1-1-2009

A two level supply chain design under demand and exchange rate uncertainty: a real options evaluation

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A TWO LEVEL SUPPLY CHAIN DESIGN UNDER DEMAND AND EXCHANGE RATE UNCERTAINTY: A REAL OPTIONS EVALUATION

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Bachelor of Industrial Engineering

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2007

A thesis

presented to Ryerson University

in partial fulfillment of the requirements for the degree of

Master of Applied Science in the Program of

Mechanical Engineering

Toronto, Ontario, Canada, 2009

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ABSTRACT

A TWO LEVEL SUPPLY CHAIN DESIGN UNDER DEMAND AND EXCHANGE RATE UNCERTAINTY: A REAL OPTIONS EVALUATION

Yasmeen Sharan

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In this thesis, a real options approach is developed to value a two level supply chain. An integrated solution framework has been developed: where (1) a product life cycle model is formed to characterize stochastic demands in the market, (2) an exchange rate lattice is presented to account for exchange rate uncertainty, (3) a supply chain model is created to utilize stochastic demands and exchange rates to maximize the firm's after tax profit, and (4) a recursive dynamic programming algorithm is developed to calculate the expected after tax profit. The model allows for capacity flexibility and factors in adjustment costs. Results show that the proposed solution framework allows decision makers to hedge against risks by switching between manufacturing options and or by changing capacity levels at the manufacturing facilities.

ACKNOWLEDGEMENTS

I am deeply indebted to my supervisor, Dr. M. Wahab, for his patience, guidance and support throughout the past two years. I would like to thank Dr. G. Kawall, the Chair of the examining committee and its members, Dr. M. Jaber and Dr. L. Fang for their valuable feedback.

I owe a debt of gratitude to my siblings and close friends for their moral support and encouragement. Most of all, I would like to thank God for guiding me in the right direction.

Finally, I would like to sincerely thank my dearest parents Jamal Sharan and Nabila El-farekh for their continuous unconditional love and support. This thesis would not have been possible without their encouragement. Thank you for always believing in me.

TABLE OF CONTENTS

Author's Declaration ii

Borrower's Page iii

Abstract iv

Acknowledgements v

Table of Contents vi

List of Tables viii

List of Figures ix

Nomenclature x

CHAPTER 1: INTRODUCTION

Introduction 1

CHAPTER 2: REAL OPTIONS BACKGROUND

2.1 Options 5

2.2 Valuation Techniques 5

2.2.1 Risk Neutral Valuation 6

2.2.2 The Black-Scholes-Merton Model 6

2.2.3 Monte Carlo Simulation 8

2.2.4 Finite Difference Methods 9

2.2.5 The Lattice Technique 10

2.3 Real Options 12

2.4 Market Price of Risk 14

CHAPTER 3: PROBLEM DEFINITION AND LITERATURE REVIEW

3.1 Background on Global Supply Chain 17

3.2 Problem Definition 18
3.3 Solution Approach 19
3.4 Literature Review 20
3.4.1 Optimization Models 20
3.4.2 Stochastic Features 22
3.4.3 Valuation Approach 23
CHAPTER 4: MATHEMATICAL MODELING
4.1 Mathematical Modeling 25
4.2 The Product Life Cycle Lattice 27
4.2.1 The Determination of Conditional Branch Probabilities 28
4.3 Exchange Rate Lattice 32
4.4 Supply Chain Network Model 34
4.4.1 Optimization Model 36
4.5 Related Costs Considered in the Overall Model 37
4.6 Recursive Dynamic Programming 38
4.6.1 The Growth Regime 39
4.6.2 The Maturity Regime 40
4.6.3 The Decay Regime 41
CHAPTER 5: NUMERICAL EXAMPLE AND RESULTS
5.1 Numerical Example 43
5.2 Results and Discussion 46
CHAPTER 6: CONCLUSION AND RECCOMENDATIONS
Conclusion and Recommendations 53
REFERENCES 55

LIST OF TABLES

Table 3.1: Main characteristics of related literature 24

Table 4.1: The five different jump events and their corresponding values and Probabilities. 33

Table 5.1: Switching costs 45

Table 5.2: Logistic costs per unit 45

Table 5.3: Product life cycle parameters 45

Table 5.4: Product demand information 45

Table 5.5: Monthly capacity levels and fixed costs 45

Table 5.6: Product price and corporate tax 45

Table 5.7: Exchange rates data 46

LIST OF FIGURES

Figure 4.1: Modeling steps 26

Figure 4.2: The heptalnomial lattice for the product life cycle 27

Figure 4.3: Supply chain network diagram 34

Figure 5.1: Optimal network configuration 46

Figure 5.2: Profit values for different American product prices 47

Figure 5.3: Profit values for different Canadian product prices 47

Figure 5.4: Profit values for different mean values for the growth regime 48

Figure 5.5: Profit values for different mean values for the maturity regime 48

Figure 5.6: Profit values for different mean values for the decay regime 48

Figure 5.7: Profit values for different standard deviation values for the growth Regime 49

Figure 5.8: Profit values for different standard deviation values for the maturity Regime 49

Figure 5.9: Profit values for different standard deviation values for the decay Regime 50

Figure 5.10: Profit values for different tax rates in Mexico 50

Figure 5.11: Profit values for different mean values of the switching probabilities from growth to maturity regime 51

Figure 5.12: Profit values for different standard deviation values for the American exchange rate 51

NOMENCLATURE

S	Stock price h
μ	Mean rate
σ	Volatility
f	Call option value
g	Real option value
λ	Market price of risk
Π	Value of the portfolio
$\Delta\Pi$	Accumulated profit or loss of the portfolio
π	Probability of traveling along the upper branch of the binomial tree
ϕ	Continuously compounded rate of return
w_z	Size of an up jump in the exchange rate lattice
d_z	Size of a down jump in the exchange rate lattice
t_i	Time at interval i
p_j	Jump probability values of the exchange rate lattice where j represents the jump event
ν_z	Instantaneous mean of exchange rate, subscript z refers to exchange rate 1,2
r	Riskless rate
ρ	Correlation between the two exchange rates
ω	Stretch parameter
O_t	Manufacturing option at time t

p	Plant index in the set of plants P
m	Market region in the set of market regions M
h_p	Country in which plant p is located
h_m	Country in which market region m is located
T_h	Corporate tax rate in country h
e_{oh}	Exchange rate of currency h with numeraire currency 0
r_m	Price of the firm's output in the market region m
l_{pm}	Variable logistics costs from plant p to market region m
F_p	Fixed manufacturing costs at plant p
P_p	Variable production cost at plant p
K_p	Capacity of plant p
D_m	Demand in market region m
γ_{mt}	Fraction of the total demand that represent the demand in market m at time t
θ_t	Total demand at time t
y_p	Open or closed plant p
y_m	Open or closed market region m
y_{pm}	Open or closed supply linkage from plant p to market region m
Q_{pm}	Shipment of finished product from plant p to market region m
Q_p	Amount of finished product produced at plant p
s_{1p}	Percentage of initial installment cost of one unit of capacity (Expansion) at a plant
s_{2p}	Percentage of initial installment cost of one unit of capacity (Contraction) at a plant
s_{3p}	Fixed switching costs at a plant

s_{4p} Fixed switching costs at a plant

c_{4p} Cost of installing one unit of capacity at a plant

CHAPTER 1

INTRODUCTION

In today's extremely competitive global market, organizations face many challenges to survive and sustain profitability. This has given a rise to new management philosophies that aim to define the most effective and efficient paths of evaluating the respective company's options. Investments are typically correlated with uncertainty; hence, most firms adopt real options analysis as part of their planning process as it provides a useful tool in evaluating an investment with managerial flexibility under uncertainty.

