in the research literature that both potential and realized benefits of flexible manufacturing systems have to be considered. Although it is well recognized that potential and realized benefits from a flexible manufacturing system are closely related to each other, yet they are still different according to the basic accounting principles that require cost be recorded as it occurs and revenue be booked as it is realized. Since potential benefits of investment in flexible manufacturing capability gives the investor the opportunity to capture future operational benefits with additional investment pending positive market development, it is appropriate to evaluate such potential benefits of a flexible manufacturing system with real options analysis. In other words, **potential benefits** offered by a flexible manufacturing system can be evaluated as an option premium, in that initial investment is required not only to run current production but also to capture the benefits of an upward movement of the general economy and emerging market demand while limiting the downside risk by staying with initial investment for base model production in case of unfavorable market developments. Realized benefits of

a flexible manufacturing system, on the other hand, will have to be evaluated with realized revenue and actual cost.

Given investor's cost of capital and the time frame of the investment in flexible manufacturing system, *realized project value* will be determined by annual operation cash flows. Most of the realized benefits of a flexible manufacturing system will be represented by increased revenue and reduced costs due to the flexible production capability to meet changing customer demand, and advanced technology integrated in the flexible manufacturing system to reduce cost related with quality improvement, elimination of scrap and material waste, timely order delivery and better customer service, very low or zero inventory with make-to-order and just-in-time production practice.

Considering investment, sale revenue, market demand for different types of products, unit selling price, fixed cost, variable cost, setup cost, equipment depreciation, and any possible salvage value after gain tax, the annual cash flow from production in year  $i$  can be expressed as follows:

$$CF(i) = [ RV(i) - FC(i) - VC(i) - OH(i) - STC(i) - DEP(i) + SV(i) ] (1 - Tr) + DEP(i) - I(i) \quad (4.3)$$

Where,

$$RV(i) = \sum_{m=1}^M RV_m(i) = \sum_{m=1}^M f_m \cdot D_m(i) \cdot P_m(i), \quad m = 1, 2, \dots, M \quad (4.4)$$

And  $f_m$  is the index variable related with market demand for product type  $m$ :

$$f_m = 1 \quad (4.5)$$

if product  $m$  is in demand and will be produced by the flexible manufacturing system in year  $i$ ; and

$$f_m = 0 \quad (4.6)$$

if product  $m$  is not going to be produced in year  $i$ .

Equation (4.4) represents the total revenue of sales of different type of products in year  $i$ ,  $m$  is the part type index ranging from 1 to  $M$ , with  $M$  being the total number of different types of products manufactured and sold in year  $i$ .  $D_m(i)$  and  $P_m(i)$  are actual demand and unit selling price of product  $m$  in year  $i$ , assume that making to order production strategy is followed where actual number of parts produced and sold equals the actual number of parts in demand in year  $i$ .

$FC(i)$  = Fixed cost of production in year  $i$

$$VC(i) = \sum_{m=1}^M VC_m(i) = \sum_{m=1}^M f_m \cdot D_m(i) \cdot UVC_m(i) \quad (4.7)$$

$OH(i)$  = Overhead cost in year  $i$

Is the total variable cost of production for all types of products manufactured and sold in year  $i$ , and  $UVC_m(i)$  is the unit variable cost of product  $m$  in year  $i$ .

$$STC(i) = \sum_{m=1}^M f_m \cdot STC_m(i) \quad (4.8)$$

Is the total setup cost for all  $M$  types of products in year  $i$ .

$DEP(i)$  = Depreciation of machines and equipment in year  $i$ .

$SV(i)$  = Net salvage value of in year  $i$  after gain tax

$I(i)$  = Investment made in year  $i$

$Tr$  = Tax rate for the investing company

Here we assume that the flexible manufacturing system is capable of producing different types of products in the same part family as long as the total demand for all types of product in a given year is within the total production capacity.

The realized benefits of the flexible manufacturing system in any given year is characterized by the annual cash flow, which reflects the flexible capability of producing different types of products in response to market demand, and the cost associated with multi-type production. Furthermore the benefits of a flexible manufacturing system in terms of cost reduction due to reduced floor space requirement, reduced level of utility and other common resource consumption, quality improvement, labor and possible material cost savings, can be reflected in reduced fixed and variable cost, while the added cost of a flexible manufacturing system in production setup for different types of products is accounted for as well.

For a given investment project in flexible manufacturing system, investment cost is relatively easy to estimate given the detailed technical and financial planning for the flexible manufacturing system by process design engineers and financial staff in close cooperation with technology and machine suppliers. It is also not too difficult to come up with good estimates of fixed and variable cost of production given that the company has good knowledge of product material and process requirements as well as the company's manufacturing capability. The factors that reflect most of the market uncertainty are market demand and unit selling prices of different types of products, along with possible changes in input factor prices. It is appropriate to assume that both market demand and selling price for a certain type of product following an Ito process with a constant drift

rate (rate of increase or decrease over time) and constant volatility rate. In other words, it is assumed that demand and unit selling price for product  $m$  in any given year  $D_m$  and  $P_m$  satisfy the following two differential equations,

$$\frac{dD_m}{D_m} = \mu_{D_m} \cdot dt + \sigma_{D_m} \cdot dz \quad (4.9)$$

$$\frac{dP_m}{P_m} = \mu_{P_m} \cdot dt + \sigma_{P_m} \cdot dz \quad (4.10)$$

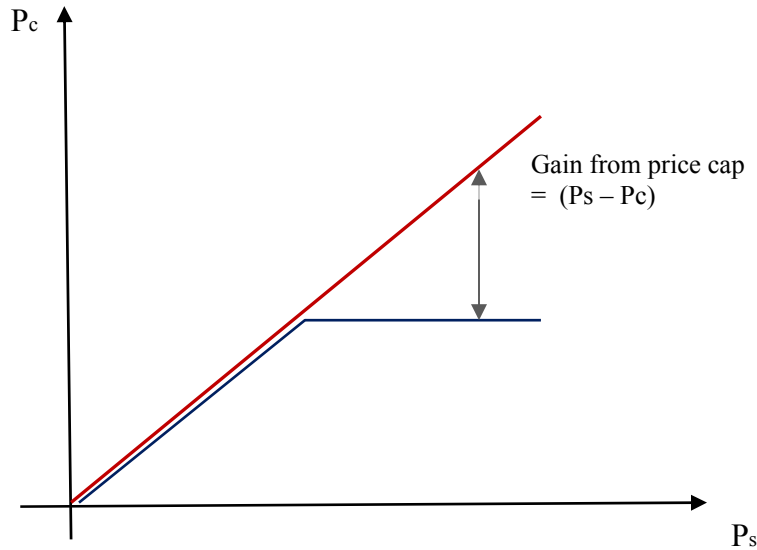
Equation (4.9) and (4.10) is consistent with the assumption that project value, which is determined by annual cash flows, follows an Ito process as well.

Since both market demand and selling price are random variables, it is difficult to calculate annual cash flow analytically. In most cases Monte Carlo simulation will be used to get a fairly accurate mean value estimate and probability distributions for annual cash flows and project value.

#### **4.5 Input Factor Price Risk Hedging to Control Variable Cost of Production**

In the production process in both domestic and international markets, the risk of input factor price increases could have a significant impact on the cost of production and operation profit. In order to reduce the risk posed by an input factor price increase, such as steel price increase, manufacturing companies could enter into a commodity option contract for important input factors, such as steel and aluminum alloy, to effectively put a price cap on those input factors for the amount required for production in the near future. This risk hedging strategy will help to manage the input price risk and effectively control the total cost of production.

The economic benefit of input factor price risk hedging through commodity option contracts can be illustrated in Figure 4.2 below.



**Figure 4.2 Steel Price Risk Hedging with an Option Contract**

Here  $P_s$  is the world market spot price of steel per ton, and  $P_c$  is the commodity option contracted price of the same grad of steel per ton. If the world market steel price increases above the option contracted price of steel, the company with a steel option contract could choose to exercise the option and get steel supply at the option contracted price, realizing a net gain of  $(P_s - P_c)$  per ton of steel, thereby effectively control the maximum cost of product input within the predetermined price specified in the option contract; if the market spot price of steel stays below the option contracted price, the company would choose not to exercise the option and purchase steel from the world spot market, paying an option premium for the benefit of input factor price risk management.



Suppose the average annual consumption of steel by a manufacturing company is  $D_s$  tons, the difference between market spot price of steel and option contracted price of steel is  $(P_s - P_c)$ , the option premium for one ton of steel is  $f_s$ , the total cost savings from the input factor price risk management strategy is:

$$R_f = D_s (P_s - P_c - f_s) \quad (4.11)$$

Manufacturing companies with input factor option contracts will be able to effectively forecast the future cost of material, and reduce the risk posed by market dynamics in input factor price. Labor contracts or agreements serve a similar purpose to make labor costs relatively easy to predicate. In the cost calculations for annual operation cash flows, the benefits from these cost control strategies must be considered.

## CHAPTER 5

### FINANCIAL INVESTMENT IN FOREIGN COUNTRIES: FOREIGN EXCHANGE RISK CONSIDERATIONS

#### **5.1 Foreign Direct Investment and Corporate Growth Strategy**

With most of the countries around the globe becoming members of the World Trade Organization (WTO), tariffs on imported goods in most countries are decreasing to the level specified in the WTO framework agreements. Other barriers to international trade and investment are decreasing as well. Trade in goods and services have increased rapidly in the last twenty years, while limitations on foreign direct investment have been largely removed. With the liberalization of trade, finance, and investment across the world, promising business growth opportunities in many international markets have opened for the expansion and growth of dynamic corporations. Three major factors, the limited growth rate in the developed nations, the increasing income of consumers in international markets, and the need for future growth of companies in developed nations through international business expansion, have been the major driving force behind the latest wave of economic globalization. Business opportunities in developing countries have become a central focus in the planning of corporate growth strategy.

To better serve domestic and international markets, companies in the automotive industry in the United States, Europe, Japan, and South Korea, have been aggressively

pursuing a global expansion business strategy. And companies which did well in their international business operations are better prepared for investment in research and development of new technologies and products in their domestic markets. A sustainable competitive advantage and continued growth is only possible when companies do well in both domestic and international markets. The successes in these two markets complement each other and could result in shared strategic advantages in new product development and global manufacturing capabilities.

With all the advantages of globalization in the automotive industry as well as in other industries, globalization does pose challenges and risks: global investment and trade liberalization could reduce profitability and competitiveness in the home market of companies which are not ready for global competition, ill equipped companies embarking on direct investment in foreign countries may not be able to achieve their investment objectives.

While the general perspective toward globalization is positive and promising, companies operate on a global basis with heavy investment in foreign countries should pay close attention to risk management in international business. Major risks in global business operations include political risk, operational risk, and foreign exchange risk. Political and operational risks can be managed through the negotiation of a fair investment agreement before the investment is undertaken, operational risk can be reduced with appropriate management strategies, while foreign exchange risk management will require an accurate prediction of the future exchange rate movement and strategies of different types of exchange risk management.

## **5.2 Foreign Exchange Risk Management in Foreign Direct Investment**

Foreign direct investment refers to business investment in foreign countries. From observations of companies that have successfully invested in international markets, some of the common competitive advantages may have been the key success factors. Those competitive advantages include: economics of scale and scope due to investor's large size and significant business operations in major international markets; advanced technology specifically developed to support their business growth; competitive position in their home markets; financial strength; and management and marketing expertise, including the appropriate strategy for business development in foreign markets.

Foreign exchange risk is the effect that unanticipated changes in exchange rate have on the value of the firm. In the economic evaluation of investment projects in foreign countries, exchange risk is the potential gain or loss in project value that occurs as a result of changes in exchange rate.

There are three types of exchange risk exposure to companies engaged in international business operations:

### **(1) Transaction Exposure**

Transaction exposure refers to risk on contracted economic value the company is due to receive or pay in foreign currency. Such as contracted payments for equipment imported from foreign countries, or contracted revenue due to receive in foreign currency. This type of exchange risk exposure can be reduced by entering a foreign currency forward, futures, or options contract.

## **(2) Translation Exposure**

Translation exposure, also referred as accounting exposure, is the potential risk posed by unexpected changes in exchange rate at the time of translating the financial statements of a foreign affiliate into home currency to generate a consolidated single financial statement for the investing company. Translation exposure can be hedged with forward, futures, and options contracts if the actual profit transfer from the affiliate to the home office will actually take place.

## **(3) Economic Exposure or Operational Exposure**

Economic exposure, also referred as operational exposure, measures the change in the present value of an investment project in a foreign country from changes in future operation cash flow due to unexpected changes in foreign exchange rate. The total effect of the economic exposure depends on the direction of the foreign exchange movement, and the impact of unexpected changes in foreign exchange rate on operation cost and revenue. Economic exposure to unexpected changes in foreign exchange rate is more complex and relatively difficult to hedge, and it must be considered in project evaluation.

### **5.3 Real Options Evaluation of Financial Investment in Foreign Countries**

When applying real options analysis to evaluate investment projects in foreign countries, the impact of changes in exchange rates on project value has to be considered, especially when the initial investment in the project is made in home currency by the investing company. In this section we will develop a simple and effective model for investment project valuation considering unexpected changes in foreign exchange rate.

### **5.3.1 Assumptions**

In developing the model, the following assumptions are made:

- (1) Initial investment in the project is made in home currency of the investing company, and the financial performance of the project will be evaluated in home currency.
- (2) Expected annual cash flows from the project are converted into home currency at the exchange rate when the project is evaluated.
- (3) Present value of the project will be calculated with a discount rate that equals to the average cost of capital of the investing company, or the required rate of return for a specific investment project.

### **5.3.2 Model Development**

#### **5.3.2.1 The Movement of Foreign Exchange Rate**

The movement of the foreign exchange rate will affect the profitability and operational cash flow of a foreign subsidiary of the investing company. For example, a company in the United States investing in Germany will evaluate periodical operation profits from its subsidiary in Germany. For a given amount of operation cash flow accumulated in Germany in the Euro, the actual value of this cash flow to the investing company in the United States in U. S. dollars will be relatively higher if the Euro unexpectedly appreciates against the U. S. dollar, and this same value will be relatively lower to the investing company in the United States if the Euro unexpectedly depreciates

against the U. S. dollar. The possible change in project value in home currency due to changes in exchange rate has to be considered in project valuation.

### **5.3.2.2 The Impact of Unexpected Changes in Foreign Exchange Rate on Project**

#### **Cash Flow and Project Net Present Value**

Suppose a company in the United States invested in a project at its subsidiary in a foreign country. Since the initial investment in this project will be made from the head office in the United States in the U.S. dollar, the company would like to evaluate the economic performance of the project in the U.S. dollar. From the best estimate of the project management team, the initial investment requirement and annual cash flows from year 1 to year  $n$  in foreign currency are as follows:

$$I, CF_1, CF_2, CF_3, \dots, CF_n$$

The project net present value in U.S. dollars can be evaluated in the following two different procedures, depending on at what time the project cash flows will be converted from foreign currency into U.S. dollars.

#### **(1) Cash Flow Conversion at the Time of Project Evaluation**

Assume the exchange rate at the time of project evaluation is  $E$  U.S. dollars per unit of foreign currency, the net present value in U.S. dollars of the project investment outlay and all cash flows, discounted back to present time, at the company's required rate of return on similar projects,  $k$ , will be,

$$NPV = \sum_{t=1}^n \frac{E \cdot CF_t}{(1+k)^t} - E \cdot I \quad (5.1)$$

Or,

$$NPV = \frac{E \cdot CF_1}{(1+k)} + \frac{E \cdot CF_2}{(1+k)^2} + \dots + \frac{E \cdot CF_n}{(1+k)^n} - E \cdot I \quad (5.2)$$

Let  $NPV_F$  be the project net present value in foreign currency, we have,

$$NPV_F = \frac{CF_1}{(1+k)} + \frac{CF_2}{(1+k)^2} + \dots + \frac{CF_n}{(1+k)^n} - I \quad (5.3)$$

It follows that the relationship between the net present value of the investment project in U.S. dollars and the net present value of the project in foreign currency is,

$$NPV = E \cdot NPV_F \quad (5.4)$$

Taking the first order derivative of NPV with respect to exchange rate E, we have,

$$\frac{d(NPV)}{dE} = NPV_F \quad (5.5)$$

And,

$$d(NPV) = NPV_F \cdot dE \quad (5.6)$$

Equation (5.6) states that the change of project net present value in terms of home currency of the investing company is the production of the project net present value in terms of the foreign currency  $NPV_F$ , and the unexpected change in exchange rate  $dE$  (U.S. dollar per unit of foreign currency).

## (2) Cash Flow Conversion at the End of Each Year

Now suppose that we want to convert annual project cash flows from foreign currency to the U.S. dollar at the end of each year, and foreign exchange rate at the end of different years during the project life are  $E_0, E_1, E_2, \dots, E_n$ . The project net present value in U.S. dollars will be,

$$NPV = \sum_{t=1}^n \frac{E_t \cdot CF_t}{(1+k)^t} - E_0 \cdot I \quad (5.7)$$



Or,

$$NPV = \frac{E_1 \cdot CF_1}{(1+k)} + \frac{E_2 \cdot CF_2}{(1+k)^2} + \dots + \frac{E_n \cdot CF_n}{(1+k)^n} - E_0 \cdot I \quad (5.8)$$

Taking partial first order derivatives of NPV with respect to  $E_0, E_1, E_2, \dots, E_n$ , we have,

$$\frac{\partial(NPV)}{\partial E_0} = -I \quad (5.9)$$

$$\frac{\partial(NPV)}{\partial E_1} = NPV_1 = \frac{CF_1}{(1+k)} \quad (5.10)$$

$$\frac{\partial(NPV)}{\partial E_2} = NPV_2 = \frac{CF_2}{(1+k)^2} \quad (5.11)$$

...

$$\frac{\partial(NPV)}{\partial E_n} = NPV_n = \frac{CF_n}{(1+k)^n} \quad (5.12)$$

Where  $NPV_i$  is the year  $i$  cash flow contribution into the total project net present value.

Now suppose there is an unexpected change in foreign exchange rate of  $\Delta E_0, \Delta E_1, \Delta E_2, \dots, \Delta E_n$ , at the end of year 0, year 1, year 2, ..., and year  $n$  respectively, the total change in the project net present value in U.S. dollars due to unexpected changes in the foreign exchange rate in each year over the project life will be:

$$d(NPV) = \sum_{i=0}^n \frac{\partial(NPV)}{\partial E_i} \cdot dE_i \quad (5.13)$$

Or,

$$d(NPV) = NPV_1 \cdot dE_1 + NPV_2 \cdot dE_2 + \dots + NPV_n \cdot dE_n - I \cdot dE_0 \quad (5.14)$$

Equation (5.14) indicates that the change of project net present value in terms of the U.S. dollar is the sum of each year's cash flow contribution to the total project net present value  $NPV_i$  multiplied by the unexpected change in exchange rate  $dE_i$  at the end of that year.

### **5.3.2.3 Consideration of Foreign Exchange Risk in Real Option Evaluation of**

#### **Investment in Foreign Countries**

One of the important issues to be considered in the economic evaluation of financial investment in foreign countries is the management of economic exposure of project value to unexpected changes in foreign exchange rate. If the project evaluation has to be done in the home office of the investing company, the impact of unexpected changes in the foreign exchange rate to the project value has to be considered, depending on the time of project cash flow conversion from foreign currency into home currency, the net change in project net present value can be calculated according to equation (5.6), or equation (5.14). If the foreign currency appreciates relative to home currency, the project value will increase by the amount of  $d(NPV)$ ; if the foreign currency depreciates relative to the home currency, the project value will be decreased by the amount of  $d(NPV)$ . The change in project net present value will affect the project value in each phase of the total investment project, such as initial phase investment  $I_0$ , expansion or growth phase investment  $I_1$ , and the total economic value of the expansion phase cash flows  $V_0$ , and eventually the impact on the real option value of the project can be calculated with Black-Scholes model or Binominal lattice model.

#### **5.4 Model Application and Concluding Remarks**

The models developed in this chapter provide a sound basis to evaluate the impact of unexpected changes in the foreign exchange rate to the net present value of a financial investment project in foreign countries, with the models developed here, project properties for real options evaluation can be calculated clearly, so that the impact of foreign exchange rate can be effectively accounted for with real options evaluation. These models could also be applied to value any investment project that produce cash inflows and incur costs in foreign currency.