The main focus of this research is primarily concerned with financial engineering and supply chain design. Financial engineering involves the use of financial theory, mathematical tools, engineering methods and the practice of programming to make investment decisions, as well as determining the risks associated with those respective decisions. Supply chain design is defined as "the process of planning, implementing and controlling the operations of the supply chain as efficiently as possible" (Mangan et al., 2008). Moreover, supply chain design addresses the distribution network and strategy, the information shared by the levels of the chain, inventory, and the cash flow of the chain. Real options analysis is directly embedded in this field of research as it is a vital evaluation technique for dealing with uncertainty.

In recent times, there has been some research devoted to global supply chain design and real options. Work published by Kouvelis et al. (2004), Wu and Lin (2005), Tsiakis and Papageorgiou (2008), along with a number of papers, have modeled cases that involved investments in several countries. Various arrays of programs have been developed for global supply chains utilizing real options. The work of Huchzermeier and Cohen (1996) and Nembhard et al. (2005) focused mainly on exchange rate uncertainty but failed to include stochastic demands. Kogut and Kulatilaka (1994) realized the importance of taking account of exchange rate uncertainty in the valuation approach; the proposed model is extremely limited and inflexible as it only considers one exchange rate and only two production location decisions.

Overall, it is apparent that a number of limitations have been observed in the current literature examined. These limitations include considering deterministic demands, constant capacity levels, and the failure to consider all the necessary production switching options. Vidal and Geotschalckx (1997) agree that more research is needed to address the realistic nature of uncertainty in the area of global distribution and supply chain planning. In this thesis, the research application is extended by incorporating exchange rate and demand uncertainties, different capacity levels and adjustment costs.

The principle contributions of this thesis are:

1. Developing a product life cycle lattice and integrating an exchange rate lattice to account for exchange rate and demand uncertainty.

2. Creating a supply chain network model that utilizes demand and exchange rates in order to obtain the most profitable supply chain linkages, while factoring in adjustment costs.

3. Presenting a recursive dynamic programming algorithm used to calculate expected after tax profits.

The remainder of this thesis is organized as follows. Chapter 2 provides background on real options and basic definitions, where the Black Scholes model will be examined along with the lattice approach. Chapter 3 identifies the problem definition and limitations along with a review of related literature. Chapter 4 contains a detailed description of the proposed model. Chapter 5 portrays a numerical example and the results. Chapter 6 presents concluding remarks and recommendations for future research.

CHAPTER 2

REAL OPTIONS BACKGROUND

2.1 Options

Options are financial instruments that provide the holder the right, but not the obligation, to engage in a future transaction on some underlying asset (Copeland and Antikarov, 2001). The two basic types of options are call and put options. A call option offers the holder the right to buy the underlying asset for a certain price, known as the strike price, by a predetermined date known as the expiration date. Whereas, a put option offers the holder the right to sell the underlying asset for certain price, by the expiration date. The vast majority of options are either European or American. European options can only be exercised on the expiration date, while American options can be exercised anytime before the expiration date. Although most traded options on exchanges are American, it is generally much easier to analyze European options.

2.2 Valuation Techniques

A number of valuation techniques have been developed to estimate the value of an option using stochastic calculus under the concept of risk neutral pricing. The most commonly used techniques are the Black Scholes-Merton model, Monte Carlo simulation, finite difference models and the lattice approach.

2.2.1 Risk Neutral Valuation

The concept of risk neutral valuation is adopted by all the valuation techniques mentioned above when estimating the value of an option. Risk neutral valuation is the most significant tool for the analysis of derivatives (Hull, 1998). The world is risk neutral when valuing a financial option under the principle of risk neutral valuation. Under risk neutral valuation, users treat all options as having expected returns equal to the risk free rate. In implementing risk neutral valuation, an option value can be calculated using the following steps: First, the risk neutral probabilities have to be solved. Second, using the risk neutral probabilities, the expected value of the option is found. Third, the expected payoff is then discounted at the risk free rate. Although the notion of risk neutral valuation implies that the world is risk neutral when pricing options, the results obtained are valid not only in a risk neutral world, but in the real world as well.

2.2.2 The Black-Scholes-Merton Model

The Black-Scholes-Merton model is the first tool to be developed for valuing options. Prior to the development of the black-Scholes model, there was no standard way of pricing an option. The authors of the Black-Scholes equation, were rewarded a Nobel Prize in economics in recognition of their contribution to the field of financial derivatives. The Black-Scholes-Merton differential equation is "an equation that must be satisfied by the price of any derivative dependent on a non-dividend-paying stock" (Hull, 2006). The Black-Scholes-Merton model is derived under the assumption that the option can be exercised only at expiration. It requires that the risk-free rate and all maturities of underlying stock price remain constant. The model also assumes that the underlying stock does not pay dividends. Moreover, it entails that there are no riskless arbitrage opportunities or transactions costs (Hull, 2006). And most importantly, the model assumes that the stock price, S, follows a geometric Brownian motion. That is,

$$dS = \mu S dt + \sigma S dz \tag{2.1}$$

Where μ is the drift rate, σ is the variance rate and dz is a Wiener process that can be regarded as adding uncertainty to the path that S follows. Let f be a call option value on S, which must also be a function of S and t. From Ito's lemma for two variables (Hull, 2006),

$$df = \left(\frac{\partial f}{\partial S} \mu S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) dt + \frac{\partial f}{\partial S} \sigma S dz \tag{2.2}$$

The authors then set up a riskless portfolio which is short one derivative and long an amount $\partial f / \partial S$ of shares. Defining Π as the value of the portfolio,

$$\Pi = -f + \frac{\partial f}{\partial S} S \tag{2.3}$$

Let $\Delta\Pi$ denote the accumulated profit or loss of the portfolio. Over the time interval Δt, the value of the portfolio is given by

$$\Delta\Pi = -\Delta f + \frac{\partial f}{\partial S} \Delta S \tag{2.4}$$

The substitution of equations (2.1) and (2.2) into (2.4) yields,

$$\Delta\Pi = \left(-\frac{\partial f}{\partial t} - \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) \Delta t \tag{2.5}$$

Since this equation does not contain the Δz term, the portfolio must be riskless during Δt. Thus, given that there are no arbitrage opportunities, the rate of return on this portfolio must be equal to the other short-term risk-free securities.

$$\Delta\Pi = r\Pi\Delta t \tag{2.6}$$

Where r is the risk-free interest rate. Substituting equations (2.3), (2.5) and (2.6) yields

$$\left(\frac{\partial f}{\partial t}+\frac{1}{2}\frac{\partial^2 f}{\partial S^2}\sigma^2 S^2\right)\Delta t = r\left(f-\frac{\partial f}{\partial S}S\right)\Delta t \tag{2.7}$$

resulting in the Black-Scholes-Merton differential equation,

$$\frac{\partial f}{\partial t}+rS\frac{\partial f}{\partial S}+\frac{1}{2}\sigma^2 S^2\frac{\partial^2 f}{\partial S^2}=rf \tag{2.8}$$

The key advantage of the Black-Scholes-Merton model is its ability to calculate a very large number of option prices in a simple manner and in a short period of time. However, the Black-Scholes-Merton model cannot be used to accurately price American options as it only calculates the option price at expiration. In addition, the position of the stock and the derivative in the model is riskless for a very short period of time and must be adjusted frequently to comply with the model's assumptions.

2.2.3 Monte Carlo Simulation

According to Hull (1998), Monte Carlo simulation is defined as a procedure for randomly sampling changes in market variables in order to value a derivative. A Monte Carlo simulation determines the value of an option from a set of randomly generated outcomes. In a Monte Carlo simulation, paths are sampled to obtain the expected payoff of an option in a risk-neutral world. The expected payoff is discounted at a risk-free rate to attain an estimate of the value of the option.

One of the main advantages of the Monte Carlo simulation is its tendency to be numerically more efficient than most procedures when dealing with three or more stochastic variables (Nembhard et al., 2005). According to Hull (2006), the time taken to carry out a Monte Carlo simulation increases approximately linearly with the number of variables, while, for most other procedures, it increases exponentially with the number of variables. Another advantage of the Monte Carlo simulation is that it offers a standard error for the estimates made. Furthermore, this approach can accommodate complex stochastic processes and payoffs. On the other hand, the Monte Carlo simulation is computationally time consuming and cannot easily be used for American options.

2.2.4 Finite Difference Methods

The implicit and explicit finite difference methods, the hopscotch method, and the Crank-Nicolson scheme are examples of finite difference methods that value derivatives by solving the differential equations that the derivatives satisfy. Once the differential equation is converted into a set of difference equations, they are solved iteratively (Hull, 2006). Finite difference methods have the advantage of handling American options. In addition, finite difference methods can be used when there are several state variables. This can only be achieved at the expense of a substantial increase in computer time. However, these methods cannot be easily applied to situations where the payoff from a derivative depends on the past history of the underlying variable (Hull, 2006).

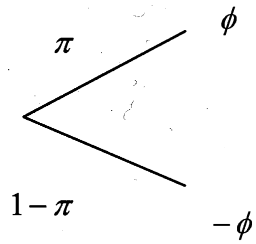
2.2.5 The Lattice Technique

The lattice technique involves dividing the life of an option into a large number of time intervals. In each time interval, the price of the underlying asset moves from its initial value to one of two new values in a binomial tree or to one of three values in trinomial tree etc. A tree of these price movements is then formed working forward from the present to expiration. The tree represents all the possible paths that the underlying asset price could take during the life of the option. The value of the option is then calculated working backwards from expiration to the present.

In order to get a good understanding of the lattice technique, the binomial lattice technique has to be introduced. The binomial lattice technique can help achieve computational efficiency in dynamic programming. According to Cox et al. (1979), a binomial lattice is governed by the geometric Brownian motion, meaning that the process over a small interval, h, entails that the continuously compounded return, b, is normally distributed with mean, μh, and volatility, $\sigma\sqrt{h}$, expressed as:

$$b \sim N(\mu h, \sigma^2 h) \tag{2.9}$$

The binomial lattice is a simple tool that is used to represent two possible outcomes of a single stochastic process.



Each node of the binomial tree has two parameters; π, the probability of traveling along the upper branch, and ϕ, the continuously compounded rate of return of the variable after traveling along that branch. In order to estimate these two parameters, the first and second moments of the process are matched with that of the normal distribution. By matching the expected return implied by a binomial lattice with that of the normal distribution, equation (2.10) is obtained.

$$\pi e^{\phi} + (1-\pi)e^{-\phi} = e^{\mu h} \tag{2.10}$$

Similarly, matching the variance of return implied by a binomial lattice with that of the normal distribution, yields equation (2.11).

$$\pi(\phi)^2 + (1-\pi)(-\phi)^2 - \mu^2 h^2 = \sigma^2 h \tag{2.11}$$

Values of π and ϕ can be obtained by solving equations (2.10) and (2.11), resulting in:

$$\pi = \frac{(e^{uh} - e^{-\phi})}{(e^{\phi} - e^{-\phi})} \tag{2.12}$$

$$\phi = \sqrt{\sigma^2 h + \mu^2 h^2} \tag{2.13}$$

The Binomial lattice approach is broadly used due to its ability to handle a variety of conditions for which other models cannot easily apply. The main advantage of the lattice approach is that it can accurately value American options, as well as European options. This is because the option life is divided into time intervals, and, at each interval, it is possible to check for the possibility of early exercise. Because this approach is fairly simple mathematically, it is commonly used by practitioners in the options market and can be implemented easily. Although the lattice approach is computationally slower than the Black Scholes model, it has higher accuracy especially for options on securities with dividend payments, as well as longer-dated options. On the contrary, one of the major limitations of the lattice approach is the fact that it is relatively slow. Additionally, the lattice approach is not practical for options with several sources of uncertainty.

2.3 Real Options

In today's unstable economy, managers realize the importance of flexible strategy when it comes to investments. In investments, as in life, mangers are faced with options that can turn an investment project from a complete failure to a major success and vice versa. Hence, it is very crucial for managers to identify their options and realize ways to get the most out of uncertain future events. The real options approach allows managers to limit downside risk by leveraging uncertainty, consequently improving investment planning and maximizing revenue. As suggested by Amram and Kulatilaka (1999), strategic investments should be planned in terms of real options as they give a better scope of a company's opportunities. A real option is defined by Copeland and Antikarov (2001) as "the right, but not the obligation to take an action at a predetermined cost called the exercise price, for a predetermined period of time-the life of the option". Using real options as a method for project evaluation has been a main driver of much research in the past 20 years (Ingersoll and Ross (1992), Huchzermeier and Loch (2001), Alvarez and Stenbacka (2001), and Bernardo and Chowdhry (2002)).

Often investment opportunities involve options that can add substantial value to a project such as abandonment, expansion, and contraction options, as well as the option to either defer or extend a project. The valuation of such options have been studied by Michaildis (2006), Panayi and Trigeorgis (1998), McDonald and Siegel (1985), Brennan and Schwartz (1985), and Triantis and Hodder (1990). Michaildis (2006) provides an example of employing real options methodology for the decision process of a ski centre enlargement project. Panayi and Trigeorgis (1998) examine multi-stage real options applications for an actual case study of an international expansion option of a bank. McDonald and Siegel (1985) use real options for the valuation of firms when there is an option to shut down. Brennan and Schwartz (1985) adopt real options for the evaluation of natural resource investment projects with stochastic output prices, keeping in mind the possibility that a project may be closed down or even abandoned if output prices are not desirable. Triantis and Hodder (1990) develop an approach for valuing flexible production systems that have profit margin functions with stochastic parameters.

The traditional approach of capturing the value of a capital investment project in an environment of uncertainty and rapid change is known as the net present value (NPV) approach. According to Hull (2006), it is difficult to account for embedded options within a project using the NPV approach as these options usually have different characteristics from the base project and require different discount rates. On the contrary, the real options method represents the new state-of-the-art technique for strategic investments valuation.

Like financial options, real options are valued under the notion of risk neutral valuation presented in section 2.2.1.