## CHAPTER 6

### ESTIMATE PROJECT VALUE VOLATILITY FOR REAL OPTIONS EVALUATION OF INVESTMENT IN FLEXIBLE MANUFACTURING SYSTEMS

#### 6.1 Introduction

Applying financial option pricing theory to evaluate financial investment in real assets in the industry requires the estimate of at least five basic input parameters for the real options evaluation model, which is similar to the financial option pricing model presented in Appendix A in Chapter 3. Suppose a company is planning to invest in a future project  $T$  years from now, the company has estimated that an investment requirement of  $I$  would be required at time  $T$ , and the present value of future cash flows generated by the investment project from year  $T$  to the end of the project life is  $V_0$ , given risk free interest rate of  $r$ , and an estimated volatility of the returns on future project value,  $\sigma$ , the value of the real option to invest in such a project  $T$  years from now can be estimated with the following basic option valuation model:

$$c = V_0 N(d_1) - I e^{-rT} N(d_2) \quad (6.1)$$

where,

$$d_1 = \frac{\ln\left(\frac{V_0}{I}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma \sqrt{T}} \quad (6.2)$$

$$d_2 = d_1 - \sigma\sqrt{T} \quad (6.3)$$

Analogous to financial options pricing theory, real options analysis applies the same model to estimate the value of future investment flexibility to the investing company with consideration of the future uncertainty in market demand and product price. The accuracy of real option analysis depends on the accurate estimate of the input parameters.

Out of the five parameters required to estimate a fair value of the real option from equation (6.1), investment requirement  $I$ , time to make the investment  $T$ , and project value  $V_0$  can be estimated with project planning information and market forecast of product demand and selling price. The risk free interest rate can be quoted from the treasury bill interest rate. The only parameter that requires additional efforts to estimate is the volatility of future project value  $\sigma$ , which is a reflection of the project value uncertainty related to market uncertainty on demand and selling price of the products the investment project is going to produce. For investment projects in the manufacturing industry, such as investment in flexible manufacturing systems in the automotive industry, the project value volatility also depends on how well the flexible manufacturing system meets market demand in product type and volume.

In financial option pricing, the volatility of a financial asset, such as a stock, is the measure of investor's uncertainty about the future returns provided by the stock, which is defined as the standard deviation of the annual return provided by the stock when the return is expressed using continuous compounding. As volatility increase, the possibility that the stock price may increase or decrease significantly in the future increases, the

price of a call or put option written on the stock will increase accordingly. Higher volatility of a stock return will indicate a higher price for the financial options written on the stock. Similarly a higher volatility of the future project value will result in a higher real option value for the flexibility integrated in the investment project in the real world industry. Because of this positive correlation between project value volatility and real option value, volatility has been viewed as a driving factor in real options valuation. On the other hand caution should be exercised in order to estimate the investment project value volatility as realistically as possible. In other words, it is very important not to select unrealistically higher volatility in order to obtain a higher real option value. After a base case evaluation of the project value and real option value of a future investment project, sensitivity analysis should be performed to assess the impact of project volatility on project real option value. This will be included in the real option analysis applications in Chapter 7 and Chapter 8.

In order to have a realistic estimate of future project value volatility for financial investment in flexible manufacturing systems, it is essential to recognize the fact that: 1) Uncertainty of project value is originated from the uncertainty of future cash flows generated by the investment project, which in turn will be affected by changes in market demand and selling price; 2) The capability of the flexible manufacturing system to meet market demand in product variety and volume of production has a direct impact on the potential strategic value of the investment project; and 3) In financial option pricing theory, the volatility of the underlying stock price is defined as the standard deviation of the annual return provided by the stock when the return is expressed using continuous

compounding. In consideration of these three factors, a few techniques to estimate future project value volatility for investment in flexible manufacturing systems will be presented in the following sections.

## 6.2 Production Capability Index of a Flexible Manufacturing System

Due to the fact that the capability of a flexible manufacturing system to meet market demand in product variety and volume of production has a direct impact on the potential strategic value of the investment project, a *Flexible Production Capacity Index*,  $F_i$ , of the flexible manufacturing system, is introduced in this section to account for the flexible production capability of the flexible manufacturing system relative to market demand, and will be used as an important factor to estimate project value volatility for investment projects in flexible manufacturing systems.

Suppose initial project value volatility,  $\sigma$ , has been estimated with the return on project value in the expansion phase, based on annual cash flows generated in the expansion phase. In consideration of the market responsiveness of the flexible manufacturing system, and the risk involved in investment for flexible manufacturing capability, total project value volatility,  $\sigma_F$ , can be estimated as follows:

$$\sigma_F = F_i \cdot \sigma \quad (6.4)$$

Where,

$$F_i = \frac{N_c}{N_d} \quad (6.5)$$

Here,  $N_c$  is defined as the number of different types of products that can be produced with the flexible manufacturing system, in case such a system is designed to cover a wider

variety of products; or  $N_c$  should be defined as the total number of products that can be produced with the flexible manufacturing system in a given period of time, in case such a system is designed to capture increased market demand with higher production capacity.  $N_d$  is the number of different types of products demanded, or the total number of products demanded in the market for the given period of time under consideration.

The flexible production capacity index as defined in equation (6.5) is a direct indication of the actual production capability of the flexible manufacturing system in relation to market demand. It also indicates how effectively the flexible manufacturing system could enable the investing company to capture the market demand either for the benefit of a wider scope of supply, or for the benefit of a larger scale of production with higher production volume, thereby creating value for the investors. On one hand the higher the index, the better the production facility is prepared with enough capacity to meet future market demand. On the other hand, the higher the index, the more the investment required to acquire such wide production flexibility with added investment. From the perspective of the total economic value of the investment project, the higher the flexible production capacity index, the larger the investment that is needed in the expansion phase. This larger investment will increase the risk of the investment project due to the increased risk of having a negative return under unfavorable market conditions. It is the responsibility of the management to have as accurate an estimate of the number of different types of products demanded in the future, and to determine the level of flexibility of the manufacturing facility that is needed to meet future demand with a reasonable capacity reserve for higher than expected market demand. A higher capacity



index will in turn result in a higher investment project risk as reflected by a higher volatility according to the total project volatility model in equation (6.4).

Similar to financial option pricing, real option value increases as volatility increase. This could be counter-intuitive because volatility is traditionally regarded as a negative factor in economic evaluation and risk management. With financial options pricing and real options analysis, however, higher volatility means higher possibility for the market or business condition to move up or down. Since an option holder will only choose to exercise the option when the market moves up, and not to exercise when the market moves down, thereby taking full advantage of the upside market movement while limiting the loss to the option premium in case of a market downward movement. This explains the core value of an option, and the fact that higher volatility leads to a higher option value. In the case of investment in a flexible manufacturing system, a key value of such a system is its ability to have the flexible capacity to meet future increased market demand, either in the types of products or in the volume of products demanded. The real option value of the operational flexibility of a flexible manufacturing system can be reflected with a higher volatility parameter by considering a production capacity index in equation (6.4).

Three interesting ranges of the value of flexible production capability index can be observed in relation to future market demand:

(1) When  $F_i = 1.0$

We have a perfect match between the production capability of the flexible manufacturing system and future market demand; the benefit of the flexible

manufacturing system will be fully represented by the actual project value based on actual market demand and cash flows. According to equation (6.4) total project value volatility  $\sigma_F$  will be the same as the initially estimated project value volatility  $\sigma$ .

(2) When  $F_i \geq 1.0$

The actual production capability of the flexible manufacturing system is greater than estimated future market demand. That means, the flexible manufacturing system has extra reserved production capability for a potential increase in market demand. And according to equation (6.4) total project value volatility  $\sigma_F$  will be greater than the initially estimated project base value volatility  $\sigma$ .

(3) When  $F_i \leq 1.0$

The actual production capability of the flexible manufacturing system is less than estimated future market demand. Current production capacity of the flexible manufacturing system could not fully meet future market demand. Total project value volatility  $\sigma_F$  will be less than the initially estimated base project value volatility  $\sigma$ .

Since a higher volatility will result in a higher real option value according to equations (6.1) to (6.3), it is consistent that a flexible manufacturing system designed with higher production capacity will have a better chance to meet future market demand, therefore has a higher potential value to the investing company as indicated by a higher real option value, given that all other input parameters stay the same.

### 6.3 Investment Project Volatility Estimate with Return on Project Value

According to financial option pricing theory, volatility of the underlying financial asset, such as the volatility of stock price, is defined as the standard deviation of the continuously compounded annual return provided by the stock.

In real options analysis, project value volatility represents the uncertainty over expected annual return from the project value, which is defined by the estimated future cash flows of generated by the investment project. Analogous to financial option pricing, project value volatility in real option analysis can be defined as the standard deviation of expected annual project return during the life of the project. The main difference is, unlike stock price, which can be easily observed from the open market, investment project value in real options analysis, is defined as the Net Present Value at time zero of future cash flows generated in the optioned phase (such as expansion or growth phase) of the investment project. For a given set of estimated future cash flows, there is only one project value. In order to estimate project value volatility in real option analysis, it is recommended by Copeland and Antikarov (2003), Mun (2006), Herath and Park (2002) that two project values should be calculated from estimated future project cash flows at the beginning of the investment project as  $V_0$  and at the end of year one as  $V_1$ , continuously compounded annual return on the optioned project value,  $k$ , can be defined as,

$$k = \text{Ln}\left(\frac{V_1}{V_0}\right) \quad (6.6)$$

Where,

$$V_0 = \sum_{i=0}^N \frac{CF_i}{(1+k)^i}, \quad (6.7)$$

$$V_1 = \sum_{i=1}^N \frac{CF_i}{(1+k)^i} \quad (6.8)$$

Here  $CF_i$  should only include the cash inflows generated in the optioned phase of the investment project from year  $(T+1)$  to year  $N$ .

The estimated initial project value volatility is the standard deviation of the project return  $k$  defined in equation (6.6),

$$\sigma = SD(k) \quad (6.9)$$

Considering the added risk of additional investment to acquire flexible manufacturing capability to meet potential market demands in the future during the optioned phase of the project life, the total project volatility for investment in a flexible manufacturing system can be estimated as,

$$\sigma_F = F_i \cdot \sigma \quad (6.10)$$

Where,  $F_i$  is the flexible production capacity index.

In practical applications of real options evaluation of investment in flexible manufacturing systems, Monte Carlo simulation can be applied to estimate the annual return on the project value based on estimated future cash flows, the standard deviation of this return can be viewed as an estimate of base project value volatility. Such estimates will be presented in Chapter 7 and Chapter 8, where investment in flexible manufacturing systems for a wider scope of supply and for a higher volume of production will be evaluated respectively in a real options framework.

#### 6.4 Project Value Volatility Estimate with Annual Operation Cash Flows

In order to consider future market uncertainty in project value, it is normally assumed that product demand and selling price are random variables following certain stochastic distributions over the duration of the project under evaluation. With given distributions for product demand, selling price, and some of the cost factors of production, it is possible to calculate annual operation cash flows with Monte Carlo simulation. Furthermore, Monte Carlo simulation could also be applied to estimate optioned project value  $V_0$  for real options analysis, which is defined as the net present value of future cash flows in the expansion phase. The output of Monte Carlo simulation for a project value estimate comes as a stochastic distribution with a mean value and a standard deviation, the initial volatility of project value could therefore be estimated as the coefficient of variance (CV) of the project value:

$$\sigma = \frac{SD(V_0)}{E(V_0)} \quad (6.11)$$

where  $E(V_0)$  is the estimated average project value, and  $SD(V_0)$  is the estimated standard deviation of the project value from Monte Carlo simulation. A similar method has been recommended by Sheldon Natenberg (1994) in his work on option volatility and pricing. With this initial estimate of project value volatility, the total project value volatility, considering the flexible production capacity index, can be found with equation (6.10).

## 6.5 Investing Company Stock Volatility as Project Value Volatility

In many cases of real options evaluation, if the investing company believes that the project currently under consideration has the same level of volatility as the average level of volatility for all other projects the company has undertaken so far, it is then appropriate to use the company's recent historical stock price volatility as an approximation of project value volatility under consideration.

Suppose a set of historical stock prices for the investing company can be observed from the stock exchange, it is relatively easy to estimate stock volatility from this set of historical stock price data. Suppose  $N+1$  observations of periodical stock price were recorded from actual trading activity, we define,

$S_i$  = Stock price at the end of the  $i$ th period ( $i = 1, 2, \dots, N$ )

$\tau$  = Length of time period in years

And define periodical continuously compounded return of the stock as,

$$u_i = \ln\left(\frac{S_i}{S_{i-1}}\right) \quad (6.12)$$

A sample estimate of the standard deviation of the periodical stock return is given as,

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (u_i - \bar{u})^2} \quad (6.13)$$

Where  $\bar{u}$  is the average return of the  $N$  periodical returns defined in equation (6.12).

Please note  $s$  is an estimate of the volatility of stock price during a time period of  $\tau$ , in other words, if  $\sigma$  is the annual volatility of the return on the stock, we have,

$$s = \sigma\sqrt{\tau} \quad (6.14)$$

And,

$$\sigma = \frac{s}{\sqrt{\tau}} \quad (6.15)$$

is the initial annual volatility of the company's stock price, which could be used as an approximation of the initial annualized volatility of the investment project value. And the total project value volatility for investment in flexible manufacturing systems can be calculated from equation (6.10).

In some literature, implied volatility from the investing company's traded stock option is occasionally used as an approximation of project value volatility, but serious concerns exist due to the fact that most traded stock options are priced higher than its fair value as indicated by Black-Scholes model (Sheldon Natenburg 1994), resulting in an unrealistically higher implied stock price volatility. For this reason, implied volatility from traded stock options will not be used to estimate investment project value volatility for the evaluation of financial investment in flexible manufacturing systems in the automotive industry, even when stock option contracts of the investing company are traded at public exchanges.

## **6.6 Stochastic Distributions of Market Demand and Product Price to Reflect**

### **Market Risk**

Fundamentally the volatility of an expansion project value depends on the volatility of future market demand and product price volatility, as well as the capability of the flexible manufacturing system to meet future market demand. That is why the base estimate of project value volatility has to be based on the best estimates of realized

project cash flow, and then multiplied by the *Production Capability Index* to account for the relative capability of flexible manufacturing system in relation to future market demand. Monte Carlo simulation can be used to estimate volatility of the return on project value and the volatility of project cash flow, with stochastic distributions of market demand, product selling price, and cost factors.

In order to appropriately account for market uncertainty in the amount of products demanded and the uncertainty in the selling price, it is normally assumed that units demanded per year for each type of products, and selling prices of those products follow certain types of stochastic distributions over the life of the investment project under consideration. The types and parameters of such distributions are estimated based on most recent marketing and sales information as well as the best estimates of future market movement in terms of the types of product demanded and the competitive pricing of those products. A few realistic and commonly used distributions, such as Pert and Triangular distributions can be assumed to represent market demand and product selling price reasonably well. More details will be given in Chapter 7 and Chapter 8 where Monte Carlo simulations will be used to estimate investment project annual cash flow, project value, as well as project value volatility.



## CHAPTER 7

### FOREIGN DIRECT INVESTMENT IN A FLEXIBLE MANUFACTURING SYSTEM FOR A WIDER SCOPE OF SUPPLY: THE GROWTH OPTION TO ADD NEW TYPES OF PRODUCTS

#### **7.1 Introduction**

According to United Nations Conference on Trade and Development (UNCTAD Report 2007), foreign direct investment (FDI) is defined as “investment made to acquire lasting interest in enterprises operating outside of the economy of the investors”. Increasing foreign direct investment in major world markets is often perceived as an important indicator of growing economic globalization and integration. And in most of the cases foreign direct investment has played a very important role in global economic cooperation, development, and prosperity.

The most well known and successful example of foreign direct investment made by the United States during the post war period was the Marshall Plan. Although operated as a government aid program, the economic aid from the United States offered much needed economic support to the European countries in their efforts to recover from the devastation brought by the war. The Marshall Plan benefited the American economy as well. The economic aid under the Marshall Plan was used to buy goods from the United

States, and those goods were shipped across the Atlantic on US commercial ships, thereby adding exports and employment to the American economy. Since that time foreign direct investment has become a truly global phenomenon, with United States still leading the world in both the amount of foreign direct investment inflows from other countries, as well as US direct investment in other countries around the world (UNCTAD Report 2007).

Since the late 20th century increasing world economic growth and integration has resulted in the increase of international trade and cross-border investment between developed countries and developing countries. More and more foreign direct investment was made in developing countries such as Mexico, Brazil, Chile, India, China, Russia, and East European countries. Major corporations from United States, Canada, Europe, Japan, and South Korea have increased their investments in emerging markets for expanded global market share, growth, and profitability. Globalization and economic cooperation has brought in very much needed capital investment, technology, and management expertise to developing countries, while at the same time developed countries have benefited from direct access to a much larger and dynamically growing world market with large operation profits which could be reinvested in research and development in the investors' home markets.

In many countries, the manufacturing industry, such as automotive industry has been the largest industry sector to receive foreign direct investment. A study for the application of real options analysis to evaluate financial investment in a foreign country

will be presented in this chapter. Since it involves investment in a foreign country, foreign exchange risk management will be discussed as well.

## **7.2 Evaluation of Financial Investment in a Flexible Engine Production Plant for the Economy of Scope**

### **7.2.1 The Investing Companies and the Engine Plant Expansion Project**

Ford Motor Company is a global automobile manufacturer headquartered in Dearborn, Michigan, United States. The company is the third largest car and truck producer in the world based on sales and production. As one of the global automotive industry leader, the company has significant business operations in all major regions and countries around the world.

With continued economic development in China over the last twenty years, business perspective for foreign investment remains promising. Since the early 1990s Ford Motor Company has been successfully pursuing a growth oriented business strategy to expand its business operations in China and other markets.

Jiangling Motor Corporation (JMC) is one of the major manufacturers of engines, light trucks, and mini vans in south China. With continuous improvement in quality, product design, and cost effectiveness, the company has successfully evolved from an automobile part supplier to a major engine and vehicle manufacturer in China. The new development strategy, since its joint-venture with Ford Motor Company in the middle 1990s, has focused on new product design, high product quality, competitive pricing, and superior customer service. Market demand for its products has been very strong since the

late 1980s, and this trend is expected to continue well into the future after its joint venture with Ford. The company has its own engine plant where all engines are manufactured and tested. Most of these engines have been used in the power-train systems in the vehicles the company has been producing, with a small percentage of the engines sold to other vehicle manufacturers, this part of the business is set to grow in the future.

After the joint venture with Ford, market demand for its light trucks, Transit mini buses, sport utility vehicles, and engines become even stronger. Top management of Jiangling Motor Corporation has been considering the expansion of its production capacity, especially its engine production capacity.

For the expansion of the engine plant, the company planned to invest in a relatively small scale in the beginning in order to improve productivity, operational efficiency, and quality of the current engine plant to meet current market demand. In the next two years, the company intended to expand its current engine plant into a modern production facility with additional new buildings, new equipment with automatic material handling systems, and advanced manufacturing process. This expansion will ensure that the engine plant could produce two or three additional types of engines to meet customer demand for their new vehicle manufacturing plans, and remain competitive and responsive for new product development within the company. With this expansion strategy for the economy of scope, the investing companies, both Ford and Jiangling Motor Corporation, will be able to produce and sell multiple types of automobile engines on a common production platform with similar production technology and the same production facility, resulting in cost advantage, production efficiency, and market

responsiveness. These advantages will be the foundation for long term business growth and profitability of the joint venture company.

The current engine plant includes five component production lines and one assembly line. A technical assessment team with engine plant managers, engineers, as well as corporate financial managers has estimated that an initial investment of 40 million US dollars would be required to purchase necessary equipment to improve the current manufacturing capability and meet market demand for the next two years. During year 2, an additional investment of 120 million US dollars will be necessary to expand the engine plant in both production capacity and flexibility to meet future market demand for more types of products.

Recognizing the new investment project in the engine plant will have a strategic impact on the long term development of the company, the technical and financial teams agreed to perform an economic evaluation of the project with both traditional Net Present Value evaluation as well as a Real Options Analysis. Although the investment project will be implemented in China, a major part of the investment will be contributed by Ford Motor Company, economic evaluation of the investment project will be performed in US dollars. All investment requirements and operation cash flows will first be estimated in Chinese Yuan and then converted into US dollars at the time of evaluation. Foreign exchange risk will be considered when appropriate. Detailed financial information estimates and investment evaluations will be presented in the following sections.