2.4 Market Price of Risk

Risk neutral valuation is the fundamental theorem of option pricing. In the presence of market risk, the problem of valuation can be reduced to the problem of valuation in a risk free world by factoring in market price of risk (Constantinides, 1978). Let the underlying asset, S, follow the Ito process

$$d\,S/S = \mu dt + \sigma dz \tag{2.14}$$

According to Lyuu (2002), any derivative that follows the Ito process $d\,h/h = \mu dt + \sigma dz$, where h is the expected payoff of the option, and whose value depends on S must satisfy

$$\mu = r + \lambda\sigma \tag{2.15}$$

Where λ is the market price of risk. The market price of risk is the excess expected return used as a compensation for taking a risk. The term $\lambda\sigma$ assesses the amount of risk taken (Lyuu, 2002). μ and σ are derived using Ito's lemma:

$$\mu = \frac{1}{h}\left(\frac{\partial h}{\partial t} + \mu S\frac{\partial h}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 h}{\partial S^2}\right), \quad \sigma = \frac{\sigma S}{h}\frac{\partial h}{\partial S} \tag{2.16}$$

Substituting (2.16) into (2.15) yields,

$$\frac{\partial h}{\partial t} + (\mu - \lambda\sigma)S\frac{\partial h}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 h}{\partial S^2} = rh \tag{2.17}$$

To follow risk neutral valuation on equation (2.17), the expected payoff h is discounted at the risk free rate of return as if the market price of risk were zero (Lyuu, 2002).

CHAPTER 3

PROBLEM DEFINITION AND LITERATURE REVIEW

3.1 Background on Global Supply Chain

In a world with a dominant globalization, the notion of global supply chain management has become more vital for corporations. A global supply network is identified as "a set of existing or potential manufacturing facilities, warehouses, and distribution centers with multiple supply configurations and customers with demand" (Tsiakis and Papageorgiou, 2008). Multinational corporations are faced with numerous options when it comes to location decisions for their suppliers, production plants, and markets. Because multinational corporations have operations in a plethora of countries, they are faced with a number of difficulties that need to be managed properly. When investing in foreign countries, companies need to consider all the factors that influence the overall costs of their decisions. These factors include tariffs, transportation costs, labor costs, laws and regulations and exchange rates. Geoffrion and Powers (1995) describe how market requirements drive more research into developing algorithms to address supply chain decisions under uncertainty. Therefore, corporations must utilize a global supply management approach that includes all the necessary factors.

Globally operated firms must give close consideration to flexibility in their supply chain network design. Because multinational firms have branches in more than one country, they adopt multi-supplier sourcing, multi-site production, and several market distributions. Utilizing operational flexibility in a supply chain network is highly valuable as it can increase a firm's profit while reducing downside risks (Huchzermeier and Cohen, 1996).

Firms must appropriately make the decision on the necessary number of suppliers and their locations. Although having fewer suppliers may be easier to manage, this may lead to potential problems, i.e., if one supplier does not deliver as scheduled, it becomes difficult to find another supplier when the pool of suppliers is limited. The importance of strategically selecting suppliers must not be underestimated as it can achieve a balance between the lowest material cost and the transportation costs. Deciding on the number and location of the plants needed is very crucial and can potentially eliminate difficult logistical problems. Firms must consider tactical plant locations that would utilize suppliers and markets included in the supply chain network. In addition, firms should factor in costs of employees, laws and regulations, shipping and duties of the countries considered for potential plant locations (Kouvelis et al., 2004). Moreover, when firms choose to supply their products overseas to foreign markets, they must be aware of the reality of uncertain demands and exchange rates. The study of facility location models and distribution planning has been a driver for many researchers such as Klose and Drexl (2005), Pirkul and Jayaraman (1998), Melo et al. (2005), Lowe et al. (2002) and Amiri (2006).

3.2 Problem Definition

This thesis addresses the operations and the valuation procedure for globally operated firms. A firm with a global production and distribution network is considered. The network consists of a number of existing manufacturing sites and market zones at fixed locations. These locations include Canada, Mexico and the United States of America. The context of this research considers a two-echelon supply chain network, production and distribution, and assumes a single product. The product can be produced at all three manufacturing sites. Multiple capacity levels at each manufacturing facility will be included in the valuation framework. Market zones can be supplied from more than one manufacturing facility. Demands in the market zones are stochastic along with the exchange rates amongst the three countries. Each country has its own tax rate and operational costs. The decisions to be made by the firm include production amounts at each facility, capacity levels at each plant, transportation links to be used in the network, and the amount of products shipped from a plant to a market zone. The objective is the maximization of the after-tax profit taking into account operational costs, capacity adjustment costs, as well as the effect of fluctuating exchange rates and stochastic demands.

3.3 Solution Approach

In this thesis, a real options valuation framework is adopted. First, a product life cycle model is to be constructed to account for uncertain demands. Second, in order to factor in uncertain exchange rates, an exchange rate lattice will be developed to incorporate all the different exchange rate scenarios. Third, an efficient supply chain network model is to be created to determine the options for supply chain network designs. This model will help determine the most profitable plant locations as well as the optimal quantities for production and distribution. The model will also integrate several production capacity levels for the production plants. Finally, a stochastic dynamic programming model is to be developed to calculate the expected after tax profit while factoring in the adjustment costs.

3.4 Literature Review

In recent times, there has been some research devoted to global supply chain and the adoption of real options and flexibility under uncertainty. The literature review has been divided into three sections:

1. Optimization models
2. Stochastic features
3. Valuation approach

3.4.1 Optimization Models

Much research has been dedicated to the development of optimization models for a variety of supply chain design networks. Sargut and Romeijn's (2007) contributions include creating a mathematical model which integrates production, inventory, transportation, backlogging and subcontracting decisions in a two-echelon supply chain with a goal of minimizing total systems costs. Kouvelis et al. (2004) studied the design of global facility networks. The authors' work mainly consists of modeling rather than an algorithmic focus. The authors present a mixed integer programming model used to provide users with the knowledge of the most preferable international facility networks for various environments. The modeling procedure incorporates design trade-offs such as government subsidies, trade tariffs and taxation issues for global facility networks. The effects of such factors on the structure of the global facility networks are reflected in the modeling framework. The model focuses on financing and corporate tax issues and is aimed to maximize a firm's discounted after tax cash flows.

Similarly, Tsiakis and Papageorgiou's (2008) research focuses on the optimization of global production and distribution networks including the effects of financial issues. The authors present a mixed integer linear programming model designed for global supply chain networks. The model proposed integrates plant locations, production, distribution, exchange rates, plant utilization, and financial issues such as duties. This model is aimed to assist managers to make decisions about production allocation, capacity and network configuration while factoring in financial aspects. Financial issues of global supply chain networks have also been considered in the works of Huchzermeier and Cohen (1996). The authors developed a mathematical model which enables the firm to maximize its after tax profits by considering exchange rate uncertainty and by having the flexibility to switch amongst a set of predetermined options. Nembhard et al. (2005) uses a similar approach to Huchzermeier and Cohen (1996); they present a supply chain model with the flexibility to select an option amongst a number of options for suppliers, plant locations and market region. They also include stochastic exchange rates and a time lag in their valuation framework.

A different approach is used in Poojari et al. (2008) by formulating a two-stage stochastic integer programming model as a strategic supply chain planning problem. This model is constructed to determine strategic decisions with respect to site locations, production, distribution and capacity policies. The authors implemented Bender's decomposition to process the problem. Kazaz et al. (2005) also developed a two-stage approach to deal with an aggregate production problem in a global manufacturing network. The problem is formulated as a two stage program whose optimal policy structure features two forms of flexibility: production hedging and allocation hedging.