## 7.2.2 Project Evaluation with Traditional Net Present Value Analysis

### 7.2.2.1 Weighted Average Cost of Capital as Project Required Rate of Return

To determine the project required rate of return, we will need to calculate the weighted average cost of capital (WACC) for Ford Motor Company which is one of the major investors, and the specific risk associated with the project. To estimate the weighted average cost of capital (WACC) for Ford Motor Company, we will use the most recent financial information of the company and the average market rate of return. Financial information from the public source such as Bloomberg Financial and Market Watch was used in this section.

From the most recent consolidated financial statements of Ford Motor Company for the period ended December 31, 2005, we have,

$$\text{Interest Expense} = \$ 1,220 \text{ Million}$$

$$\text{Long Term Debt, } D = \$ 16,900 \text{ Million}$$

The most recent average cost of debt for Ford Motor can be estimated as,

$$k_d = \text{Interest Expense} / \text{Long Term Debt}$$

$$= 1220/16900 = 0.0722 = 7.22\%$$

Also from the most recent income statement, we can calculate the actual tax rate as follows:

$$T_r = \text{Income Tax Expense} / \text{Income Before Tax}$$

$$= 512 \text{ million USD} / 1996 \text{ million USD} = 0.26 = 26\%$$

From Bloomberg financial, the 10-year US Treasury-Bill current rate can be found as the **risk free rate of return**,

$$r = 4.625\%$$

From UBS Financial Service, we can find the year-to-date rate of return on S&P 500 Index as the average market rate of return,

$$k_m = 0.1407 = 14.07\%$$

From Ford Motor Company's key financial statistics, we have the company Beta,

$$\beta = 2.27$$

According to the Capital Asset Pricing Model, we can estimate the cost of equity as follows,

$$\begin{aligned} k_e &= r + \beta (k_m - r) \\ &= 0.04625 + 2.27 * (0.1407 - 0.04625) = 0.2607 \end{aligned}$$

With Total Equity (Market Cap), E = \$ 15,430 Million, Weighted Average Cost of Capital for Ford Motor Company will be,

$$\begin{aligned} WACC &= k_d (1 - T_r) [D/(D+E)] + k_e [E/(D+E)] \\ &= 0.0722 (1 - 0.26) [16900/(16900 + 15430)] + \\ &\quad 0.2607 [15430/(16900 + 15430)] \\ &= 0.15 = 15\% \end{aligned} \tag{7.1}$$

Considering both the private risk involved with financial investment in an international market, and the relative financial stability of the economy in China, following Ford Motor Company's risk management policy, it is assumed to be appropriate to add a 4% risk premium to the weighted average cost of capital, so as to

account for the added risk associated with this specific investment projects. Therefore, the *Required Rate of Return* for this project will be:

$$\begin{aligned} k &= \text{RRR} = \text{WACC} + \text{Project Specific Risk Adjustment} \\ &= 15\% + 4\% = 19\% \end{aligned} \quad (7.2)$$

This required rate of return will be used for this project evaluation.

#### **7.2.2.2 Estimate of Sales Revenue and Cost of Production**

The investment in the engine plant expansion project will be implemented in two phases:

**Phase I**, a relatively small initial investment of 40 million US Dollars will ensure the smooth operation of the current plant to meet ongoing market demand for the next two years, while technical evaluation and vendor selection for the new technology and equipment to be used in the expanded new plant will be carried out.

**Phase II**, a larger investment of 120 million US Dollars in year 2 for new facility and equipment to expand the plant into a new engine manufacturing facility with a wider scope of production capacity and better flexibility to meet future market demands.

Sales revenue for the engine plant for year 1 has been estimated at 152 million US Dollar, and will increase by 5% from year 1 to year 2. Revenue in year 3, one year after the engine plant expansion completed, is projected at 272 Million US Dollar, and it is expected to grow by 5% for the following five years, given strong market demand and growth potential.



Jiangling Motor Corporation has been well known for its cost effectiveness. With an appropriate depreciation schedule and tax rate information, the total cost of goods sold, including all variable and fixed costs, depreciation and interest expense, has been estimated at 132 million US Dollars in year 1, and 238 million US Dollars in year 3. Similarly cost is assumed to increase by 5% annually.

### **7.2.2.3 Project Net Present Value Analysis with Monte Carlo Simulation**

#### **(1) Selection of Risk Factors as Simulation Input**

The net present value for any investment project is most closely related with sales revenue and total cost of the business operation.

In the analysis of the Ford-JMC Engine Plant Expansion Project, we will choose total sale revenue and total cost as the simulation input. Based on the most recent experience of the top management and the sales forecast on market demand, the most likely value of sales revenue for the engine plant for year 1 has been estimated at 152 million US Dollars, and will increase by 5% from year 1 to year 2. Revenue in year 3, one year after the engine plant expansion is completed, is projected at 272 Million US Dollars, and it is expected to growth by 5% for the following five years, given the strong market demand and growth potential. To reflect the market risk in demand, all annual sales revenue values are assumed to be random variables following Pert distributions with appropriate minimum, most likely, and maximum values assigned in Table 7.1.

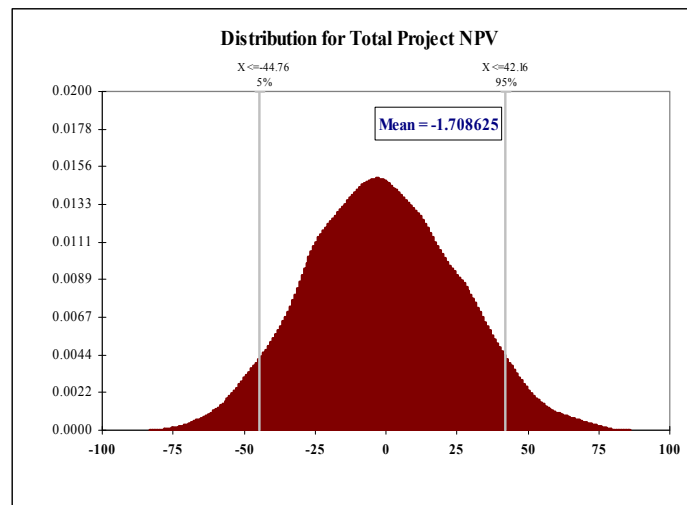
**Table 7.1 Simulation of Project Annual Cash Inflows and Net Present Value**

<b>Input Data (Base Value)</b>		<b>Distributions for Inputs</b>							
Revenue at year 1	152	Pert (132,152,174)							
Revenue at year 3	272	Pert (236,272,312)							
Total Cost at year 1	132	Pert (118,132,145)							
Total Cost at year 3	238	Pert (214,238,261)							
Tax Rate	0.33	Fixed							
MARR	0.1900	Fixed							
<b>Income Statement</b>									
<b>Year</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
<b>Sales Revenue</b>		152.33	160.50	272.67	285.67	299.83	315.00	330.17	347.17
<b>Total Cost</b>		131.83	137.83	237.83	249.83	261.83	275.67	287.00	302.67
Taxable Income		20.50	22.67	34.83	35.83	38.00	39.33	43.17	44.50
Income Tax at 33%		6.77	7.48	11.50	11.83	12.54	12.98	14.25	14.69
<b>Net Income</b>		13.74	15.19	23.34	24.01	25.46	26.35	28.92	29.82
<b>Cash Flow Statement</b>									
Cash Flow from Operations		13.74	15.19	23.34	24.01	25.46	26.35	28.92	186.74
Net Investments	<b>40.00</b>		<b>120.00</b>						
<b>Net Cash Flow</b>	(40.00)	13.74	(104.81)	23.34	24.01	25.46	26.35	28.92	186.74
<b>Overall Project NPV</b>				<b>- 1.71</b>					
<b>Project Phase I NPV (NPV1)</b>				<b>-17.73</b>					
<b>Current Value of Project Phase II Cash Inflows Vo</b>				<b>100.76</b>					

With appropriate tax rate information of 33% (China tax rate for companies with foreign investment), total cost of goods sold, including all variable and fixed costs, has been estimated at 132 million US Dollars in year 1, and 238 million US Dollars in year 3. Similarly cost is assumed to increase by 5% annually, and all annual costs are random variables following Pert distribution.

- (2) Simulation Distribution of Overall Project NPV and Expansion Project Value Vo

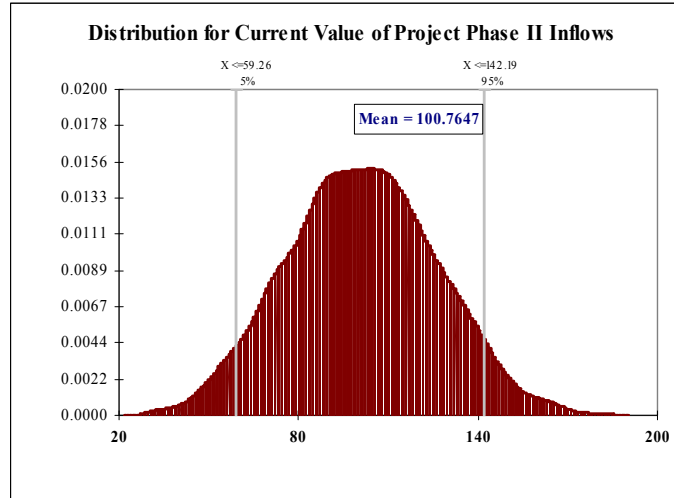
With sales revenue and total cost set up as simulation inputs in Table 7.1, stochastic distributions for overall project net present value (NPV), the net present value for Project Phase I (NPV<sub>1</sub>), and the net present value of all cash inflows in Project Phase II, which is  $V_o$ , can be estimated with Monte Carlo simulation. With 10,000 iterations a distribution for total project NPV was simulated with output shown in Figure 7.1. And the simulation output for the current value of project Phase II cash inflows,  $V_o$ , was given in Figure 7.2 below.



**Figure 7.1** Distribution of Total Project NPV

As we can see from the simulation output in Figure 7.1, total project NPV is roughly normally distributed around a mean value of  $-1.71$  Million USD. And current value of the expansion project,  $V_o$ , is also roughly normally distributed with a mean value of,

$$V_o = 100.76 \text{ Million USD} \quad (7.3)$$



**Figure 7.2    Distribution of the Present Value of Project Phase II Cash Inflows**

and a standard deviation of 25.40 Million USD. These values will be used in the later section to estimate the volatility of the project value. It can be noted that the present value of the expansion project will always be positive, with a minimum value of 11.67 Million USD and a maximum value of 186.86 Million USD.

The net present value for Project Phase I is,

$$NPV_1 = - 17.73 \text{ Million USD} \quad (7.4)$$

This negative NPV for Phase I investment is due to the relatively large initial investment to run current production, and to have the capability for future flexible expansion with additional investment, also due to the small net cash inflows in the first two years with limited scope of production. For the phased investment project for engine plant expansion, it is hoped that future production for a wider scope of product supply after Phase II investment is completed will bring better returns and give the investing company a better competitive advantage in the market.

The overall project NPV, considering initial investment and expansion investment, as well as all cash inflows from operations, is,

$$\text{NPV} = -1.71 \text{ Million USD} \quad (7.5)$$

According to traditional net present value evaluation, this investment project may not be approved.

### **7.2.3 Project Evaluation with Real Options Analysis**

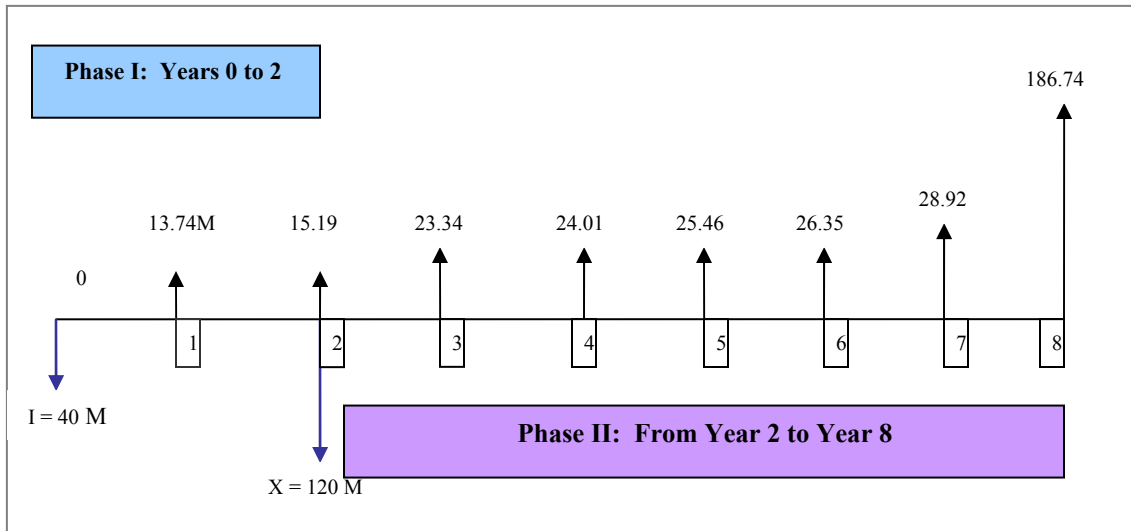
The financial investment in the Ford-JMC joint venture engine plant could also be evaluated with real options analysis. In order to do so, the phased investment project is put in a real options framework, and the key parameters required to conduct a real options analysis have to be determined.

As has been discussed in early sections, in order to keep the original production running while preparing for the expansion project in year 2, it is necessary to carry out the whole project in two phases. This approach will allow management the flexibility to modify the scale of investment according to market development. The value of flexibility in making investment decisions can be valued in a real options perspective. In other words, real options analysis is well fitted for economic evaluation of phased investment in the industry. In our analysis of the Ford-JMC joint venture engine plant expansion project, the whole investment will be implemented in two phases:

**Phase I:** Invest 40 million US Dollars in the current engine plant now, so as to make necessary improvements in the engine plant manufacturing process and equipment, to meet the current market demand for at least two years. This phase of

investment is necessary not only to keep the current operation, but to prepare for future investment to expand the engine plant if market development is favorable.

**Phase II:** Invest 120 million US Dollars in year 2 to expand the current engine plant into a larger engine manufacturing facility with the flexibility to produce more types of products for strategic growth in the future, given positive economic development and strong market demand. The Phase II investment is only an option to the joint venture company, although it is highly likely that the company would choose to do so in order to keep its competitive market position and grow its business.



**Figure 7.3 Investment Requirements and Cash Flow Schedule in Millions of US Dollars Estimated at the Beginning of 2005**

Cash flow for each year has been estimated with Monte Carlo simulation, and the investment and cash flow schedule is shown in Figure 7.3.

### **7.2.3.1 Parameter Estimate for Real Options Analysis**

In order to conduct a real options analysis, we need to estimate all basic parameters. Those parameters are: the current value of the expansion project cash inflows in Phase II, investment cost for the expansion, time from now to make the expansion decision, risk free rate of return, and the volatility of project value.

#### **[1] Current Value of All Cash Inflows after the Expansion**

As we already estimated with Monte Carlo simulation, the current value of all future cash inflows after expansion in year 2, discounted at the project required rate of return of 19%, is,

$$V_0 = 100.76 \text{ Million USD} \quad (7.6)$$

#### **[2] Investment Required for the Expansion Phase Implementation**

Based on a review of investment requirements for similar projects recently implemented in China, the management has estimated that the investment required for the expansion in project Phase II will be,

$$X = 120.00 \text{ Million USD} \quad (7.7)$$

which represents the exercise price of the real option to expand the production capacity for a wider scope of supply.

#### **[3] Time to Make the Expansion Decision**

Although the time to expansion could be any time from now into the next few years, management has come to a understanding that starting the expansion two years from now would be most appropriate, given the time required to finalize the technical design for the expanded engine plant, the time required to select the best vendors for

machines and equipment, and the need to have a larger engine production capacity as soon as possible to capture the best growth opportunity, therefore, time to exercise the expansion option is set in two years from now.

$$T = 2 \text{ years} \quad (7.8)$$

#### **[4] Risk Free Rate of Return**

Although the 10-year US Treasury bill rate of return can be used as the risk free rate of return for investment evaluation, the fact that the investment will be made in a foreign country usually raises expected rate of return, it is therefore appropriate to adjust the US risk free rate of return slightly upward to reflect a higher expected risk free rate of return for investment made in a foreign country, such as China.

The average rate of return on 10-year US Treasury Bill in 2005 (when the investment project was initially evaluated) was 4.29%, with an upward adjustment of 1.75% to reflect higher expected return for investment in a foreign country, the risk free rate of return for real option valuation is,

$$r = 4.29\% + 1.75\% = 6.04\% \quad (7.9)$$

#### **[5] Volatility of the Phase Two Project Value**

Volatility of the project value generated by the cash inflows during the expansion phase is a key parameter in real options evaluation. Similar to the valuation of financial options, the higher the variability of the underlying asset, it is likely that the more valuable the option written on the underlying asset will tend to be. Therefore it is very important to estimate the volatility of the project value appropriately. In real options



analysis there are several approaches to estimate project volatility, here we will present two base estimates with regard to the Ford-JMC engine plant expansion project.

#### **A. Estimate Volatility of Project Value with Monte Carlo Simulation**

##### **<1> Estimate Project Value Volatility with the Coefficient of Variance of the Expansion Project Value $V_0$**

As discussed in earlier sections, the current value of the expansion project,  $V_0$  can be obtained from Monte Carlo simulation with appropriate input values and their probability distributions. The output of project value estimate comes with a mean value of 100.76 Million USD, and a standard deviation of 25.40 Million USD, the expansion phase (optioned phase) project value volatility can be estimated with its own coefficient of variance:

$$\sigma_1 = \frac{SD(V_0)}{E(V_0)} \quad (7.10)$$

or,

$$\sigma_1 = 25.40/100.76 = 0.25 \quad (7.11)$$

##### **<2> Estimate Project Value Volatility with Return on Project Value**

As it has been discussed in the literature and in Chapter 6, project value volatility could also be estimated with the standard deviation of the return on project value. Two project values can be calculated from estimated future project cash flows at the beginning

of the investment project as  $V_0$  and at the end of year one as  $V_1$ , continuously compounded annual return on the optioned project value,  $k$ , is defined as,

$$k = \text{Ln}\left(\frac{V_1}{V_0}\right) \quad (7.12)$$

Where,

$$V_0 = \sum_{i=0}^N \frac{CF_i}{(1+k)^i} \quad (7.13)$$

$$V_1 = \sum_{i=1}^N \frac{CF_i}{(1+k)^i} \quad (7.14)$$

Here  $CF_i$  should only include the cash inflows generated in the optioned phase of the investment project from year  $(T+1)$  to year  $N$ . In the FDM-JLC engine plant expansion project evaluation, those cash flows are the ones generated in the expansion phase after year 2.

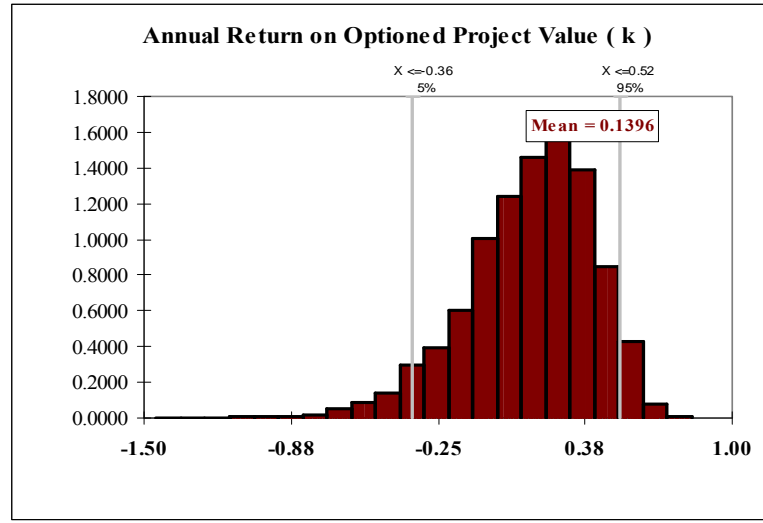
With Monte Carlo simulation, return on the optioned (Phase II) project value,  $k$ , can be estimated as a simulation output. The estimated initial project value volatility is the standard deviation of the project return  $k$ , or,

$$\sigma_2 = \text{Standard Deviation of } (k) \quad (7.15)$$

From our simulation, the output for this value is,

$$\sigma_2 = 0.27 \quad (7.16)$$

And the distribution of the continuously compounded annual rate of return on the optioned project value,  $k$ , based on equation (7.12), is shown in Figure 7.4.



**Figure 7.4** Distribution of the Return on Phase II Project Value  $k$

The simulation distribution of the annual rate of return on the expansion project value is roughly normally distributed, consistent with the basic assumptions made in the development of financial option pricing theory, where it is assumed that the annual return on an optioned share of common stock follows a normal distribution, and the stock price itself follows a lognormal distribution. Similarly it is assumed in real option analysis that annual return on optioned project value roughly follows a normal distribution.