3.4.2 Stochastic Features

The importance of including uncertainties while conducting future plans for multinational firms is paramount. Li and Rugman (2007) extend the applications of real options theory to multinational enterprises that utilize foreign investments. Their work focuses on the determination of location and choice of market entry under price uncertainty. The authors present two real options models, one for the choice of location and the other for the market entry mode. The authors concluded that multinational enterprises are inclined to pursuing a localization strategy in the home country when they have fewer opportunities of exercising real options in foreign countries.

Although Sargut and Romeijn (2007), Tsiakis and Papageorgiou (2008), Huchzermeier and Cohen (1996) and Nembhard et al. (2005) all assume demand to be deterministic in their developed models, many other researches realized the importance of including stochastic demands in their valuation framework. Poojari et al. (2008) factor in demand uncertainty by developing an approximate distribution of the demand using the generalized lambda distribution. Furthermore, Bollen (1999) included demand uncertainty by incorporating a stochastic product life cycle into his solution framework. He used a regime switching process to represent the product life cycle starting with the growth regime which is then followed by the decay regime. Bollen's framework also includes valuing the option to change a project's capacity. Moreover, the valuation framework factors in switching costs. Bhatnagar and Sohal (2005) focused their work on factors that impact supply chain competitiveness. The three main factors discussed are location factors, supply chain uncertainty and manufacturing practices. Although the authors account for supply, process and demand uncertainties under the three main sources of uncertainty in supply chain, there was no cite of the exchange rate uncertainty.

However, Kogut and Kulatilaka (1994) realized the importance of including exchange rate uncertainty in the valuation approach. Although the proposed model incorporates exchange rate uncertainty, it becomes extremely limited and inflexible as it only considers one exchange rate and only two production location decisions. An alternative method of dealing with exchange rate uncertainty is presented by Kazaz et al. (2005). In their two stage approach, the authors defer the allocation decision until the realization of the exchange rate. Huchzermeier and Cohen (1996) and Nembhard et al. (2005) propose a multinomial approximation model for generating exchange rate scenarios and their transition probabilities. Their work reveals that flexibility in the facility networks can be used as a hedge against exchange rate fluctuations in the future.

3.4.3 Valuation Approach

Most existing literature reviewed in this chapter use a real options approach. Dynamic programming is typically used for valuing real options. Kogut and Kulatilaka (1994) developed a stochastic dynamic programming formulation designed to value production switching between two plant locations. Huchzermeier and Cohen (1996) developed a stochastic dynamic programming formulation to valuate global manufacturing options with switching costs. Bollen (1999) created an option valuation framework that incorporates a stochastic product life cycle by using a regime switching process. Bollen's dynamic programming formulation also includes valuing the option to change a project's capacity while including switching costs.

Sargut and Romeijn (2007) propose dynamic programming algorithms for lot sizing problems in serial supply chains under various assumptions on costs, inventory structure, subcontracting opportunities, production and subcontracting capacities. Their proposed methods allow for backlogging at the manufacturing level, as well as outsourcing and overtime production opportunities. On the other hand, Nembhard et al. (2005) use a Monte Carlo simulation technique for the valuation of operational flexibility. The authors indicate that their proposed Monte Carlo simulation procedure can easily include a large number of variables into the valuation process by yielding close estimates for the true option value. Table 3.1 summarizes some of the reviewed literature.

Table 3.1: Main characteristics of related literature.

Model Characteristics	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Stochastic features							
Exchange Rates	X			X		X	X
Demand	X	X			X		
Status of Facilities							
Variable number of locations	X	X	X	X		X	
Variable transportation links	X	X	X	X		X	
Capacities							
Multiple Capacities at plants	X	X	X		X		
Adjustment Costs	X				X		X
Mathematical Model							
Maximizes Profits	X	X	X	X		X	X
Includes Tax and duties	X		X	X		X	
Factors in uncertainty	X	X		X		X	
Enables option switching	X			X		X	X

References considered in this table: [1] This thesis; [2] Poojari et al. (2008); [3] Tsiakis and Papageorgiou (2008); [4] Huchzermeier and Cohen (1996); [5] Bollen (1999); [6] Nembhard et al. (2005); [7] Kogut and Kulatilaka (1994).

Overall, a number of limitations have been observed in current literature resulting from the failure of considering all the necessary factors. In this thesis, a real options framework is implemented by incorporating exchange rate and demand uncertainty, different capacity levels for the production plants, and capacity adjustment costs. The model can be easily used for more than one exchange rate and can include several plant locations and markets.

CHAPTER 4

MATHEMATICAL MODELING

4.1 Modeling Framework

In order to accomplish the objective of this thesis, numerous models have been developed. The solution framework for this complex problem has been divided into sections. Each section is aimed to tackle a part of the overall problem. First, a lattice is constructed to represent the stochastic product life cycle. This lattice will be used to forecast the demand of the product in the market over the next few years. Second, an exchange rate lattice is formed to incorporate different possible future exchange rate scenarios. Third, once the lattices mentioned earlier are formed, an efficient supply chain network model is developed. This model will help determine plant locations that will yield the most profits, as well as the optimal quantities for production and distribution from the plants to the markets based on the demand and the exchange rate scenarios. Furthermore, the model will incorporate different capacity levels for production.

In order to solve such a complex problem, the fourth step includes partitioning the planning horizon [0, *T*] into many small time intervals such that the sub-problem can be solved easily, where $t=T$ is the end of the planning horizon. Although the planning horizon is divided into time intervals, making the overall problem discrete, the discounted after tax profit calculated by the recursive dynamic programming algorithm is optimal. At each time interval, the supply chain model will be solved taking into consideration the realized demand and exchange rates obtained from the lattices mentioned earlier. Subsequently, a recursive dynamic programming algorithm will be used to calculate the expected after tax profit. And since several capacity levels are considered, a capacity adjustment cost function will be developed to count for the cost of switching from one capacity level to the other. The overall modeling framework is presented in Figure 4.1.

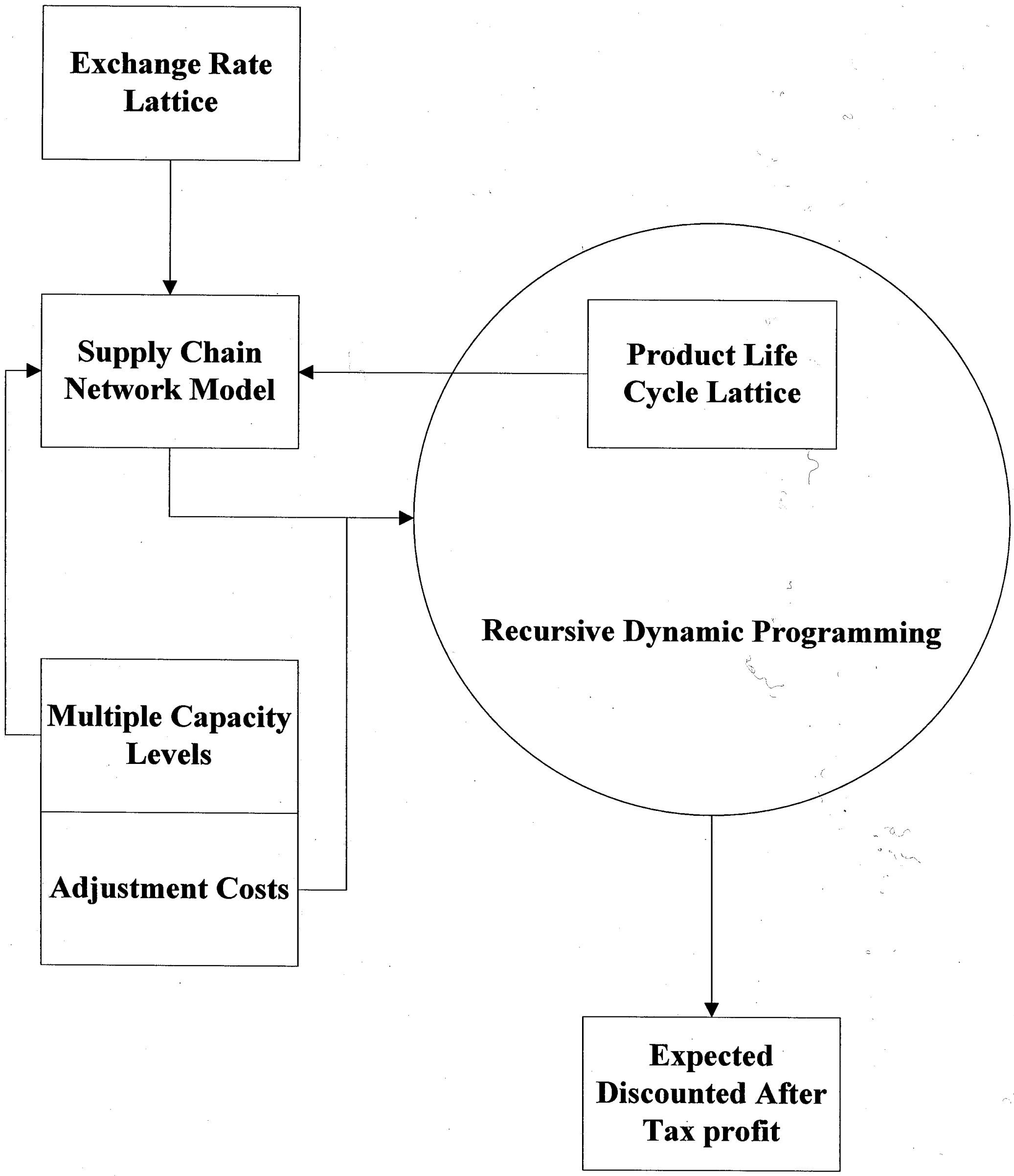


Figure 4.1: Modeling steps

4.2 The Product Life Cycle Lattice

A product progresses through a sequence of stages following its introduction to the market. These stages represent the nature of the demand in the market. Each stage is known as a regime. During the first stage, known as the growth regime, demand and sales are increasing. Once demand and sales hit a plateau, the product then enters the second stage which is known as the maturity regime. Finally, when demand and sales start declining, the product enters the final stage of the product life cycle known as the decay regime. As emphasized in Pisano and Wheelwright (1995), product life cycles are of utmost importance as they effect expectations of a project's future profits and thus the value of a project's real options. The lattice approach, which is explained in the next section, can be used to model the product life cycle.

Bollen's (1999) approach of developing the pentanomial lattice was expanded to develop the heptalnomial lattice dashboard life cycle for this problem. Figure 4.2 demonstrates one of the possible scenarios of the product life cycle, where (i) and $(i+6)$ represent the growth regime while, $(i+1)$, $(i+3)$, and $(i+5)$ represent the maturity regime and $(i+2)$, $(i+3)$, and $(i+4)$ represent the decay regime.

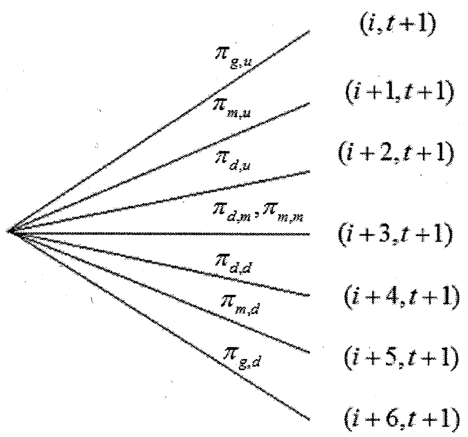


Figure 4.2: The heptalnomial lattice for the product life cycle.

In the heptalnomial lattice, two out of the three regimes will be presented by trinomial lattices and one by a binomial lattice due to the fact that its middle branch has a conditional branch probability equal to zero. In Figure 4.2, the growth regime is represented by the binomial lattice and both the maturity and decay regimes are presented by trinomial lattices.

4.2.1 The Determination of Conditional Branch Probabilities

The product life cycle is a regime switching process with three different regimes: growth regime, maturity regime, and decay regime. These three regimes are represented by a heptalnomial lattice. Similar to the binomial lattice, the continuous compounded return of the heptalnomial lattice is normally distributed. In a three regime regime-switching process, the instantaneous mean and volatility of each regime are constant within each regime. The step sizes of all three regimes are spaced equally to ensure that the nodes in the heptalnomial lattice are merged and the number of nodes is minimized. In order to achieve equally spaced step sizes, two out of the three regimes must be adjusted. Let ϕ_1, ϕ_2, and ϕ_3 represent the demand step sizes of regimes 1, 2, and 3, where the demand step sizes are calculated using equation (2.13) in chapter 2. According to Wahab (2006), in order to determine the two regimes that need adjustments, the following must be done.

1. Determine ϕ, where $\phi = \max(\phi_1, \frac{\phi_2}{2}, \frac{\phi_3}{3})$, given that $\phi_1 < \phi_2 < \phi_3$

2. If $\phi = \phi_1$, then ϕ_2 is increased to $2\phi_1$, and ϕ_3 to $3\phi_1$. In this case, regime 1 is constructed as a binomial lattice. Regimes 2 and 3 are constructed as trinomial lattices. Given that regime 1 is constructed as a binomial lattice, the conditional branch probability can be

obtained using equation (2.12). On the other hand, since regimes 2 and 3 are constructed by trinomial lattices, let u, m, and d represent the upward, middle, and downward branches in the trinomial lattice. Matching the first and second moments of the trinomial lattice with that of the process governing the corresponding regime yields the following conditional branch probabilities.

$$\pi_{\phi_2,u}e^{(2\phi_1)} + \pi_{\phi_2,m}e^{(0)} + \pi_{\phi_2,d}e^{(-2\phi_1)} = e^{\mu_2 h} \tag{4.1}$$

$$\pi_{\phi_2,u}(2\phi_1)^2 + \pi_{\phi_2,d}(-2\phi_1)^2 - (\mu_2 h)^2 = \sigma_2^2 h \tag{4.2}$$

$$\pi_{\phi_3,u}e^{(3\phi_1)} + \pi_{\phi_3,m}e^{(0)} + \pi_{\phi_3,d}e^{(-3\phi_1)} = e^{\mu_3 h} \tag{4.3}$$

$$\pi_{\phi_3,u}(3\phi_1)^2 + \pi_{\phi_3,d}(-3\phi_1)^2 - (\mu_3 h)^2 = \sigma_3^2 h \tag{4.4}$$