Considering the expanded flexible production capacity of the flexible manufacturing system, for which additional investment was made in year 2, to meet potential market demands in the future during the optioned phase of the project life, the total project volatility for investment in a flexible manufacturing system can be estimated as,

$$\sigma_F = F_i \cdot \sigma \quad (7.17)$$

Where,  $F_i$  is the flexible production capacity index defined in section 6.2 as,

$$F_i = \frac{N_c}{N_d} \quad (7.18)$$

Here,  $N_c$  is the number of different types of products that can be produced with the flexible manufacturing system, in case such a system is designed to cover a wider variety of products;  $N_d$  is the projected number of different types of products demanded in the future.

Assuming that the number of different types of products that can be produced with the flexible manufacturing system is,

$$N_c = 5$$

And the projected number of different types of products demanded during the life of the investment project is,

$$N_d = 4$$

The flexible production capacity index for the expanded engine plant will be:

$$F_i = \frac{N_c}{N_d} = \frac{5}{4} = 1.25 \quad (7.19)$$

That means, after the additional investment of 120 million US Dollar in year 2, the expanded engine plant has a flexible production capacity to cover possible new types of products that could be in demand in the future of the project life, and still has a 25% flexible production capacity reserve, based on the best estimate of the types of products demanded in the future.

With a flexible production capacity index of 1.25, the total volatility of the expansion project value can be estimated as,

$$\begin{aligned}\sigma_F &= F_i \cdot \sigma \\ &= 1.25 \times 0.25 = 0.3125\end{aligned}\tag{7.20}$$

Here expansion project value volatility was used to determine the investment project volatility.

## **B. Approximation of Project Value Volatility with Investing Company Historical Stock Return Volatility**

From the most recent weekly historical stock price of Ford Motor Company from January 01, 2005 to June 30, 2006, we can calculate the continuously compounded weekly rate of return as,

$$r_i = \ln\left(\frac{P_i}{P_{i-1}}\right) \quad i = 1, 2, \dots, N \tag{7.21}$$

Where  $P_i$  and  $P_{i-1}$  are two consecutive weekly stock prices.

The sample standard deviation of these weekly returns, is calculated as,

$$s = 0.0448 \tag{7.22}$$

The annualized volatility of Ford stock return will be,

$$\sigma = \frac{s}{\sqrt{7/365}} = 0.3235 \tag{7.23}$$

With similar considerations of flexible production capability index, and based on investing company's historical stock return volatility, the estimate of the investment project volatility will be,

$$\begin{aligned}\sigma_F &= F_i \cdot \sigma \\ &= 1.25 \times 0.3235 = 0.4044\end{aligned}\tag{7.24}$$

Since Ford Motor Company is the major investor in the engine plant expansion project, and the investment evaluation is performed from the major investor's point of view, it is appropriate to use the project volatility estimated from the historical stock return volatility of the investing company, therefore, volatility for real option evaluation of the investment project will be,

$$\sigma_F = 0.4044 \quad (7.25)$$

### 7.2.3.2 Real Options Evaluation of the Investment Project

With all the necessary parameters estimated in the last section, the Ford-JMC joint venture engine plant expansion project Phase II could now be evaluated as a real option. Since the time to make the expansion decision is 2 years, which was determined by the management together with technical and financial staff of the company, to allow just enough time to carry out the technical design, process evaluation, and vendor selection; also not to wait too long to miss the high market demand; it is therefore appropriate to evaluate the real option as a two-year European call option, where,

$$\begin{aligned} V_0 &= 100.76 \text{ M USD} & X &= 120.00 \text{ M USD} \\ T &= 2 \text{ years} & \sigma &= 0.4044 \\ r &= 6.04\% \end{aligned}$$

Applying Black-Scholes Model for a European call option evaluation, we have,

$$c = V_0 N(d_1) - X e^{-rT} N(d_2) \quad (7.26)$$

Where,

$$d_1 = \frac{\text{Ln}(V_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$$

$$= \frac{\text{Ln}(100.76 / 120) + (0.0604 + 0.4044^2 / 2) \times 2}{0.4044\sqrt{2}} = 0.1916$$

$$d_2 = d_1 - \sigma\sqrt{T} = 0.1916 - 0.4044\sqrt{2} = -0.3803$$

$$N(d_1) = 0.5760 \quad N(d_2) = 0.3519$$

From equation (7.26),

$$c = 100.76 \times 0.5760 - 120 e^{-0.0604 \times 2} \times 0.3519$$

$$= 20.61 \text{ Million USD} \quad (7.27)$$

This real option value is the value of the Phase II investment project with the option to expand the engine plant in two years from now, in order to capture future growth potential in market demand.

After investing the initial 40 million USD to improve and keep the operation of the engine plant, the Ford-JMC joint venture company has the option to expand the engine plant into a wider scope engine manufacturing facility to meet growing market demand for different types of automobile engines. **The Strategic Net Present Value** for the combined investment project, which is the net present value of the initial Phase I investment, plus the real option value to expand the production capacity with additional investment in year 2, is therefore,

$$\begin{aligned} \text{SNPV} &= \text{Net Present Value of Initial Phase I Investment} + \\ &\quad \text{Real Option Value to Expand in Year 2} \\ &= -17.73 + 20.61 \\ &= 2.88 \text{ Million USD} \end{aligned} \quad (7.28)$$

The combined value of project Phase I and the value of investment in expansion in Phase II, is estimated to be 2.88 Million USD. The company should approve this investment project based on real option analysis. The company should invest in Phase I now, and be prepared to implement the engine plant expansion in year 2 for future production and benefit with a wider scope of supply in Phase II.

### 7.2.3.3 Sensitivity Analysis of Project Option Value to Changes in the Value of Key Input Parameters

Real option value depends on the value of parameters associated with the option. It is important to understand how sensitive the option value is to changes in each of the input parameter value. In this section we will perform a sensitivity analysis of the value of the option evaluated in the previous section.

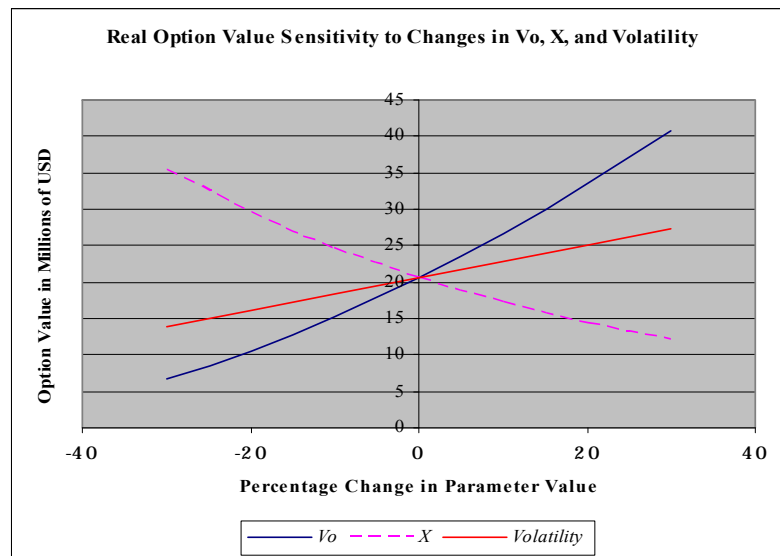


Figure 7.5 Real Option Value Sensitivity to Changes in  $V_0$ ,  $X$ , and Volatility



By changing the value of one parameter at a time, while keeping all other parameters unchanged, sensitivity charts can be generated with changing option values corresponding to percentage changes in the value of each parameter.

As we can observe from Figure 7.5, a 10% increase in  $V_0$ , the current value of all cash inflows in project Phase II, will cause a 30% increase in the real option value, although the decrease of the real option value is not so dramatic as the current value of project Phase II cash inflows decreases. As the exercise price  $X$  increases, the value of the real call option decreases quickly, a 10% increase in exercise price will cause the real option value to drop by 16%. Also as one could expect, real option value increases as the project value volatility, which represents market risk, increases: a 10% increase in volatility will cause the real option value to increase by about 11%, and a 10% decrease in volatility will lead to a 10.5% decrease in real option value.

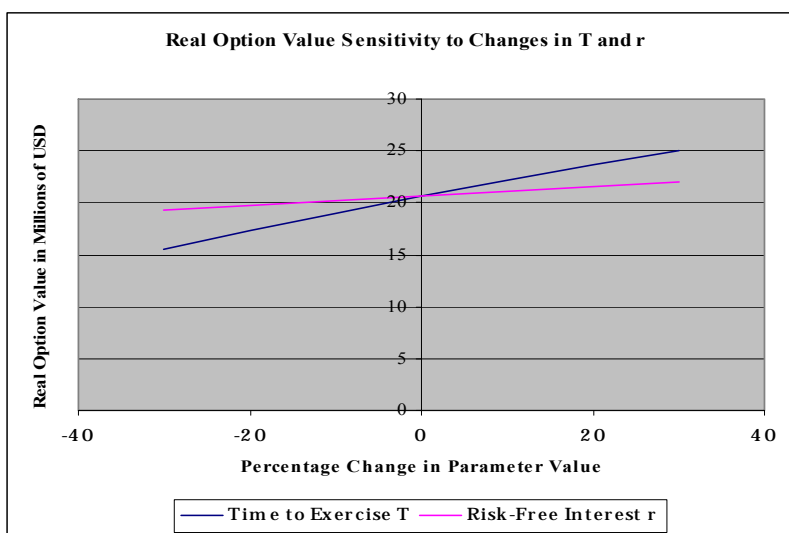


Figure 7.6 Project Real Option Value Sensitivity to Changes in T and r

Figure 7.6 represents the sensitivity of project real option value to changes in time to exercise and risk free interest rate. As we can see from Figure 7.6 above, a 10% increase in risk free interest rate will result in an increase of project real option value by only 2.2%, while a similar percentage increase in the time to expiration will increase the option value by roughly 7.5%.

### **7.3 The Impact of Changes in Foreign Exchange Rate on Investment Project Evaluation with Real Options Analysis**

In real options evaluation of financial investment in foreign countries, real option value of the investment project could be affected by changes in foreign exchange rate, mostly because of the fact that changes in foreign exchange rate will affect estimated operation cash flows and project value  $V_0$ , as well as initial investment  $I$  and expansion investment  $X$ . If the project evaluation has to be done in the home currency of the investing company, while investment requirements and operation cash flows are estimated in local currency and translated into investing company's home currency, the impact of changes in the foreign exchange rate over time on project value and investment requirements have to be considered.

For the Ford-JMC joint venture investment in the engine plant expansion project, all investment requirements and future operation cash flows are estimated in Chinese Yuan (CNY) at the beginning of 2005 and translated into USD with a single exchange rate of 8.2765 Chinese Yuan per US Dollar, or 0.1208 US Dollar per Chinese Yuan. Due to the time required for market research and technical planning, the actual project was

initiated at the beginning of 2007, time zero changed from beginning of 2005 to beginning of 2007. Then the actual project time line, investment requirements, and cash flow schedule, based on exchange rate of 0.1208 USD/CNY on January 01, 2005, had to be modified according to projected changes of exchange rate at the end of each year in the future in relation to the exchange rate on January 01, 2005, which was used to generate the base investment and cash flow schedule as shown in Figure 7.3 in section 7.2.3 above.

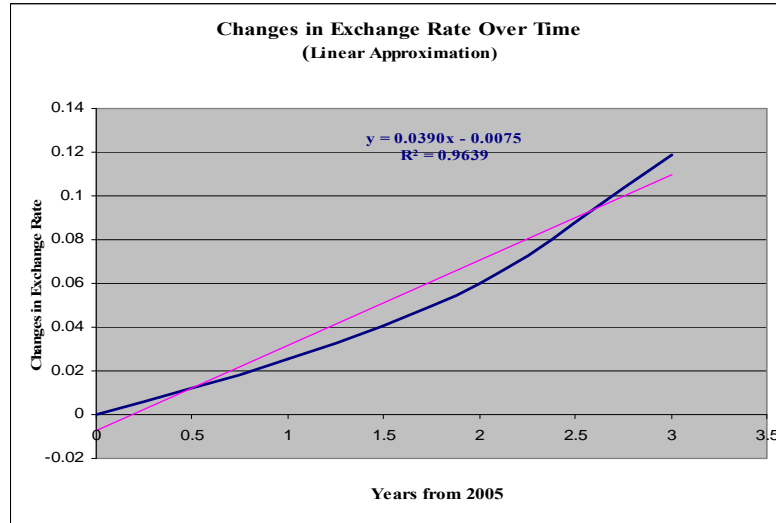
While the foreign exchange rate between the US Dollar and the Chinese Yuan changed gradually since the middle of 2005, investment requirements and cash flows in USD had to be modified according to the actual timeline, when the project was actually implemented in 2007.

In order to consider changes in initial investment I, investment for Phase II project expansion X, and operation cash flows with the projected exchange rates at the end of each future years from 2008 to 2015, historical data of USD-CNY exchange rate from January 2005 to December 2007 was collected from Bank of China published exchange rate information. Three regression models are developed to project possible trends of future exchange rate movement: The linear model, the second order polynomial model, and the third order polynomial model. The regression chart and model of each type are listed below with brief comments.

#### <1> **The Linear Model**

The mathematical model for a linear representation of the changes in exchange rate over time is,

$$Y = 0.0390 x - 0.0075 \quad (7.29)$$



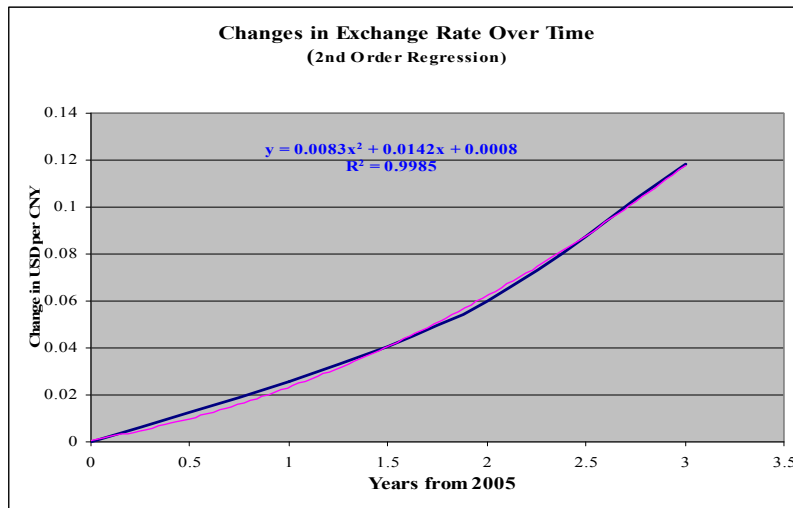
**Figure 7.7 Linear Model of Historical Exchange Rate Between USD and CNY (January 2005 to December 2007)**

Where  $Y$  is the accumulative change in US Dollar per Chinese Yuan since January 2005,  $x$  represents time in years since the beginning of 2005. A graphic representation of this model is shown in Figure 7.7. Based on the linear model projection, exchange rate between US Dollar (USD) and Chinese Yuan (CNY) at the end of 2015 will be approximately 0.1670 USD per CNY, or 5.9880 CNY per USD, verse 8.2781 CNY per USD at the beginning of 2005.

### <2> The Second Order Polynomial Model

Similarly, a second order polynomial model can be obtained as follows, with the same notation and covers the same period of historical data.

$$Y = 0.0083 x^2 + 0.0142x + 0.0008 \quad (7.30)$$



**Figure 7.8 2<sup>nd</sup> Order Model of Historical Exchange Rate Between USD and CNY (January 2005 to December 2007)**

A graphic representation of this model is shown in Figure 7.8.

Based on the second order model, an exchange rate of 0.2357 USD per CNY, or 4.2430 CNY per USD could be expected by the end of 2015 if the second order trend of Chinese Yuan appreciation during the last three years since 2005 continues through 2015.

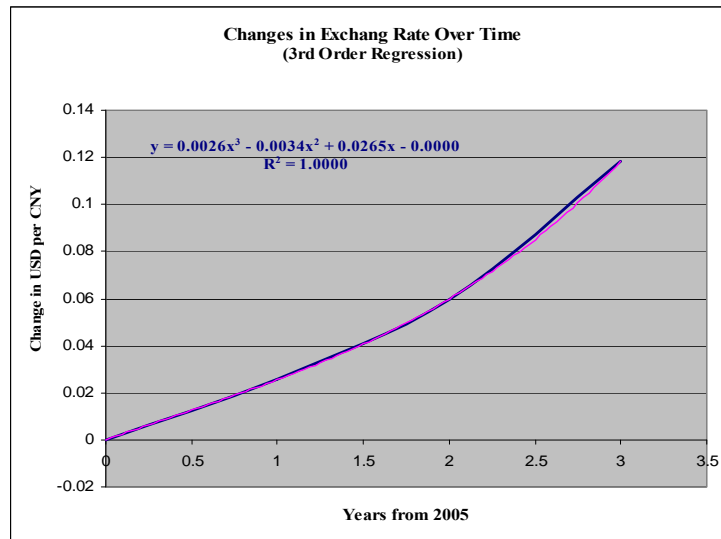
### <3> The Third Order Polynomial Model

With the same set of historical exchange rate data, a third order regression model can be developed as follows:

$$Y = 0.0026x^3 - 0.0034x^2 + 0.0265x \quad (7.31)$$

With a graphic representation in Figure 7.9.

The projection from this third order model indicates an even faster appreciation of Chinese Yuan against US Dollar in the future years. An exchange rate of 0.4258 USD per Chinese Yuan, or 2.3484 CNY per USD could be expected by the year of 2015 if the



**Figure 7.9 3<sup>rd</sup> Order Model of Historical Exchange Rate Between USD and CNY (January 2005 to December 2007)**

projection of the 3<sup>rd</sup> order model holds true until year 2015.

In order to select a reasonable regression model to estimate accumulative changes in exchange rate, the following major factors must be considered: a) The data set that was used to generate the regression models are relatively small with only 3 years of historical data, as compared to the whole project life of 8 years; b) The fast appreciation of Chinese Yuan against major foreign currencies, including the US Dollar, in the last 3 years, is based on the fact that the exchange rate of CNY against major foreign currencies has not changed much for a long time from the 1990s until 2005. The changes in exchange rate during the last three years is partially due to trade and economic policy discussions and dialogue between Chinese and US government agencies; c) The fast rate of appreciation of CNY against major foreign currency in the last three years is not likely

to continue long into the future, this rate of appreciation could slow down in the future;

d) For the economic evaluation of industrial investment project in China by an US company, the selection of an exchange rate projection model where Chinese Yuan appreciates too quickly against the USD well into the long future will largely and perhaps unrealistically boost the operation cash flows generated by such an investment project when annual operation cash flows are translated from Chinese Yuan into the US dollar, leading to risky investment decisions.

For the reasons discussed above, the linear model of exchange rate projection will be used to get a realistic and conservative estimate of accumulative changes in CNY vs. USD exchange rate since 2005, so that new investment requirements and operation cash flows in future years can be established based on the initial estimates made in 2005 according to the following equation:

$$M_i = (1 + \Delta E_i)M_0 \quad (7.32)$$

Where  $M_i$  represents future operation cash flow or investment requirement  $i$  years from 2005 based on projected future changes in exchange rate;  $M_0$  is the corresponding operation cash flow or investment requirement estimated at the 2005 exchange rate;  $\Delta E_i$  is the accumulative change in exchange rate  $i$  years from 2005.

The impact of changes in exchange rate on investment requirements and future operation cash flows is summarized in Table 7.2 below, where new investment requirements and cash flows after considering changes in exchange rate are re-calculated according to equation (7.32) and listed in the last two rows of the table.