Equations (4.1) and (4.2) are for regime 2, and equations (4.3) and (4.4) are for regime 3. Keeping in mind that all probabilities sum up to one, the solutions of these equations are:

$$\pi_{\phi_2,u} = \frac{e^{\mu_2 h} - e^{(-2\phi_1)} - \pi_{\phi_2,m}(1 - e^{(-2\phi_1)})}{(e^{(2\phi_1)} - e^{(-2\phi_1)})} \tag{4.5}$$

$$\pi_{\phi_2,m} = 1 - \phi_2^2 / (2\phi_1)^2 \tag{4.6}$$

$$\pi_{\phi_2,d} = 1 - \pi_{\phi_2,u} - \pi_{\phi_2,m} \tag{4.7}$$

$$\pi_{\phi_3,u} = \frac{e^{\mu_3 h} - e^{(-3\phi_1)} - \pi_{\phi_3,m}(1 - e^{(-3\phi_1)})}{(e^{(3\phi_1)} - e^{(-3\phi_1)})} \tag{4.8}$$

$$\pi_{\phi_3,m} = 1 - \phi_3^2 /(3\phi_1)^2 \tag{4.9}$$

$$\pi_{\phi_3,d} = 1 - \pi_{\phi_3,u} - \pi_{\phi_3,m} \tag{4.10}$$

3. If $\phi = \frac{\phi_2}{2}$, then ϕ_1 is increased to $\frac{\phi_2}{2}$, and ϕ_3 to $\frac{3\phi_2}{2}$. In this case, regime 2 is constructed as a binomial lattice, whereas regimes 1 and 3 are constructed as trinomial lattices.

4. If $\phi = \frac{\phi_3}{3}$, then ϕ_1 is increased to $\frac{\phi_3}{3}$, and ϕ_2 to $\frac{2\phi_3}{3}$. In this case, regime 3 is constructed as a binomial lattice, whereas regimes 1 and 2 are constructed as trinomial lattices.

In the case where $\phi = \frac{\phi_2}{2}$, or $\phi = \frac{\phi_3}{3}$, the regime that is not adjusted is constructed as a binomial lattice with, π, the probability of traveling along the upper branch, obtained using equation (2.16), whereas the other two regimes are constructed as trinomial lattices with *u*, *m*, and d representing the upward, middle, and downward branches in the trinomial lattice. Again, by matching the first and second moments of the trinomial lattice with that of the process governing the corresponding regime, and since all probabilities sum up to one, the solutions of these equations are:

$$\pi_{\phi_1,u} = \frac{e^{\mu_1 h} - e^{(-\phi_2/2)} - \pi_{\phi_1,m}(1 - e^{(-\phi_2/2)})}{(e^{(\phi_2/2_1)} - e^{(-\phi_2/2)})} \qquad (4.11)$$

$$\pi_{\phi_1,m} = 1 - \phi_1^2/(\phi_2/2)^2 \qquad (4.12)$$

$$\pi_{\phi_1,d} = 1 - \pi_{\phi_1,u} - \pi_{\phi_1,m} \qquad (4.13)$$

$$\pi_{\phi_3,u} = \frac{e^{\mu_3 h} - e^{(-3\phi_2/2)} - \pi_{\phi_3,m}(1 - e^{(-3\phi_2/2)})}{(e^{(3\phi_2/2_1)} - e^{(-3\phi_2/2)})} \qquad (4.14)$$

$$\pi_{\phi_3,m} = 1 - \phi_3^2/(3\phi_2/2)^2 \qquad (4.15)$$

$$\pi_{\phi_3,d} = 1 - \pi_{\phi_3,u} - \pi_{\phi_3,m} \qquad (4.16)$$

$$\pi_{\phi_1,u} = \frac{e^{\mu_1 h} - e^{(-\phi_3/3)} - \pi_{\phi_1,m}(1 - e^{(-\phi_3/3)})}{(e^{(\phi_3/3)} - e^{(-\phi_3/3)})} \qquad (4.17)$$

$$\pi_{\phi_1,m} = 1 - \phi_1^2/(\phi_3/3)^2 \qquad (4.18)$$

$$\pi_{\phi_1,d} = 1 - \pi_{\phi_1,u} - \pi_{\phi_1,m} \qquad (4.19)$$

$$\pi_{\phi_2,u} = \frac{e^{\mu_2 h} - e^{(-2\phi_3/3)} - \pi_{\phi_2,m}(1 - e^{(-2\phi_3/3)})}{(e^{(2\phi_3/3)} - e^{(-2\phi_3/3)})} \qquad (4.20)$$

$$\pi_{\phi_2,m} = 1 - \phi_2^2/(2\phi_3/3)^2 \qquad (4.21)$$

$$\pi_{\phi_2,d} = 1 - \pi_{\phi_2,u} - \pi_{\phi_2,m} \qquad (4.22)$$

4.3 Exchange Rate Lattice

Since the United States, Canada, and Mexico are the countries considered in the scope of this problem, an exchange rate model is of utmost importance. Given that three countries are considered, only two exchange rate scenarios should be modeled (the third can be derived from the other two). A lattice can be formulated for the two exchange rate scenarios and their transition probabilities. According to Kamrad and Ritchken (1991), for a pair of exchange rates (X_1, X_2), there are five different possible outcomes after a given interval of time, these possible outcomes are:

1) Both exchange rates go up;
2) The first exchange rate goes up while the second one goes down;
3) Both exchange rates go down;
4) The first exchange rate goes down while the second one goes up;
5) Both exchange rates remain the same (no change);

The exchange rate pair $(X_1(t_i), X_2(t_i)),\ i = 0,1,2...,n-1$(where i represents the time interval) can take any one of the five jump values with $\sum_{j=1}^{5} p_j = 1$. Table 4.1 summarizes the jump events and their corresponding values and probabilities. In Table 4.1, $w_z = \exp(\omega\sigma_z\sqrt{\Delta t})$ defines the size of an up jump while $d_z = (w_z)^{-1}$ is the down jump size where z=1,2 corresponds to the associated exchange rate.

Table 4.1: The five different jump events and their corresponding values and probabilities.

Jump event	**Corresponding values**	**Probability**
(up, up)	$X_1(t_0)w_1, X_2(t_0)w_2$	p_1
(up, down)	$X_1(t_0)w_1, X_2(t_0)d_2$	p_2
(down, down)	$X_1(t_0)d_1, X_2(t_0)d_2$	p_3
(down, up)	$X_1(t_0)d_1, X_2(t_0)w_2$	p_4
(none, none)	$X_1(t_0), X_2(t_0)$	p_5

Exchange rates $(X_1(t_i), X_2(t_i))$ have an instantaneous mean and variance equal to $\nu_z = \frac{r-\sigma_z^2}{2}$ and σ_z^2 respectively, where r is the riskless rate and σ is the instantaneous volatility. Let ρ represents the correlation between the two exchange rates. By adopting Kamrad and Ritchken's (1991) approach of introducing a normal random variable with mean $\nu_z \Delta t$ and variance $\sigma_z^2 \Delta t$, the first two moments of the approximating distribution are set equal to the true moments of the continuous distribution. This leads to the development of the following equations for the calculation of probabilities p_1 to p_5:

$$p_1 = \frac{1}{4}\left\{\frac{1}{\omega^2} + \frac{\sqrt{\Delta t}}{\omega}\left(\frac{\nu_1}{\sigma_1} + \frac{\nu_2}{\sigma_2}\right) + \frac{\rho}{\omega^2}\right\} \tag{4.23}$$

$$p_2 = \frac{1}{4}\left\{\frac{1}{\omega^2} + \frac{\sqrt{\Delta t}}{\omega}\left(\frac{\nu_1}{\sigma_1} - \frac{\nu_2}{\sigma_2}\right) - \frac{\rho}{\omega^2}\right\} \tag{4.24}$$

$$p_3 = \frac{1}{4}\left\{\frac{1}{\omega^2} + \frac{\sqrt{\Delta t}}{\omega}\left(-\frac{\nu_1}{\sigma_1} - \frac{\nu_2}{\sigma_2}\right) + \frac{\rho}{\omega^2}\right\} \tag{4.25}$$

$$p_4 = \frac{1}{4}\left\{\frac{1}{\omega^2} + \frac{\sqrt{\Delta t}}{\omega}\left(-\frac{\nu_1}{\sigma_1} + \frac{\nu_2}{\sigma_2}\right) - \frac{\rho}{\omega^2}\right\} \tag{4.26}$$

$$p_5 = 1 - \frac{1}{\omega^2} \tag{4.27}$$

where ω is a stretch parameter with value $\omega \geq 1$, used to ensure that all probabilities are non negative.