**Table 7.2 Impact of Changes in Exchange Rate on Investment Requirements and Operation Cash Flows**  
(In Millions of US Dollars)

<i>Year</i>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>
Cash Flows at 2005 Ex Rate	0.00	13.74	15.19	23.34	24.01	25.46	26.35	28.92	186.74
Investments at 2005 Ex Rate	40		120						
Changes in Exchange Rate Since 2005 ( $\Delta E$ )*	<b>0.0599</b>	<b>0.1185</b>	<b>0.1485</b>	<b>0.1875</b>	<b>0.2265</b>	<b>0.2655</b>	<b>0.3045</b>	<b>0.3435</b>	<b>0.3825</b>
Cash Flows at Future Ex Rates	0.00	15.37	17.44	27.72	29.45	32.22	34.37	38.85	258.16
Investments at Future Ex Rates	42.40 (I)		137.82 (X)						

With the updated investment requirements and future operation cash flows in the last two rows of Table 7.2, Net present value for the initial phase of the investment project from 2007 to 2009,  $NPV_1$ ; the expansion project value  $V_0$  (the net present value of expansion phase cash inflows from 2010 to 2015), and the over all project net present value,  $NPV$ , can be calculated according to the following equation:

$$NPV = \frac{ECF_1}{(1+k)} + \frac{ECF_2}{(1+k)^2} + \dots + \frac{ECF_n}{(1+k)^n} - EI - \frac{EX}{(1+k)^j} \quad (7.33)$$

Where,

$ECF_i = (1+\Delta E_i) \cdot CF_i =$  Exchange rate adjusted cash inflow in year  $i$

$EI = (1+\Delta E_i) \cdot I =$  Exchange rate adjusted initial investment

$EX = (1+\Delta E_i) \cdot X =$  Exchange rate adjusted expansion investment

And  $k = 19\%$



is the required rate of return. For the Ford-JMC Engine Plant Expansion Project, we have: Initial phase project net present value,

$$NPV_1 = -42.40 + \frac{15.37}{1.19} + \frac{17.44}{1.19^2} = -17.17 \text{ Million USD} \quad (7.34)$$

Net present value of expansion phase project cash inflows,

$$\begin{aligned} V_0 &= \frac{27.72}{1.19^3} + \frac{29.45}{1.19^4} + \frac{32.22}{1.19^5} + \frac{34.37}{1.19^6} + \frac{38.85}{1.19^7} + \frac{258.16}{1.19^8} \\ &= 132.43 \text{ Million USD} \end{aligned} \quad (7.35)$$

And the total project net present value,

$$NPV = NPV_1 - \frac{137.82}{1.19^2} + V_0 = 17.94 \text{ Million USD} \quad (7.36)$$

Now after considering the impact of changes in exchange rate, we have an overall project net present value of 17.94 Million USD, even though the initial phase of the investment project has a negative NPV of 17.17 Million USD. For real options evaluation of the project value in the expansion phase, we will use the same parameter values except current value of expansion phase project cash inflows and expansion investment requirement, which will take exchange rate adjusted values:

$$\begin{aligned} V_0 &= 132.43 \text{ M USD} & X &= 137.82 \text{ M USD} \\ T &= 2 \text{ years} & r &= 6.04\% \\ \sigma &= 0.4044 \end{aligned}$$

Applying Black-Scholes Model for a European call option evaluation according to equation (7.26), we have,

$$c = V_0 N(d_1) - X e^{-rT} N(d_2)$$

Similarly,

$$d_1 = \frac{\ln(V_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$$

$$= \frac{\ln(132.43/137.82) + (0.0604 + 0.4044^2 / 2) \times 2}{0.4044\sqrt{2}} = 0.4274$$

$$d_2 = d_1 - \sigma\sqrt{T} = 0.4274 - 0.4044\sqrt{2} = -0.1445$$

$$N(d_1) = 0.6655 \quad N(d_2) = 0.4426$$

From equation (7.26),

$$c = 132.43 \times 0.6655 - 137.82 e^{-0.0604 \times 2} \times 0.4426$$

$$= 34.07 \text{ Million USD} \quad (7.37)$$

This real option value is the value of the optioned Phase II investment project to the investors. Total project value, or the strategic net present value of the overall investment project, will be,

$$\begin{aligned} \text{SNPV} &= \text{Net Present Value of Initial Phase I Investment} + \\ &\quad \text{Real Option Value to Expand in Year 2} \\ &= -17.17 + 34.07 \\ &= 16.90 \text{ Million USD} \end{aligned} \quad (7.38)$$

Compared with real options evaluation of the same investment project in section 7.2, where project investment requirements and operation cash inflows were based on 2005 USD-CNY exchange rate, strategic net present value of the overall investment project increased from 2.88 million USD to 16.90 million USD. This is due to the fact that Chinese Yuan (CNY) is expected to appreciate in relation to US Dollar (USD), which results in increases in both investment requirements and operation cash inflows,

and eventually an increased real option value for the expansion phase project, when accounted for in US Dollars.

It is also worth noting that after considering changes in exchange rate during the project life, even the overall project net present value, has increased from negative 1.70 million USD to positive 17.94 million USD, the overall investment project would be approved even based on traditional NPV standard alone.

#### **7.4 Concluding Remarks and Recommendations**

Both real options analysis and net present value evaluation of the Ford-JMC engine plant expansion project illustrates the common issues and typical economic evaluation process of investment analyses for strategic capital budgeting decisions in the automotive industry. With a special consideration of the fact that such industrial investment is made in a foreign country, the impact of changes in exchange rate during the life time of the project must be considered. Based on the evaluation presented in this chapter, consistent appreciation of the currency of the hosting country, where the actual operation cash flows are realized, will increase the project value when accounted for in the investing country's home currency. Similar principles and financial evaluation methods can be applied to capital budgeting processes in the general manufacturing industry as well as other industries for industrial investment in foreign countries.

The analysis presented here includes traditional Net Present Value evaluation, Monte Carlo simulation with key project economic inputs as random variables. It also illustrates the calculation of expected values of project Phase I NPV, the current value of

all cash inflows generated in project Phase II, as well as the estimated project value volatility, all these values are used as input parameters in the real options evaluation of the engine plant expansion project as a 2-year real European call option.

Unlike traditional NPV analysis, real option evaluation helps us to understand the true value of the management and operational flexibility in the timing and decision making for financial investment in the industry, where real world investment decisions have to be made, with regard to project value, market condition, as well as competitive landscape, which can be reflected indirectly in the project value volatility, average return in the market, and the timing to pursue certain projects.

Sensitivity analysis is conducted for real options evaluation, which gives us important insights into the sensitivity of the project real options value to changes in project input variables.

Based on our evaluation, we recommend that the real option to expand the joint venture engine plant should be taken and carried out as planned, which will not only return a positive value to the investing company in terms of Strategic Net Present Value (SNPV), but also help to put the company in a more competitive position in the dynamic China market, which is now an important part of the world market.

Investment evaluation considering changes in foreign exchange rate indicates that: 1) Changes in exchange rate between the investing company's home currency and the currency of the investment hosting country has to be considered when investment is made in home currency and revenue is realized in the currency of the hosting country; 2) Appreciation of the hosting country's currency relative to the investor's home currency

will tend to increase the value of the investment project to the investor, and a depreciation of the hosting country's currency will tend to reduce the value of the investment project to the investor.

CHAPTER 8  
FINANCIAL INVESTMENT IN A FLEXIBLE MANUFACTURING SYSTEM  
FOR INCREASED VOLUME OF PRODUCTION

**8.1 Introduction**

The economy of scale in the manufacturing industry originated from the fact that total unit cost of production declines as the total volume of production per period increases. Economy of scale can be achieved in many industries where market demand requires higher volume of production. In general the economy of scale can be a critical determining factor of the structure of a given industry: The higher the break even demand that has to be exist for a business in an industry to operate profitably, the stronger the need to develop the economy of scale, and the more concentrated the industry tends to be, that means a relatively small number of large firms are competing in the market. Conversely, if the minimum scale of efficient operation is small relative to total market demand, a fragmented market exists where many small and medium-sized firms serve the total demand of the market. Whenever economies of scale exist, firms in the industry will tend to direct their strategy towards building a large volume of production, although the economy of scope has to be considered at the same time given today's changing technology and consumer demand.

Typically the successes of firms in the automotive industry are built on both the economy of scope and scale. With the economy of scope firms thrive by offering wide selections of competitive products, while with the economy of scale firms accomplish financial success through cost advantage with high volume of production and competitive pricing strategies. The investment project for Ford-JMC engine plant expansion presented in the last chapter is a typical example of investment for the benefit of the economy of scope, where the expanded engine plant will have the capacity to supply a wider range of products to customers in the dynamically growing China market. In the following sections, real options evaluation of investment in an automotive electronics manufacturing plant will be presented. Success of the investment project will largely depend on stable and increasing market demand for certain types of products.

In the face of global competition, rising performance and fuel consumption standards, changing market demand and government regulations, manufacturers of automotive electronic products are more and more in favor of flexibility in technology development and production planning. Advanced manufacturing technologies, such flexible manufacturing systems, are able to provide automotive electronic suppliers with a competitive manufacturing strategy for quick response to changes in market demand either in the types of products or in the quantity of certain products demanded. A well designed flexible manufacturing system could enable auto electronics manufacturers to meet productivity, quality, and operation profitability objectives and stay competitive in the long run. An application of real options analysis to evaluate financial investment in a flexible electronics manufacturing system will be presented in this chapter to illustrate the

advantage of a specially designed flexible manufacturing system to capture the benefit of increased market demand while maintaining its capability to produce a main range of products during the life time of the investment project. Net Present Value evaluation will be presented first to get a basic understanding of the financial performance of the investment project from the perspective of traditional financial management, and to set up the base for simulation analysis in order to assess the risk associated with key project performance indicators, such as total project NPV. Simulation analysis will also help to generate important parameters for real options analysis.

## **8.2 Net Present Value Evaluation of Financial Investment in an Automotive Electronics Manufacturing Plant**

### **8.2.1 Phased Investment Requirements of the Project**

A leading supplier of automotive electronics in the United States is planning for an investment project to improve its production capability with flexible manufacturing systems to meet the growing market demand for advanced automotive electronics products. The objective of the investment project is to upgrade the company's current automotive electronic production facility according to a new strategic production capacity plan, which takes into consideration of the current production needs and the projected market demand for new product design with higher production volume in the next five to seven years. The investment project will involve in an initial investment of 160 million US dollars now for new manufacturing equipment such as automatic pick and place machines, SMT machines, wave Solder PTH machines, automatic optic inspection



machines, and other necessary equipment and technology to replace most of the outdated equipment and transform the current plant into a modern, efficient, and fully automatic auto electronics production facility, that will have shorter production process paths, better quality control, and enough flexibility to cover three major types of automotive control products: transmission control (TMC) units, engine control (EGC) units, and combined engine/transmission control (CBC) units, and leave the possibility open for increased volume of production in the future.

In order to meet increasing future market demand for those products, an additional investment of 110 million US dollars will be required three years from now to expand production capacity from 2.2 million units per year to 3.0 million units per year. The investment project will consider six years into the future from now, and will be implemented in two phases: Phase I, Invest 160 million US dollars now for production facility reengineering and upgrade with flexible manufacturing capabilities to meet current and projected production needs in the first three years, and to acquire enough flexibility in order to keep the option open for future investment in capacity expansion. Phase II, Invest an additional 110 million US dollars in special tooling and automation in year three for added production capacity, if market demand for the company's products is indeed going to grow in the future.

### **8.2.2 Operation Cash Flow Based on Estimated Market Demand**

Based on best available customer information and market demand forecast, annual demand for the company's major products: transmission control (TMC) units,

engine control (EGC) units, and combined engine/transmission control (CBC) units in the next seven years are estimated to grow at a low rate of two percent per year in the first three years, and to grow at a higher rate of six percent per year in the last four years, due to better production capability to manufacture basic modules as well as more sophisticated products, and due to the expansion of customer base. A detailed annual demand forecast during seven years of the project life is listed in Table 8.1 below.

**Table 8.1 Projected Market Demand for the Company's Products**  
(In Thousands of Units)

<i>Year</i>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
TMC		600	612	624	662	701	743
EGC		1100	1122	1144	1213	1286	1363
CBC		317	323	329	349	370	392
<b>Total</b>		2017	2057	2098	2224	2357	2499

From a market study and a survey of major customers, it is estimated that market demand for the three types of automotive controllers will increase by two percent in the first three years, and then increase by six percent annually from year three to six, due to improved economy and the rebound of the automotive industry, also due to higher quality and cooperative engineering and production planning with key customers, since the company will be able to better serve customers after the implementation of the investment project for better technology and flexible manufacturing equipment.

Although product quality will always be improved over time, and product design will become more and more efficient, automotive electronics manufacturers face constant

pressure from OEM companies to reduce cost, therefore it is expected that price of the automotive controllers will remain more or less stable over the life time of the investment project, with the selling price of 115 USD per unit for TMC controllers, 180 USD per unit for EGC controllers, and 250 USD per unit for CBC controllers. A summary of projected revenue is shown in table 8.2.

**Table 8.2 Summary of Projected Sales Revenue**  
(In Thousands of US Dollars)

<i>Year</i>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
TMC		69,000	70,380	71,788	76,095	80,661	85,500
EGC		199,833	203,830	207,907	220,381	233,604	247,620
CBC		80,222	81,827	83,463	88,471	93,779	99,406
<b>Total Revenue</b>		349,056	356,037	363,157	384,947	408,044	432,526

The investing company has implemented a continuous quality improvement program with lean production initiative. This program has been very successful and it is expected to continue well into the future. As a result of this quality improvement and lean production program, annual cost of both material and labor are expected to be reduced by two percent and one percent respectively, cost of warranty, and overhead cost, including administrative, marketing and sales, will be kept at their lowest level. A summary of the cost of production is listed in Table 8.3.

In order to account for the market risk and operational risk associated with quantity demanded, selling price, costs of material and labor, random variables were defined for these input factors, and Monte Carlo simulation was used to get an estimate of project annual cash flows over the six years under consideration.

**Table 8.3 Cost of Production for All Three Types of Controllers**  
(In Thousands of US Dollars)

Year	0	1	2	3	4	5	6
<b>TMC Specific Costs</b>							
Material		1,800	32,436	33,085	35,070	37,174	39,404
Material Economics			649	-1,310	-2,062	-2,886	-3,786
Labor		3,150	3,213	3,277	3,474	3,682	3,903
Labor Economics			-32	-65	-103	-145	-191
Overhead Allocation		6,458	6,521	6,585	6,910	7,251	7,610
Cost of Warranty		414	415	416	433	451	469
Total Variable Costs		41,822	41,904	41,987	43,721	45,527	47,409
Fixed Cost		8,500	8,925	9,371	9,840	10,332	10,848
Total Cost of Production		50,322	50,829	51,358	53,561	55,859	58,258
<b>EGC Specific Costs</b>							
Material		104,867	106,964	109,103	115,649	122,588	129,944
Material Economics			-2,139	-4,320	-6,801	-9,517	-12,485
Labor		12,375	12,623	12,875	13,647	14,466	15,334
Labor Economics			-126	-256	-405	-570	-752
Overhead Allocation		29,081	29,366	29,654	31,119	32,656	34,269
Cost of Warranty		1,463	1,467	1,471	1,532	1,596	1,663
Total Variable Costs		147,786	148,154	148,526	154,742	161,220	167,974
Fixed Cost		8,500	8,925	9,371	9,840	10,332	10,848
Total Cost of Production		156,286	157,079	157,897	164,581	171,552	178,823
<b>CBC Specific Costs</b>							
Material		52,778	53,833	54,910	58,205	61,697	65,399
Material Economics			-1,077	-2,174	-3,423	-4,790	-6,283
Labor		6,650	6,783	6,919	7,334	7,774	8,240
Labor Economics			-68	-138	-218	-306	-404
Overhead Allocation		14,963	15,109	15,257	16,011	16,802	17,632
Warranty		744	746	748	779	812	846
Total Variable Costs		75,134	75,327	75,521	78,688	81,988	85,429
Fixed Cost		8,500	8,925	9,371	9,840	10,332	10,848
Total Cost of Production		83,634	84,252	84,893	88,527	92,320	96,278
<b>Total Cost of Goods Sold</b>		<b>290,242</b>	<b>292,160</b>	<b>294,148</b>	<b>306,670</b>	<b>319,732</b>	<b>333,358</b>

Capital investments in manufacturing equipment and automation systems are considered to have a lifetime of five years, and therefore the five-year depreciation schedule was used to calculate fixed asset depreciation during the project life. The capital asset acquired through additional investment in year three will not be fully depreciated, but non salvage value will be assumed due to the fact that all the capital

equipment will continue to be used for production even after the sixth year. A brief income statement and statement of operational cash flow is given in Table 8.4.

**Table 8.4 Project Income and Cash Flow Statement**  
(In Thousands of US Dollars)

Year	0	1	2	3	4	5	6
Total Revenue		349,056	356,037	363,157	384,947	408,044	432,526
Cost of Goods Sold		290,242	292,160	294,148	306,670	319,732	333,358
Capital Investments	160,000			110,000			
Depreciation Rate 1		0.2000	0.3200	0.1920	0.1152	0.1152	0.0576
Depreciation 1		32,000	51,200	30,720	18,432	18,432	9,216
Depreciation Rate 2					0.2000	0.3200	0.1920
Depreciation 2					22,000	35,200	21,120
Total Depreciation		32,000	51,200	30,720	40,432	53,632	30,336
Income before Tax		26,814	12,677	38,289	37,845	34,680	68,832
Income Tax at 35%		9,385	4,437	13,401	13,246	12,138	24,091
Net Income		17,429	8,240	24,888	24,599	22,542	44,741
Operations Cash Flow		49,429	59,440	55,608	65,031	76,174	75,077
Investments	-160,000			-110,000			
<b>Total Cash Flow</b>	<b>-160,000</b>	<b>49,429</b>	<b>59,440</b>	<b>-54,392</b>	<b>65,031</b>	<b>76,174</b>	<b>75,077</b>

Although there will be future revenue realized beyond year six, it is important to recognize that modifications and upgrades of manufacturing technology and equipment will be required every three or four years, given the fast development and changes in technology, material, and product design in the automotive electronics industry. Those changes and technology upgrades will always require additional investment. And predication of market demand far into the future will be very difficult and not practical. For reasons mentioned here, it is conservative not to consider any future revenue beyond

the life of the current project, but rather leave it as the start point for next cycle of production planning and project evaluation at the end of the current project life.

### 8.2.3 Economic Evaluation of the Investment Project with Net Present Value

With operation cash flow of the investment project established through Monte Carlo simulation where market demand, price, and key cost factors are assumed to be random input variables, the financial performance of the phased investment project can be evaluated with net present value as follows.

For the initial investment of 160 million US dollars at the beginning of the project for advanced technology with flexible manufacturing capability, and for the purpose of running the current project until year three, project Phase I net present value can be calculated considering operation cash flows from year one to year three, and the initial investment, with a required rate of return of,

$$k_R = 15\% \quad (8.1)$$

which was estimated by the management based on the cost of capital of the investing company.

$$NPV_1 = \sum_{i=1}^3 \frac{CF_i}{(1+k_R)^i} - I \quad (8.2)$$

That is,

$$\begin{aligned} NPV_1 &= \frac{49.429}{(1+0.15)} + \frac{59.440}{(1+0.15)^2} + \frac{55.608}{(1+0.15)^3} - 160.000 \\ &= -35.510 \text{ Million USD} \end{aligned} \quad (8.3)$$



Nevertheless, a negative NPV for project Phase I does rise concerns among some financial and operational managers, if the positive perspective of the project Phase II was not fully taken into consideration, where expansion investment will not only help to create increased sales but also to make the company more responsive to changing market demand with added manufacturing flexibility at a higher volume of production.

Taking into consideration of all operation cash flows estimated from Monte Carlo simulation as shown in Table 8.4, the net present value of the overall investment project can be calculated as follows with both initial and additional investments included in the evaluation:

$$\begin{aligned}
 \text{NPV} &= \sum_{i=1}^6 \frac{(CF_i - X_i)}{(1 + k_R)^i} - I \\
 &= \frac{49.429}{(1+0.15)} + \frac{59.440}{(1+0.15)^2} + \frac{55.608 - 110.000}{(1+0.15)^3} + \frac{65.031}{(1+0.15)^4} + \\
 &\quad \frac{76.174}{(1+0.15)^5} + \frac{75.077}{(1+0.15)^6} - 160.000 \\
 &= - 0.325 \text{ Million USD} \tag{8.4}
 \end{aligned}$$

Here,

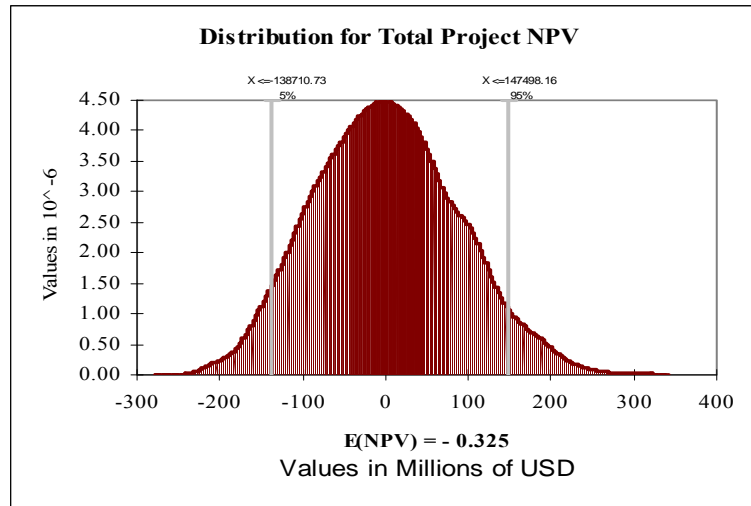
$$I = 160 \text{ Million USD} \tag{8.5}$$

is the initial investment. And

$$X_3 = X = 110 \text{ Million USD} \tag{8.6}$$

is the additional investment required in year three. The distribution of the total project net present value is graphed in Figure 8.2.





**Figure 8.2 Distribution of Total Project NPV**

The small negative overall project net present value of 0.325 million US dollars indicates that the project is a little short of break even according to traditional net present value evaluation. Even a small negative net present value will cause the project be rejected. Management of the investing company will be very cautious in undertaking this project based on net present value evaluation alone.

### **8.3 Real Options Analysis of Financial Investment in the Automotive Electronics Manufacturing Plant**

The same investment project with phased investments in the automotive electronics manufacturing facility discussed in the last section could also be evaluated in a real options perspective. The initial investment will not only serve the purpose for current production until a further investment decision can be made up to year three, it

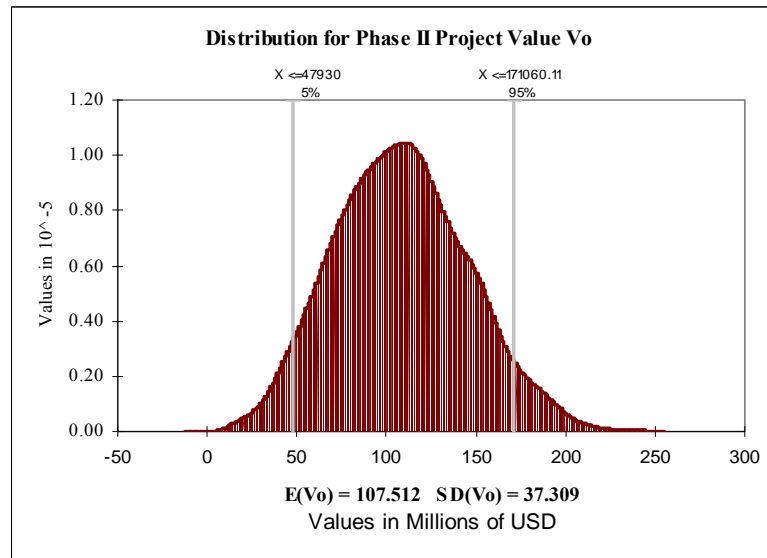
also serve the purpose to create the base for manufacturing flexibility in order for the investing company to respond quickly to future increase in market demand of its automobile control units. If the projected market demand does increase in the future, an additional investment will be committed to capture the increased market demand. If future market demand turns out to be flat or even decreasing, the company will stay with the initial investment and continue its current production. The management flexibility in making phased investment decisions according to market development has value by itself. This value of management flexibility can be estimated with real options analysis, applying financial option pricing theory with key input parameters estimated from real world investment project.

### **8.3.1 Parameter Estimation for Real Options Analysis**

Five key parameters need to be estimated before real options analysis can be applied to get an estimate of the real option value of the Phase II investment in the automotive electronics manufacturing facility under consideration. Two of the most important parameters, current value of operation cash flows generated in Phase II of the investment project,  $V_0$ , and volatility of the return on optioned (Phase II) project value,  $\sigma$ , can be estimated with Monte Carlo simulation, while additional investment,  $X$ , is estimated by the management, time to implement additional investment is determined as three years from now, and the risk free interest rate is the ten-year US treasury bill rate. A summary of the parameter estimate is given below.

**<1> Current Value of Project Phase II Cash Flows, Vo**

With market demand, selling price, and cost components estimated in the last section, the net present value of project Phase II cash inflows, discounted at a required rate of return of 15%, can be determined through Monte Carlo simulation.



**Figure 8.3 Distribution of Optioned Project Value Vo**

The expected value of Vo can be calculated with the expected cash flows from year four to year six.

$$\begin{aligned}
 V_o &= \sum_{i=4}^6 \frac{CF_i}{(1+k_R)^i} \\
 &= \frac{65.031}{(1+0.15)^4} + \frac{46.174}{(1+0.15)^5} + \frac{75.077}{(1+0.15)^6} \\
 &= 107.512 \text{ Million USD} \tag{8.7}
 \end{aligned}$$

The distribution of the optioned Phase II project value  $V_0$  is shown in Figure 8.3.

**<2> Project Phase II Investment Requirement, X**

Investment required to implement the capacity expansion for a higher volume of production for the flexible manufacturing system, is estimated at 110 million USD. This value is determined by the management and the production planning team in close contact with the equipment suppliers. This investment requirement is typically much higher with an automatic material handling system.

**<3> Estimate of Project Value Volatility,  $\sigma$**

The base volatility of the optioned project value can be estimated with the coefficient of variance of the optioned project value,  $V_0$ ,

$$\sigma_1 = \frac{SD(V_0)}{E(V_0)} \quad (8.9)$$

From the simulation output,

$$E(V_0) = 107.512 \text{ Million USD} \quad (8.10)$$

$$SD(V_0) = 37.309 \text{ Million USD} \quad (8.11)$$

And the first estimate of the base volatility is,

$$\sigma_1 = \frac{37.309}{107.512} = 0.3470 \quad (8.12)$$

A second estimate of the base optioned project value volatility can be obtained through the estimate of volatility of the return on optioned (Phase II) project value, where two project values can be calculated from estimated project Phase II cash flows at the

beginning of the investment project as  $V_0$  and at the end of year one as  $V_1$ , and then define continuously compounded annual return on the optioned project value,  $k$ , as,

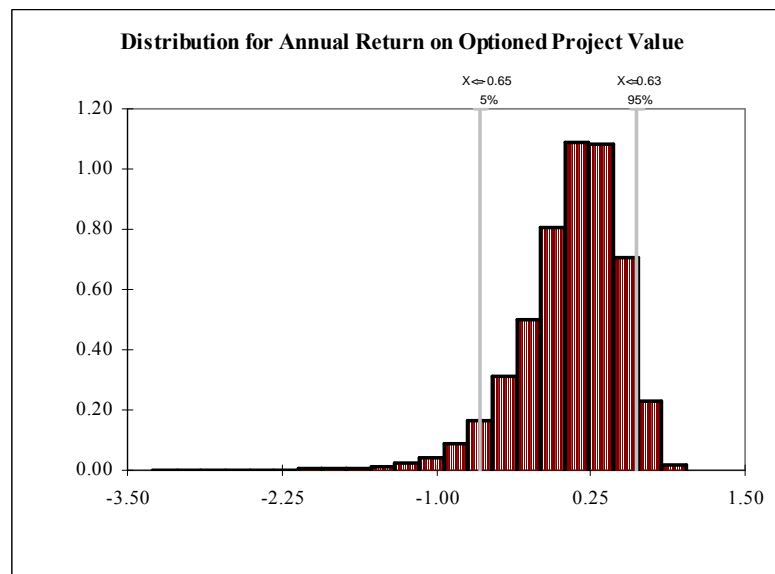
$$k = \text{Ln}\left(\frac{V_1}{V_0}\right) \quad (8.13)$$

Where,

$$V_0 = \sum_{i=0}^N \frac{CF_i}{(1+k)^i} \quad (8.14)$$

$$V_1 = \sum_{i=1}^N \frac{CF_i}{(1+k)^i} \quad (8.15)$$

Here the only non-zero cash flows are those cash flows generated in Phase II of the project from year four to year six.



**Figure 8.4 Distribution of Annual Return on Phase II Project Value**

An output for continuously compounded annual return on the optioned project value,  $k$ , was setup in the Monte Carlo simulation according to equations (8.13) to (8.15). The output of the statistical distribution of the annual return ( $k$ ) is shown in Figure 8.4, with a mean annual return of about 9.02% and a standard deviation of 0.4024.

This standard deviation of project Phase II annual return can be used as an estimate of the base project value volatility. In other words,

$$\begin{aligned}\sigma_2 &= \text{SD}(k) \\ &= 0.4024\end{aligned}\tag{8.16}$$

According to the simulation output.

Since the volatility of the continuously compounded annual return on the optioned project value is the closest analogy to the continuously compounded annual return on the underlying stock in financial option pricing, and since real option analysis is based on financial option pricing theory, the volatility estimated from the standard deviation of the continuously compounded annual return on the optioned project value,  $\sigma_2$ , will be used as the base volatility of the value of the Phase II investment project.

Considering the operational benefit and financial risk associated with the expansion investment in the flexible electronics manufacturing system: The operational benefit is that the flexible manufacturing capability acquired through additional investment in Phase II of the investment project will allow the company to capture sales revenue from increased market demand in the future if market demand is stronger than expected; The financial risk in the expansion project is that the higher flexible manufacturing capability of the manufacturing system, the larger the expansion

investment will be required. Larger expansion investment represents higher financial risk for the whole investment project in an uncertain market environment. This added investment risk is taken into consideration in real options analysis through the flexible production capability index  $F_i$ , defined as,

$$F_i = \frac{N_c}{N_d} \quad (8.17)$$

Here,  $N_c$  is the total units of automotive controllers that can be produced with the flexible manufacturing system after additional investment. And  $N_d$  is the estimated units of automotive controllers demanded during the life of the investment project.

The total Phase II project value volatility, considering both the volatility due to market demand, pricing, and operation cost variability, as well as the impact of flexible manufacturing capability index, can be calculated as,

$$\sigma_F = F_i \cdot \sigma \quad (8.18)$$

For the automotive electronics investment project, the production planning team has determined that the additional investment in year three will bring the total production capacity of the flexible manufacturing system to three million units per year as compared to its current production capacity of 2.2 million units per year. So that we have,

$$N_c = 3.000 \text{ million units per year}$$

And the largest estimated number of different types of automotive controllers demanded during the life of the investment project (see Table 8.1) is,

$$N_d = 2.499 \text{ million units per year}$$

The flexible production capacity index for the expanded flexible auto electronics manufacturing facility will be:

$$F_i = \frac{N_c}{N_d} = \frac{3.000}{2.499} = 1.20 \quad (8.19)$$

It means that, with an additional investment of 110 million US Dollars in year three, the upgraded auto electronics manufacturing plant has a flexible production capacity to cover all projected market demand during the life of the project, and still has a 20% capacity reserve to respond quickly to any unexpected increase in market demand in the future.

With the base volatility estimated in equation (8.16), and the flexible manufacturing capability index of the manufacturing system given in equation (8.19), the total volatility of Phase II project value can be calculated according to equation (8.18),

$$\begin{aligned} \sigma_F &= F_i \cdot \sigma \\ &= 1.20 \times 0.4024 \\ &= 0.4829 \end{aligned} \quad (8.20)$$

This is the total volatility of Phase II project value of the investment project in the flexible automotive electronics manufacturing facility.

#### <4> **Timing of Phase II Investment for Expanded Manufacturing Capacity**

Time to make additional investment decision for expanded production capacity depends on projected market demand during the life of the investment project. Based on current and future demand from major customers in the automotive industry, the trend of more and more control and electronic functions integrated in automobile manufacturing process, and the development of new technologies for better vehicle performance, safety, and fuel economy, it is expected that demand for automotive controllers from the investing company will continue to increase at a relatively low rate from year one to year



three. Starting from year four, a higher rate of market demand for automotive controllers could be expected. The additional investment is timed to capture the higher market demand from year four. Therefore it is determined that such additional investment should be made in year three, so that expanded production capacity will be ready to meet the higher market demand from year four and thereafter. In a real options perspective, the time to exercise the expansion option, pending higher market demand, is set at year three, or,

$$T = 3 \quad (8.21)$$

#### <5> Risk Free Interest Rate

Since the investment will be made in an automotive electronics manufacturing facility in the United States, the 10-year US Treasury bill rate should be used as the risk free interest rate in real options analysis. The 10-year US-Treasury bill rate at the time of additional investment in the project is about 4.5%, therefore,

$$r = 0.045 \quad (8.22)$$

will be used in real option analysis here.

### **8.3.2 Real Options Analysis of the Investment Project for Capacity Expansion of a Flexible Automotive Electronics Manufacturing Plant**

With all input parameters estimated in the last section, a real option value of the Phase II investment in the flexible automotive electronics manufacturing system can be estimated with Black-Scholes model, with the following input parameters:

$$\begin{aligned}
V_0 &= 107.512 \text{ Million USD} \\
X &= 110 \text{ Million USD} \\
\sigma &= 0.4829 \\
T &= 3 \text{ years} \\
r &= 0.045
\end{aligned}$$

According to Black-Scholes Model for a European call option evaluation, the value of the real call option to undertake additional investment in the automotive electronics manufacturing facility, can be determined by,

$$c = V_0 N(d_1) - X e^{-rT} N(d_2) \quad (8.23)$$

Where,

$$\begin{aligned}
d_1 &= \frac{\ln(V_0 / X) + (r + \sigma^2 / 2)T}{\sigma \sqrt{T}} \\
&= \frac{\ln(107.512 / 110) + (0.045 + 0.4829^2 / 2) \times 3}{0.4829 \sqrt{3}} = 0.5523
\end{aligned}$$

$$d_2 = d_1 - \sigma \sqrt{T} = 0.5523 - 0.4829 \sqrt{3} = -0.2842$$

$$N(d_1) = 0.7096 \quad N(d_2) = 0.3881$$

From equation (8.23) the real option value is,

$$\begin{aligned}
c &= 107.512 \times 0.7096 - 110 e^{-0.045 \times 3} \times 0.3881 \\
&= 38.99 \text{ Million USD} \quad (8.24)
\end{aligned}$$

This is the value of the Phase II investment to the investing company, valued as a real option to take on additional investment in year three to capture higher market demand in year four and beyond.

Recall the net present value evaluation of the initial phase investment made at the beginning of the investment project for current production until the end of year three. The net present value for this initial phase of the investment project was calculated in section 8.2.3 as,

$$NPV_1 = - 35.51 \text{ Million USD}$$

From real options point of view, the combined value of the two-phased investment project to the investor, can be expressed as a Strategic Net Present Value, or SNPV, which is the combined value of Phase I project NPV and the real option value of the Phase II project:

$$\begin{aligned} SNPV &= NPV_1 + c \\ &= - 35.51 + 38.99 \\ &= 3.48 \text{ Million USD} \end{aligned} \quad (8.25)$$

Compare this combined project value of positive 3.48 million USD with a total project NPV of negative 0.325 million USD in section 8.2.3, one could make the observation that real option approach gives a higher evaluation of flexible investment made in an economic environment where project value is uncertain, due to uncertainties in market demand, selling price, and cost components. In addition, real options evaluation tend to assign a value to management flexibility in making investment decisions according to market development, that is, to stay with a base or low scale of production when market demand is weak, and to invest for a larger scale of production when market demand is strong and increasing. While traditional NPV evaluation is based on

discounted cash flow alone, real options analysis adds value by considering the benefit of making flexible investment decisions pending market development.

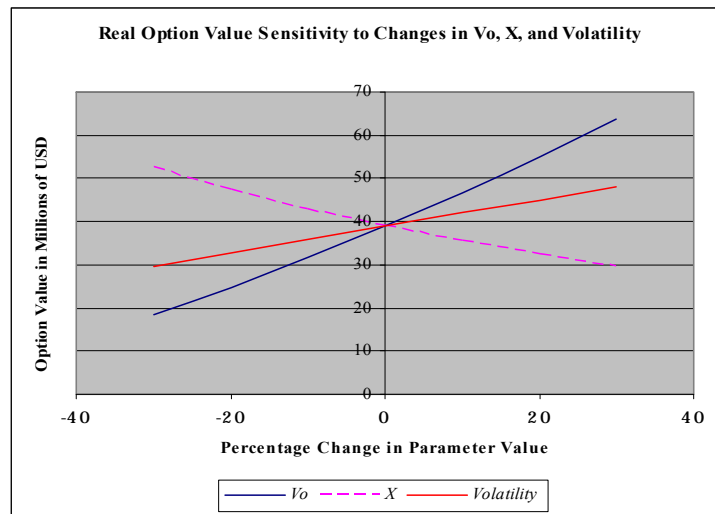
Based on the positive strategic net present value of 3.481 million USD from real options analysis, the company should make the initial investment to run current production while watching the market development and new technology available. And the company should be prepared to make the additional investment when market development does turn out to be positive.

### **8.3.3 Real Option Value Sensitivity to Changes in Input Parameters**

The value of a real option depends on the input parameters, which are estimated from real world investment project under consideration and from the general condition of the economy in which the investment project would be implemented.

It is important for the investor to understand which parameters have the greatest impact on the real option value of a certain investment project, and pay close attention to get accurate estimates of those parameters. For the phased investment project implemented in the automotive electronics manufacturing facility, sensitivity analysis of the impact to project real option value by each of the input parameters is carried out separately, with the results presented in Figure 8.5 and Figure 8.6.

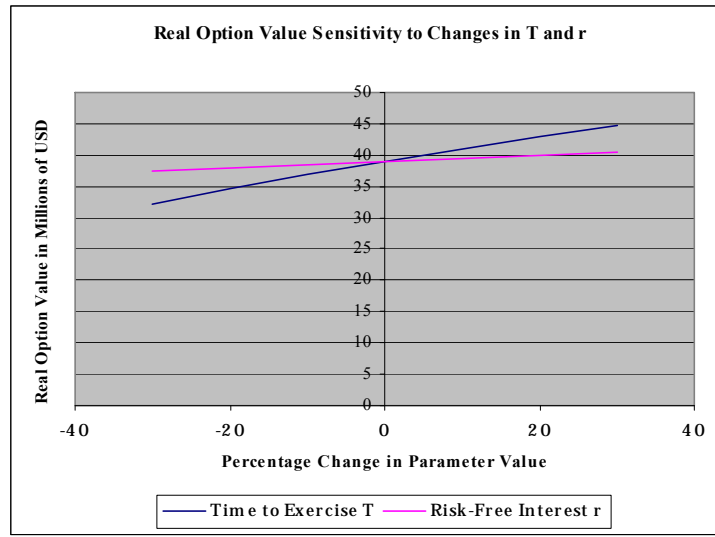
Figure 8.5 illustrates the impact on real option value by changes in Phase II project value ( $V_0$ ), Phase II investment requirement  $X$ , and the volatility of return on project value. A 10% decrease in project value will lead to 19% decrease in real option value, a 10% increase in project value will lead to a 20% increase in real option value.



**Figure 8.5 Real Option Value Sensitivity to Changes in  $V_0$ ,  $X$ , and Volatility**

As far as additional investment is concerned, a 10% decrease in investment requirement will cause the real option value to increase by 10%, and a 10% increase in investment will cause the real option value to drop by about 9%. The impact of volatility on real option value could also be observed from Figure 8.5, a 10% increase in volatility will lead to a 8% increase in real option value, and a 10% decrease in volatility will result in a decrease of real option value of 9%.

From Figure 8.6 it is clear that real option value will increase as time to exercise and the risk free interest increase. A 10% increase in the time to exercise will cause the real option value to increase by 5.1%, and a 10% decrease in the time to exercise will lead to a 5.4% decrease in real option value.



**Figure 8.6 Real Option Value Sensitivity to Changes in T and r**

Risk free interest rate has a similar impact on real option value, as risk free interest rate increase by 10%, real option value increase only by 1.3%, and a 10% decrease in risk free interest rate will result in a 3.8% decrease in real option value.

Based on the sensitivity analysis above, the input parameters that have the most important impact on real option value are, in the order of importance, optioned project value ( $V_0$ ), expansion investment requirement ( $X$ , the real option exercise price), the volatility of the optioned project value ( $\sigma$ ), time to exercise the real option ( $T$ ), and risk free interest rate ( $r$ ).

Since the volatility of project value has the third strongest impact on the real option value of a given investment project, it is very important to estimate project value volatility as accurately as possible.

Either defined by the volatility of optioned phase project value (coefficient of variance of optioned project value), or by the standard deviation of annual return on optioned project value, or defined by the volatility of annual returns on common stock of the investing company, project value volatility should be an accurate representation of the risk associated with the optioned phase project value to the investing company. In most of the investment projects in the manufacturing industry, project value will largely depend on future market demand, future price movement, and future projection of cost of production, these factors will define future operation cash flows, thereby defining the project value based on those operation cash flows. The volatility of those factors combined will define the volatility of the project value. In most cases there are more than two or three uncertain factors that would affect the project value. It is practical to set up a simulation model to estimate project value and its volatility. In some other cases where the investment project bears a similar level of operational risk as those projects pursued by the investing company in comparable economic and market conditions, the investing company's stock return volatility can be used as an approximation of the project value volatility. In still other cases, such as initial investment in natural resource exploration and development, where operation cash flows are difficult to estimate in the early stage of project evaluation, volatility of most recent market price of such resources can be a good indication for the volatility of the investment project value involving exploration and production of those natural resources. Simply because of the fact that economic values of such investment projects are closely related to the price of those resources.

#### **8.4 Conclusion**

Due to fast technology advancement, global market competition, and higher standard for vehicle performance, safety, and fuel economy, automotive electronics suppliers are facing increasing pressure from OEM manufacturers in the automotive industry to reduce cost and improve quality. Changing industry standard and government regulations increase long term operational risk for companies in the automotive electronics industry. While it is essential to invest in new design and manufacturing technologies in order to stay ahead of market competition, higher degrees of uncertainty exists in the projection of future market demand, cost of material and labor, as well as the cost to meet environmental regulations. The large amount of initial investment required to establish a new automotive electronics manufacturing facility, or even to upgrade an existing facility, combined with demand and price uncertainty, rise management concerns on the economic return of such investment projects. One approach to long term strategic investment project implementation is to make the investment in two or more phases. An initial investment to keep the manufacturing facility up to the current and near term operational and technology requirements in order to meet current market demand, and lay the foundation for additional investment in the future for new product design and for expansion in production capacity, if positive market developments does occur over time. This phased investment strategy helps companies to reduce financial and operational risk in making one-time large investments in manufacturing technology and equipment that could become obsolete in the future due to fast technology development and changes in market conditions. As an alternative technique of economic evaluation of financial



investment in the industry, real options analysis is well suited for evaluation of phased investments, where initial investment was viewed as “paying” a premium for a “real option” to take on additional investment in the future for long term growth and economic return to the investor.

In this chapter both real options analysis and net present value evaluation were applied to evaluate the economic performance of a two-phased investment project in an automotive electronics manufacturing facility. Although net present value evaluation indicates a relatively small amount of negative total project NPV, further analysis in a real options perspective revealed a positive total project value. This positive total project value, also known as the Strategic Net Present Value, not only takes into consideration of the economic value from operational cash flow generated during the life of the investment project, it also accounts for the added value of making flexible management decisions in the timing and the amount of investment needed according to the latest market development that has direct impact on the investing company’s business operation.

Monte Carlo simulation was performed to establish statistical distributions of annual operation cash flows and phased investment net present values with given distributions of market demand, product selling price, and cost of production, these simulation input factors are defined as random variable to reflect market risk. Monte Carlo simulation also helped to estimate the risk associated with the return on project value, which was used as a key input in real options analysis. Sensitivity analysis was

performed on the investment project real option value in order to identify the most important factors that have significant impact on project real option value.

Based on real options analysis the investment project should be implemented as planned. And the major factors to influence the economic value of the investment project are: Market demand, selling price, cost factors, and investments required. Accurate projection of market demand in the amount of products and their selling price, accurate estimate of investment requirements, and cost control will help ensure the success of the investment project. Uncertainty in market demand should be closely watched in order to choose the right time for additional investment. In the analysis presented here, it is assumed that through market research the management had determined that a higher market demand would occur in year four and continue into the next three years, therefore the time for additional investment was set in year three.

## CHAPTER 9

### CONCLUDING REMARKS AND FUTURE RESEARCH NEEDS

#### **9.1 Concluding Remarks**

Originated from financial option pricing theory, real options evaluation of financial investment in non-financial industries has evolved into a practical tool for capital budgeting and strategic business planning where large sums of capital investments are required and higher degree of financial and operational risk exist. In most cases such investments will have a long term, strategic impact on the business development and growth of the investing company.

In the highly competitive automotive industry, as in many other manufacturing industries, innovative new product development capability, application of advanced technologies in product design and manufacturing processes, constant improvement of quality and customer service, as well as global market expansion, have become the key success factors. One of the advanced manufacturing technologies, flexible manufacturing system, has found increasing applications in the automotive industry due to its advantages of high degree of integration of advanced manufacturing technologies, quick response to changing market demand in product type and volume of products demanded,

and high operational efficiency with automatic machine control and automatic material handling capabilities.

In addition to many of the complex technical issues associated with design and implementation of flexible manufacturing systems, economic evaluation of financial investment in those systems can be a challenging task (Small 2006). Most of the flexible manufacturing systems require relatively large amounts of initial capital investment in manufacturing equipment and control systems to acquire the production capabilities needed to meet current demand, and to have enough reserve in flexibility to be expanded or modified with additional investment in the future, in case new types of products or a higher volume of similar products are demanded in the future. With traditional capital budgeting techniques, such as net present value evaluation, the large initial investment in a flexible manufacturing system could not be fully justified with a positive economic return during the first few years of operation, before additional investment is needed to expand or modify the system for changing market demand in future years. The negative economic return from the early phase of the investment often make it difficult for financial executives to approve such investment projects, although they may be well aware of future potentials of such investment projects.

With real options analysis on the other hand, the combined value of the initial investment and the operation cash flows generated in the first few years before additional investment is needed for capacity expansion, is viewed as a real option premium to be paid in order to acquire the opportunity, but not the obligation, to expand production capacity and capture the economic benefit of increased market demand with additional

investment at the time of expansion, if market development does produce a higher demand. The additional investment required for capacity expansion is viewed as the price to exercise the real option for the benefit generated by future operation cash flows. The most important advantage of real options analysis is to evaluate the management and operational flexibility of capital investment in flexible manufacturing systems in explicit financial values, so that a strategic net present value for the complete investment project, which may include more than one phase, can be clearly calculated and compared with traditional net present value of the investment project. The assessment of the economic value of management and operational flexibility in taking different investment actions pending market and business environment development, through real options analysis, helps to provide important insights into complex strategic business management issues, so that sound management and investment decisions can be made to address both short term and long term operational and financial objectives in today's highly competitive global market environment.

In order for real options analysis to be better understood and applied in capital budgeting and strategic business planning in the automotive industry, the fundamental principles and development of financial option pricing theory were reviewed, the conceptual analogy between financial option pricing and real option analysis were discussed to establish the real option analysis framework. Also in this study, realized and potential benefits of a flexible manufacturing system were discussed in detail, where realized benefits will be evaluated with net present value from operational cash flows, and potential benefits of such systems will be evaluated with real options analysis.

With the increasing trend of global business integration and foreign direct investment in the automotive industry in emerging markets, exchange risk become a important issue in international business development and investment project planning. An analytical model and financial management measures were recommended to account for foreign exchange risk in economic evaluation of investment in foreign countries.

A unique model of flexible production capability index was developed to account for the benefit of flexible manufacturing systems for real options evaluation of financial investment in such systems.

Two cases of application demonstrating real options evaluation of financial investment in flexible manufacturing systems were presented in the last two chapters of the research to illustrate the benefit of flexible manufacturing systems, and the benefit of real options analysis. In close connection with real options analysis, Net present value evaluation was used as a basic technique of project value estimate throughout the study.

Sensitivity analysis was performed to identify the important input factors that have the highest impact on the real option value of a given investment project, and thereby to direct management attention to address the corresponding aspects of the business operation, so that business performance and financial return can optimized.

## **9.2 Areas for Future Research**

In order to apply financial option pricing theory to evaluate capital investment in non-financial industries, an analogy between financial options and real options was made in order to establish real options analysis framework, and to determine real options

analysis input parameters corresponding to those in financial option pricing. It is important to recognize that while financial option pricing theory was based on sound mathematical development and it has a closed form analytical model, the Black-Scholes model, it does require a set of assumptions. In order to understand and apply real options analysis technique appropriately for economic evaluation of investment in non-financial industries, it is important to understand some of the imperfections in the analogy between financial option pricing and real options evaluation.

First, in financial option pricing model development, publicly traded common stock is the underlying asset. It is assumed that stock price follows a lognormal distribution, and both stock return and the volatility of the stock return are constant during the life of the financial option under consideration. This set of assumptions are made for the following major reasons: a) Stock price could not assume a negative value; b) Lognormal stock price distribution is consistent with stock price “random walk” assumption; c) Constant stock return and constant volatility is required for the differential equation of a financial option price function to have a closed form solution with appropriate boundary conditions. Although the assumption of lognormal stock price distribution is commonly regarded as a close description of stock price behavior in the long run, the assumption that stock return and its volatility are constant is made largely for the sake of a closed form model development.

In real options analysis, the input parameter corresponding to stock price in financial option pricing is the net present value of operation cash flows generated in the optioned phase of the investment project, discounted back to present time at the weighted

average cost of capital of the investing company. This value is normally positive if any cash inflows are expected in the optioned phase (expansion phase, for example) of the investment project. Similar to the returns on stock value, the return on optioned project value was assumed to be constant in order to apply financial option pricing model for real options analysis. Considering the fact that the net present value of the optioned phase project is determined by future operation cash inflows during the optioned phase of the investment project, and those cash flows will be affected by the market demand and price of the products or service provided in the optioned phase of the investment project, the net present value of the optioned phase cash flows will be a random variable determined by the random variables of market demand, price, and cost. Similar to financial option pricing where stock price is assumed to follow a random walk, it is a close approximation to assume that optioned phase project value in real options analysis also follows a random walk, so that financial option pricing model can be used in real options evaluation.

The major difference between stock price in financial option pricing and project value in real options analysis, is that common stocks are publicly traded at organized exchanges while neither investment projects nor their values can be publicly traded. In other words, a share of publicly traded stock has a higher degree of **liquidity** than the economic value of an investment project pursued by a company in the non-financial industries.

It is intuitive to assume that the value of a real option to the investing company itself may not be affected too much by the fact that the value of the investment project is not publicly traded, as long as operation cash flows, cost of the investment project,



volatility of the project value are appropriately estimated. To the investors at large who may choose to invest in any publicly traded securities, the value of the same investment project may not be as well recognized as by the company that made the investment in this particular project, because the investing company may have better information, expertise, and knowledge about the investment project than the general public. In other words, the relatively low degree of liquidity of the underlying asset in real option analysis could result in a relatively lower perceived value by investors in the public. Further studies on the liquidity and accurate estimates of the underlying assets in real options analysis may help to better understand the true value of real options in different choices in strategic investment planning.

Second, while the exercise price of a financial option is predetermined and fixed in the option contract, the “exercise price”, or the investment required to expand an investment project and generate future operation cash flows in real options analysis, is estimated by the investing company, and it could change over time. It is obvious that changes in investment requirement will affect the real option value of a given investment project. One way to analyze the impact of changes in investment requirement to real option value is to performance a sensitivity analysis to see how sensitive real option value is to changes in investment requirement. Similarly investment requirements could also be setup as a random input variable in simulation analysis to investigate the impact of changes in investment requirement to real option value.

Third, in financial option pricing, the volatility is defined as the standard deviation of the continuously compounded annual return on the underlying stock. With

historical stock prices readily available from public source of financial information, it is fairly easy to estimate stock return volatility with historical prices. In real options analysis, on the other hand, return on optioned project value could not be easily estimated from public information, since the value of an investment project is not normally traded in any organized exchange, and could not be observed publically. One practical technique to estimate the volatility of return on investment project value is to use the volatility of optioned project value calculated from operation cash flow generated during the optioned phase of the investment project. Ultimately the volatility of operation cash flows from optioned phase of the investment project will determine the volatility of return on project value. This estimated volatility of return on project value will be used as an input to the real options analysis model.

In order to obtain accurate estimate of project value volatility for real options analysis of industrial investment projects, it is important to consider the management and operational flexibility in making strategic investment decisions. The phased structure of real options analysis of industrial investment project applying financial option pricing theory, make it possible to view a whole investment project in different phases, the implementation of future phase investment is no longer a one-time “go” or “no go” decision at the beginning of the total investment project, rather it will depend on the on-going information collection and market development with regard to the outlook of business perspective. This “learning process” in strategic investment decision making allows management to make investment commitment according to latest market development instead of make all investment commitment at the beginning of the project.

In other words, the decision to make further investment become a “management option”, the management will choose to make such investment only if market development is favorable. This structural analogy between real option analysis and financial option pricing allows real options analysis to account for the management flexibility in investment decision making.

Operational flexibility in real options analysis refers to the capability of the investing company to increase its production capacity either in the scope or scale of production in response to changing market demand, such as the capability of an energy company being able to scale up production capacity in a relatively short period of time in response to a projected increase in market demand. Such operational flexibility is important in value creation in any investment project, and it should be considered either in the form of increased revenue or increased volatility. Further research in this regard would be helpful in real option application in non-financial industries to evaluate the economic value of investment project where operational flexibility exists.

Since option theory allows investors to exercise an option when a high degree of upside uncertainty exist, taking advantage of favorable market development; and not to exercise an option when downside risk is high, thereby limiting downside risk; option value increases as the degree of uncertainty increases. Either in financial option pricing or in real options analysis, a higher volatility would result in a higher option value, all other parameters being equal. In the application of real options analysis in economic evaluation of investment projects in the non-financial industry, cautions should always be exercised when overly enthusiastic project managers or business analysts are tempted

into presenting a higher real options valuation of a certain investment project by applying a unrealistically high value of volatility. This will only leads to the company taking up risky projects that may result in financial losses. It is always necessary to estimate the volatility parameter very carefully in real options analysis, considering both market uncertainty and operational flexibility, in order to arrive at a realistic and accurate project evaluation. Future research in project volatility estimate in different industries will help to ensure the appropriate application of real options analysis in those industries. As it is pointed out by a recent study (Michael Small 2006), an accurate and simple approach to real options analysis will increase the acceptance and application of this important capital budgeting technique in strategic investment evaluation in non-financial industries. Future research in this regard in different industries will promote the understanding of real options and hopefully leads to better investment decisions for long term, strategic growth.

Strategic business planning requires prudent financial analysis and economic evaluation to guide management decisions. Due to the fact that strategic investment often involves long term, large investment, and high degree of market and operational uncertainty, real options analysis, when applied appropriately together with other fundamental economic evaluation techniques, such as net present value evaluation, could provide useful insights into investment decision making in many non-financial industries.

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APPENDIX  
FINANCIAL OPTIONS EVALUATION WITH  
THE BLACK-SCHOLES MODEL

**A1. The Basic Concept of Financial Options**

In general terms, a financial option is a contract which gives its holder the right, but not the obligation, to buy or sell a certain type of financial asset at a predetermined price within a specified future period of time. In the following sections, financial options on common stocks will be used to illustrate the structure and pricing mechanics of a typical financial option.

There are two types of financial options: a call option and a put option. A call option gives the option holder the right but not the obligation to buy an asset by a certain date at a predetermined price, whereas a put option gives the option holder the right but not the obligation to sell an asset by a certain date at a predetermined price.

Based on the specified period of expiration, or date of expiration, a financial option could either be an American option or a European option. In the context of financial option pricing and trade, neither “American” nor “European” has anything to do with geographic locations, but rather, a distinction between two different time structures in option pricing and exercise. American options can be exercised at any time from the date of option contract up to the date of option expiration; whereas European options can

only be exercised on the date of expiration. Although most of the options that are traded on exchanges are American options, European options are generally easier to analyze due to the simple time structure in which a specific expiration date, namely the only exercise date, is clearly specified. On the other hand, due to the flexibility in the date of exercise from the date of option contract up to the date of expiration, American options normally have a higher value than European options on the same underlying asset with similar specifications. The value of a European option could serve as the lower bound of the value of its American counterpart. For the purpose of simplicity, the financial options we are going to discuss in the following sections are European options; the properties of American options can be deduced from those of the corresponding European options. A European option on stock normally has the following basic properties:

Time to expiration,  $T$ , refers to the period of time in years from the date of option contract to the date on which the option can be expired. The date of expiration, or the date of maturity, will be clearly specified in the option contract.

The price specified in an option contract is known as the strike price, or exercise price,  $X$ , at which the buyer of a call option has the right to buy the stock, and the buyer of a put option has the right to sell the stock.

Current stock price,  $S_0$ , is the current market price of the underlying stock on which the option contract is written.

$S_T$ , is the actual market price of the stock at the time of maturity, or at the time of exercise of the option. Relevant to financial option pricing, the volatility of the stock

price,  $\sigma$ , is defined as the standard deviation of the return on the stock. And  $r$  is the risk free interest rate.

The cost of a call option contract to the buyer of the option is referred as the price of the call option, commonly denoted as  $c$  for a European call option, and  $C$  for its American counterpart. Similarly, the cost of a put option contract to the buyer of the option is referred as the price of the put option, denoted as  $p$  for a European put option, and  $P$  for an American put option.

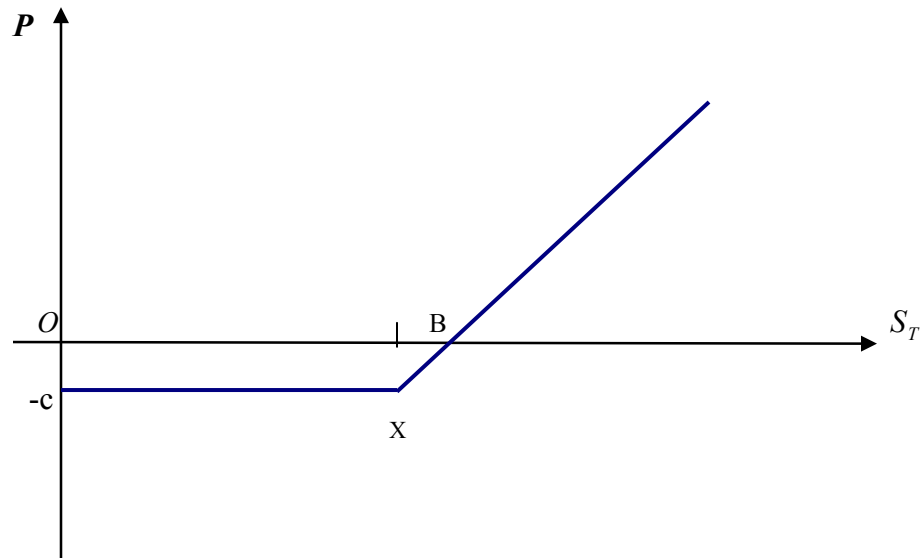
## **A2. Payoff and Net Profit at Expiration of a European Call Option**

A call option is a financial instrument that offers the option buyer the potential of an unlimited profit in the perspective of an increase of the underlying asset above and beyond the strike price while limits the loss of the option buyer within the cost of the option contract. Figure A.1 illustrates all possible outcomes, or net profit,  $P$ , for the buyer of a call option on one share of a publicly traded stock. Suppose the market price of the stock at the time of expiration is  $S_T$ , which may assume any value at the time of option expiration, as showing on the horizontal axes. Strike price of the call option,  $X$ , is predetermined in the option contract, and the cost to the buyer of the option to enter into the option contract is  $c$ . The net profit of the option can be expressed as:

$$P = \text{Max} [ (S_T - X) - c, -c ] \quad (\text{A.1})$$

The term  $\text{Max} [(S_T - X), 0]$  is commonly referred as the payoff of the call option at expiration.

After considering the cost of entering the option contract,  $c$ , net profit for the buyer of the option will be either  $(S_T - X) - c$ , in case the stock price  $S_T$  at the time of option maturity is higher than the strike price  $X$ .



**Figure A.1 Net Profit for the Buyer of a Call Option**

On the other hand, if the stock price at the time of option maturity is equal or lower than the strike price, the buyer of the call option will not exercise the option, the pay off of the option will be zero, and the net profit will be  $-c$ , since the option holder still have to pay for the option contract at a price of  $c$ . While receiving unlimited payoff by the amount of  $(S_T - X)$  in case market condition is favorable and the stock price exceeds the strike price at the time of expiration, and receiving no payoff in case the stock price drops below the strike price, the maximum loss for the option buyer is limited to the cost of entering the option contract. This is the fundamental reason why financial option contracts can be used effectively for market risk management.

### A3. Payoff and Net Profit at Expiration of a European Put Option

Whereas a call option is designed to protect and benefit the investor in case the price of the underlying asset goes up, a put option, which gives the buyer of the option the right but not the obligation to sell a certain asset at a predetermined price (strike price,  $X$ ) within a certain period of time, is a financial instrument that aims at reducing the risk to investors in case the price of the underlying asset goes down. Unlike the buyer of a call option, who expects the price of the underlying asset to move up, the buyer of a put option expects the price of the underlying asset to go down in the near future, and therefore wishes to hedge the risk against downward movement of the market.

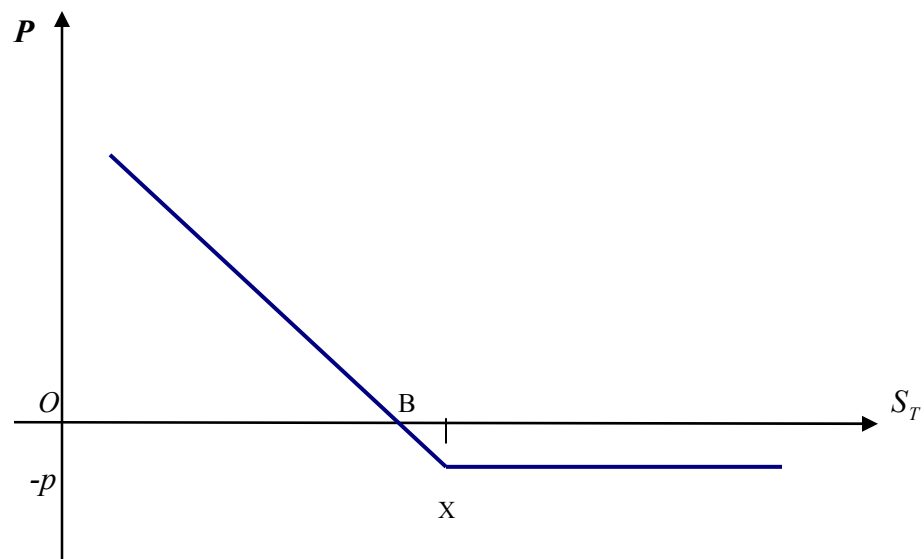


Figure A.2 Net Profit for the Buyer of a Put Option

In other words, the buyer of a call option and the buyer of a put option have opposite perspectives of the future price movement of a certain underlying asset, and

therefore use different financial instruments to reduce investment risk and hope to benefit from the expected market price movement in their own different perspectives.

A put option offers the option buyer the potential of a large profit in the perspective of a decrease of the underlying asset price well below the strike price while limits the loss of the option buyer within the cost of the option contract in case the underlying asset price goes up. Figure A.2 shows the net profit for the buyer of a put option on a publicly traded stock.

Assume the market price of the underlying stock at the time of expiration is  $S_T$ , which may assume any value depending on the performance of the stock. The strike price of the put option,  $X$ , is predetermined in the option contract, and the cost to the buyer of the option is  $p$ . The solid line in Figure 3.2 indicates the net profit of the put option to its buyer, which can be expressed as:

$$P = \text{Max} [ ( X - S_T ) - p, -p ] \quad (\text{A.2})$$

Similarly, the term  $\text{Max} [ ( X - S_T ), 0 ]$  is commonly referred as the payoff of the put option at expiration.

After considering the cost of entering the option contract,  $p$ , net profit for the buyer of the put option will be  $( X - S_T ) - p$ , in case the stock price  $S_T$  at the time of option maturity is less than the strike price  $X$ . On the other hand, if the stock price at the time of expiration of the put option is equal to or greater than the strike price, the buyer of the put option will choose not to exercise the option, and will have paid the cost of the put option,  $p$ , for the benefit of being protected against potential downward price movement of the underlying stock.

Although the price of a call or put option,  $c$ , or  $p$ , has been taken into consideration in predicating the net profit of an option contract with equation (A.1) or equation (A.2), these two equations do not include any other transaction costs associated with the financial options discussed above.

As mentioned earlier, most stock options are generally American rather than European, therefore the investor would not have to wait until the expiration date to exercise the option. In many cases it may be optimal to exercise American options before the expiration date.

#### **A4. Stock Option Valuation with the Black-Scholes Model**

Stock options are the most commonly traded financial options. The theory and practical methods of stock option valuation form the foundation of financial option analysis. Developed since the early 1970s by Fischer Black, Myron Scholes, and Robert Merton, the Black-Scholes Model is the most widely applied closed-form model for financial option pricing. It is surely the foundation of real option analysis.

##### **A4.1 Assumptions Underlying the Black-Scholes Model**

In order to develop the Black-Scholes option pricing model, the following assumptions were made:

1. Stock price at any future time follows a lognormal distribution (consistent with random walk assumption) with expected return on the stock,  $\mu$ , and the volatility of the stock,  $\sigma$ , being constant for the duration of the option life.

2. There are no transaction costs or taxes. All securities are perfectly divisible.
3. There are no dividends on the stock during the life of the option.
4. There are no risk free arbitrage opportunities.
5. Security trading is continuous.
6. Risk-neutral valuation, which implies that the expected rate of return from all securities in a risk neutral world is the risk free interest rate, and the investor could borrow and lend at the risk free rate of interest. Short selling of a financial asset is possible without penalty.
7. The short term risk free interest rate,  $r$ , is constant during the life of the option.

In the next sections the following notations will be used in the development of financial option valuation models, unless noted otherwise.

$S$  = Stock price as a variable

$S_0$  = Current stock price, or the stock price at the time of option contract

$S_T$  = Stock price at the time of option expiration

$X$  = Strike price, or exercise price of the stock option.

$T$  = Time to expiration of the stock option

$r$  = Continuously compounded annual risk free interest rate

$f$  = Price of a financial derivative, such as an option on a share of stock

$c$  = Current price of a European call option

$C$  = Current price of an American call option



$p$  = Current price of a European put option

$P$  = Current price of an American put option

#### **A4.2 The Wiener Process and the Ito Process**

A Wiener process is a special type of Markov stochastic process where only present value, or current value of the stochastic variable, is relevant in the predication of its future value. The past history of the stochastic variable is irrelevant. This property of the Wiener process is consistent with the weak form of the market efficiency theory, or the random-walk theory, which indicates that publicly traded security prices accurately reflect all information in historical prices and respond quickly to new information as soon as it becomes available. It also indicates that no one could constantly profit from examining historical stock prices.

In addition to its application in financial engineering and option pricing to model stock price movement, a Wiener process also has wide applications in other fields of mathematical and physical sciences. In physics it is used to study Brownian motion, the diffusion of minute particles suspended in fluid, and other types of diffusion; it forms the basis for the rigorous path integral formulation of quantum mechanics; and it can be applied to represent a white noise process in mechanical and electrical engineering.

The Wiener process  $z(t)$  is characterized by three facts:

1.  $z(0) = 0$
2.  $z(t)$  is almost surely continuous over time
3.  $z(t)$  has independent increments with a distribution of

$$[z(t) - z(0)] = z(t) \sim N(0, t) \quad (\text{A.3})$$

$N(\mu, \sigma^2)$  denotes the normal distribution with expected value  $\mu$  and variance of  $\sigma^2$ . The condition of a Wiener process that it has independent increments means that if,  $0 \leq t_1 \leq t_2 \leq t_3 \leq t_4$ , then,  $z(t_2) - z(t_1)$  and  $z(t_4) - z(t_3)$  are independent random variables. In other words, over any limited time interval of  $T$ , the incremental increase of a variable that follows a Wiener process is independent and normally distributed with a mean of zero and a standard deviation of  $\sqrt{T}$ . This leads to an important property of the Wiener process:

$$\Delta z = \varepsilon \sqrt{\Delta t} \quad (\text{A.4})$$

Where  $\varepsilon$  is a random variable following a standard normal distribution with mean of zero and variance of 1.

As  $\Delta t$  approaches zero, we have,

$$dz = \varepsilon \sqrt{dt} \quad (\text{A.5})$$

In order to describe the movement of a random variable that follows a random walk over time, a generalized Wiener process can be defined as,

$$dx = a dt + b dz \quad (\text{A.6})$$

where  $a$  and  $b$  are constants, and  $dz$  is the basic Wiener process as described in equation (A.5). The generalized Wiener process has an average drift of  $a$  per unit of time, and variance of  $b^2$  per unit of time.

When the drift rate and variance of a generalized Wiener process are no longer constant, but change with the underlying variable  $x$ , and time  $t$ , a Ito Process can be defined as follows,

$$dx = a(x, t) dt + b(x, t) dz \quad (\text{A.7})$$

In other words, an Ito process is a generalized Wiener process, with an instantaneous drift rate per time period of  $a(x, t)$ , and an instantaneous rate of deviation of  $b(x, t)$ .

Based on random walk theory and the assumption that the expected rate of return on the stock,  $\mu$ , and the standard deviation of the expected return,  $\sigma$ , are constant during the life of the stock option, it is reasonable to assume that stock price  $S$ , can be represented by an Ito process with an instantaneous expected drift rate of  $\mu S$  and instantaneous standard deviation of  $\sigma S$ . This can be written as,

$$dS = \mu S dt + \sigma S dz \quad (\text{A.8})$$

or,

$$\frac{dS}{S} = \mu dt + \sigma dz \quad (\text{A.9})$$

Over a short period of time  $\Delta t$ , the average change in stock price is  $\Delta S$ , which can be written as,

$$\Delta S = \mu S \Delta t + \sigma S \Delta z \quad (\text{A.10})$$

These equations represent a widely used model for stock price movement with a constant drift rate and random variability.

#### **A4.3 Ito's Lemma and Lognormal Stock Price Distribution**

Ito's Lemma is the procedure used in stochastic calculus to find the differential of a function of a particular type of stochastic process.

Let  $x(t)$  be an Ito process, or generalized Wiener process defined in (A.7),

$$dx = a(x, t) dt + b(x, t) dz \quad (\text{A.7})$$

where  $dz$  is the basic Wiener process and  $a(x, t)$  and  $b(x, t)$  are functions of the underlying variable  $x$ , and time  $t$ .

Now let  $f(x, t)$  be a stochastic function of  $x$  and  $t$  with continuous second derivatives. According to Ito's Lemma, the total differential equation of  $f(x, t)$  with respect to  $x$  and  $t$  is,

$$df = \left( \frac{\partial f}{\partial x} a + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial x^2} b^2 \right) dt + \frac{\partial f}{\partial x} b dz \quad (\text{A.11})$$

Where  $dz$  is the same Wiener process defined in equation (A.5).

Recall that stock price follows a generalized Wiener process as defined in equation (A.8). Let  $f(S, t)$  be a stochastic function of stock price  $S$  and time  $t$ , applying Ito's Lemma to  $f(S, t)$ , we have,

$$df = \left( \frac{\partial f}{\partial S} \mu S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) dt + \frac{\partial f}{\partial S} \sigma S dz \quad (\text{A.12})$$

The average change of  $f$  over a short period of time  $\Delta t$  will be,

$$\Delta f = \left( \frac{\partial f}{\partial S} \mu S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) \Delta t + \frac{\partial f}{\partial S} \sigma S \Delta z \quad (\text{A.13})$$

It should be noted that  $f$  is a function of the underlying stock price and time  $t$ , and the value of  $f$  is affected by the same uncertainty factor  $dz$ . In other words, the uncertainty factor  $dz$  in equation (A.12) is the same uncertainty factor underlying the stock price.

In order to derive the process followed by Ln S, we define a stochastic function

G,

$$G = \text{Ln } S$$

Since,

$$\frac{\partial G}{\partial S} = \frac{1}{S}, \quad \frac{\partial^2 G}{\partial S^2} = -\frac{1}{S^2}, \quad \text{and} \quad \frac{\partial G}{\partial t} = 0$$

Apply Ito's Lemma to G, we have,

$$dG = \left(\mu - \frac{\sigma^2}{2}\right)dt + \sigma dz \quad (\text{A.14})$$

Since it is assumed that  $\mu$  and  $\sigma$  are constant for the life of the option, equation (A.14)

indicates that

$$G = \text{Ln } S$$

follows a generalized Wiener process with a constant drift per time period of  $\left(\mu - \frac{\sigma^2}{2}\right)$

and a constant variance per time period of  $\sigma^2$ . And the change in G between the current

time, t, and some future time, T, is normally distributed with a mean of  $\left(\mu - \frac{\sigma^2}{2}\right)(T - t)$ ,

and a variance of  $\sigma^2 (T - t)$ .

Let the value of G at time t be Ln S, and its value at time T be Ln  $S_T$ , where  $S_T$  is the stock price at time T. The change in Value G during the time interval (T - t) is,

(Ln  $S_T$  - Ln S), which has a normal distribution:

$$(\text{Ln } S_T - \text{Ln } S) \sim N \left[ \left(\mu - \frac{\sigma^2}{2}\right)(T - t), \sigma\sqrt{T - t} \right] \quad (\text{A.15})$$

And the stock price itself follows a Lognormal distribution.

With the stock price following a Lognormal distribution, the probability distribution of the continuously compounded rate of return on the stock can be derived as follows.

Let the annualized continuously compounded rate of return on the stock between  $t$  and  $T$  be  $\eta$ , it follows that,

$$S_T = S e^{\eta(T-t)}$$

And,

$$\eta = \frac{1}{T-t} \text{Ln} \frac{S_T}{S} \quad (\text{A.16})$$

From (A.15) we have,

$$\left( \text{Ln} \frac{S_T}{S} \right) \sim N \left[ \left( \mu - \frac{\sigma^2}{2} \right) (T-t), \sigma \sqrt{T-t} \right] \quad (\text{A.17})$$

And,

$$\eta \sim N \left[ \left( \mu - \frac{\sigma^2}{2} \right), \frac{\sigma^2}{\sqrt{T-t}} \right] \quad (\text{A.18})$$

Therefore the continuously compounded rate of return on the stock over a time period of

$(T-t)$  follows a Normal distribution with mean of  $\left( \mu - \frac{\sigma^2}{2} \right)$  and standard deviation of

$\frac{\sigma^2}{\sqrt{T-t}}$ . This rate of return over a longer time period of  $(T-t)$  is different from the

annualized continuously compounded rate of return over a short period of time, due to the relatively larger uncertainty of the stock price movement and the uncertainty of the return on the stock over a relatively longer period of time  $(T-t)$ . In other words, the annualized expected rate of return in an infinitely short period of time is  $\mu$ , and the expected

continuously compounded rate of return over a relatively longer period of time is  $(\mu - \frac{\sigma^2}{2})$ . In the following sections we will use  $\mu$  as the expected annualized rate of return on a stock. Fortunately as we will show in the next section, in a risk neutral world the price of a stock option does not depend on the rate of return on the stock.

#### **A4.4 The Differential Equation for Stock Option Valuation and the Black-Scholes Option Pricing Model**

In the last section we assumed that the underlying stock price  $S$  follows an Ito process as described in equation (A.8),

$$dS = \mu S dt + \sigma S dz \quad (\text{A.8})$$

Let  $f(S, t)$  be the current market price of a financial derivative, such as a stock option, written on the underlying stock having a current price of  $S$ , and we already have in equation (A.12),

$$df = \left( \frac{\partial f}{\partial S} \mu S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) dt + \frac{\partial f}{\partial S} \sigma S dz \quad (\text{A.12})$$

Recall from last section that the Wiener process  $dz$  as defined in equation (A.5) is the same risk factor underlying the market price of the stock price  $S$ , and the stock option price  $f$ . According to the risk neutral valuation principle, a portfolio of the underlying stock and the option on the stock can be constructed in such a way that this portfolio will earn a risk free rate of return regardless of the stock price movement in the future, that is, the uncertainty related with future stock price movement, or the effect of the Wiener

process in the stochastic process describing the stock price in equation (A.8), can be eliminated. The appropriate portfolio to achieve this objective will contain:

$$-1 \quad \text{Option on the stock, and}$$

$$\frac{\partial f}{\partial S} \quad \text{Shares of the underlying stock}$$

Or, a short position in the stock option combined with a long position in  $\frac{\partial f}{\partial S}$  shares of the underlying stock. The value of this portfolio is therefore,

$$\Pi = -f + \frac{\partial f}{\partial S} S \quad (\text{A.19})$$

And the change in the value of the portfolio over a very short period of time  $\Delta t$  will be,

$$\Delta \Pi = -\Delta f + \frac{\partial f}{\partial S} \Delta S \quad (\text{A.20})$$

Substituting  $\Delta f$  and  $\Delta S$  as defined in equation (A.13) and equation (A.10), we have,

$$\Delta \Pi = -\left(\frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2\right) \Delta t \quad (\text{A.21})$$

Due to the fact that  $\Delta z$  is not included in equation (A.21), the portfolio must be risk less during the short time period  $\Delta t$ , and therefore must earn the same rate of return as other short term risk free securities. It follows that,

$$\Delta \Pi = r \Pi \Delta t \quad (\text{A.22})$$

where  $r$  is the annualized risk free interest rate.

Substitute  $\Pi$  and  $\Delta \Pi$  from (A.19) and (A.21) into equation (A.22), we have,

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

With  $\Delta t$  cancelled out, we have,



$$\frac{\partial f}{\partial t} + rS \frac{\partial f}{\partial S} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 = rf \quad (\text{A.23})$$

This is the differential equation of the stock option price  $f(S, t)$  expressed in terms of partial derivatives of  $f(S, t)$  with respect to the underlying stock price  $S$ , and time  $t$ . It is also referred as the Black-Scholes differential equation. For a European call option with a time to expiration of  $T$ , the key boundary condition for the Black-Scholes differential equation is,

$$f = \text{Max} ( S - X, 0 ) \quad \text{when } t = T \quad (\text{A.24})$$

The expected value of the European call option today, is the expected final value of  $\text{Max} ( S - X, 0 )$  in a risk neutral world,

$$c = E [ \text{Max} ( S - X, 0 ) ] \quad (\text{A.25})$$

It is the call option payoff discounted back to today at the risk-free interest rate. Therefore , we have,

$$\begin{aligned} c &= e^{-r(T-t)} E[\text{Max}(S - X, 0)] \\ &= e^{-r(T-t)} \int_x^\infty (S - X)g(S)dS \end{aligned} \quad (\text{A.26})$$

where  $g(S)$  is the probability density function of  $S$ , which can be written as,

$$g(S) = \frac{1}{\sigma S \sqrt{2\pi(T-t)}} e^{-\frac{[\text{Ln}(\frac{S}{S_0}) - (r - \frac{\sigma^2}{2})(T-t)]^2}{2\sigma^2(T-t)}} \quad (\text{A.27})$$

and  $r$  is the risk free interest rate.

It can be verified that this probability density function satisfies the principle of risk-neutral valuation by calculating the expected future value of the stock,

$$S_T = E [S] = \int_0^{\infty} S g(S) dS = S_0 e^{r(T-t)} \quad (\text{A.28})$$

The current value of the European call option on stock can be found by integration of the right hand side of equation (A.26) with the probability density function  $g(S)$  in equation (A.27):

$$c = S_0 N(d_1) - X e^{-r(T-t)} N(d_2) \quad (\text{A.29})$$

Similarly, the current value of a European put option on the same underlying stock is,

$$p = X e^{-rT} N(-d_2) - S_0 N(-d_1) \quad (\text{A.30})$$

where,

$$d_1 = \frac{\text{Ln} \left( \frac{S_0}{X} \right) + \left( r + \frac{\sigma^2}{2} \right) (T - t)}{\sigma \sqrt{T - t}} \quad (\text{A.31})$$

$$d_2 = d_1 - \sigma \sqrt{T - t} \quad (\text{A.32})$$

Here,  $N(x)$  is the value of the cumulative standard normal distribution function. It can be determined as,

$$N(x) = \text{Probability of } [ X \leq x ] \quad (\text{A.33})$$

where  $X$  follows standard normal distribution.

Equation (A.29) and (A.30) are the basic Black-Scholes models for valuation of European call and put options written on a share of common stock having a current market value of  $S_0$ .

It is important to note that the Black-Scholes differential equation (A.23) and the option valuation models do not involve any variable that reflects the risk preference of investors, such as the expected return on the stock,  $\mu$ . This property of the model is consistent with the risk neutral valuation assumption, that in a risk neutral world, the expected return on all securities is the risk free interest rate (Hull 1993, 2002).

Another important concept implied by the general principle of risk neutral valuation is that a risk free position is possible to set up with the option and the underlying stock. Investors in such risk free positions can only expect a return equals to the risk free interest rate, so that there is no arbitrage opportunities. Even a risk free position is possible to achieve with option contracts and the underlying stocks, such a position is dynamic and will last for a very short period of time. The investor has to adjust his investment portfolio of stocks and options frequently to maintain his risk free position.