4.4 Supply Chain Network Model

Firms are faced with several options to where they should produce and supply their products. A supply chain network model can help give a perspective on the optimal scenarios that must be considered. The supply chain network shown in Figure 4.3, describes a single period problem which is solved numerous times at each time interval.

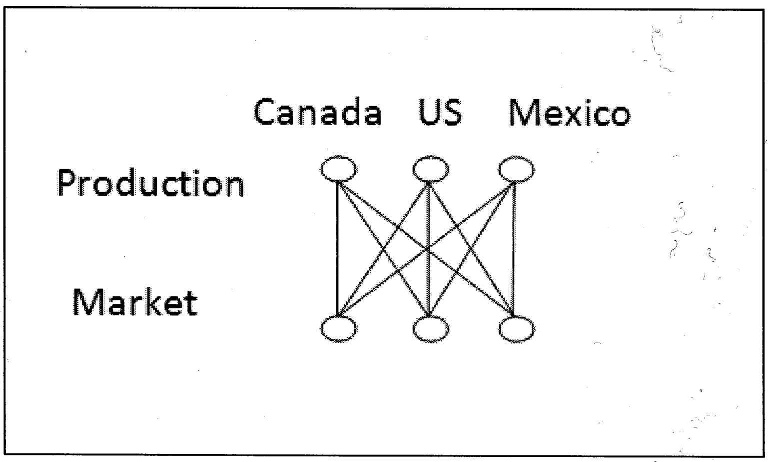


Figure 4.3: Supply chain network diagram.

A particular manufacturing option, O_t, defines the distribution network of the supply chain. Each option specifies the open or closed facilities within the global network, as well as the open or closed linkage between the facilities and the market regions, i.e., one option may be to produce in the US and Mexico and to only supply the market in Canada.

Influenced by the supply chain model developed by Huchzermeier and Cohen (1996), a supply chain model is formulated to account for the uncertainties that a firm is faced with. The main goal of this model is to maximize the firm's after tax profits by utilizing the decision variables. The decision variables that the firm is concerned with are usually related to the quantity of parts produced and location of the production, as well as transportation quantities and the selection of the markets.

This model will solve a single-period sub problem formulation for exchange rate scenario, $\bar{e}$, capacity, K, and demand, D. Prior to introducing the model, the following parameters and decision variables must be defined:

p = the plant index in the set of plants P;

m = the market region in the set of market regions M;

h_p = the country in which plant p is located;

h_m = the country in which market region m is located;

T_h = the corporate tax rate in country h;

e_{oh} = the exchange rate of currency h with numeraire currency 0;

r_m = the price of the firm's output in the market region m;

l_{pm} = the variable logistics costs from plant p to market region m;

F_p = the fixed operating costs at plant p;

P_p = the variable production cost at plant p;

K_p = the capacity of plant p;

D_m = Demand in market region m;

γ_{mt} = Fraction of the total demand that represents the demand in market m at time t;

θ_t = The total demand at time t;

$\gamma_{mt}\theta_t = D_m \quad m \in M$;

y_p = the open or closed plant p;

y_m = the open or closed market region m;

y_{pm} = the open or closed supply linkage from plant p to market region m;

Q_{pm} = the shipment of finished product from plant p to market region m;

Q_p = The amount of finished product produced at plant p;

π = The total discounted after tax profit for all plants;

4.4.1 Optimization Model

$$\pi(\bar{e}, \bar{D}, \bar{K}) = \max \sum_{p \in P} e_{oh_p} (NET_p - TAXES_p)$$

Subject to

$$PROFIT_p - LOSS_p = NET_p \qquad p \in P \qquad (4.28)$$

$$TAXES_p = T_{h_p} PROFIT_p \qquad p \in P \qquad (4.29)$$

$$NET_p = \sum_{m \in M} (e_{pm} r_m - l_{pm}) Q_{pm} - F_p y_p - P_p Q_p \qquad p \in P \qquad (4.30)$$

$$Q_p \le K_p y_p \qquad p \in P \qquad (4.31)$$

$$\sum_{p \in P} Q_{pm} \le d_m y_m \qquad m \in M \qquad (4.32)$$

$$\sum_{m \in M} Q_{pm} \le Q_p \qquad p \in P \qquad (4.33)$$

$$Q_{pm} \le B y_{pm} \qquad p \in P \quad m \in M \qquad (4.34)$$

$$LOSS_p, PROFIT_p, TAXES_p \ge 0 \qquad p \in P \qquad (4.35)$$

$$Q_{pm} \ge 0 \qquad p \in P \quad m \in M \qquad (4.36)$$

$$Q_p \ge 0 \qquad p \in P \qquad (4.37)$$

$$y_p \in \{0,1\} \qquad p \in P \qquad (4.38)$$

$$y_m \in \{0,1\} \qquad m \in M \qquad (4.39)$$

$$y_{pm} \in \{0,1\} \qquad p \in P \quad m \in M \qquad (4.40)$$

B = big number

The objective function determines the firm's after tax profit or loss, π, which is identified as the net profit minus taxes. The net profit and taxes at a particular plant are presented in equations (4.28), (4.29), and (4.30). Constraint (4.31) ensures that the quantity produced at plant p does not exceed the maximum capacity. Constraint (4.32) guarantees that the quantity of products shipped to a market does not exceed the demand of the market region it's being shipped to. Constraint (4.33) used so that a plant will not ship more products than produced. As for constraint (4.34), it assures that products will be shipped only if the linkage from the plant to the market is open. The use of a very large number, *B*, is very crucial in constraint (4.34). Adding a large number, *B*, will ensure that if $Q_{pm} > 0$, then $y_{pm} = 1$, and when $y_{pm} = 0$, it will then imply that $Q_{pm} = 0$ (Winston, 2004). Constraints (4.35), (4.36) and (4.37) ensure that loss, profit, taxes, products shipped and produced are non-negative. The binary variables in constraints (4.38) and (4.39) determine the plants that should be used for production as well as the markets. Moreover, the binary variable in (4.40) will identify the linkage between production locations the markets, i.e., binary variables will characterize the manufacturing strategy option.

4.5 Related Costs Considered in the Overall Model

Real options provide the firm with the flexibility to switch between capacity levels. The option to either expand or contract the capacity is very valuable and can be extremely beneficial; however, there are costs associated with this flexibility. Equations (4.41) and (4.42), adopted from Bollen (1999), represent the cost associated with capacity expansion and contraction, respectively. For plant p, function $S(K_{tp}, K_{t+1p})$ is classified to represent cash flow correlated with the changing capacity from K_{tp} to K_{t+1p}.

$$S(K_{tp}, K_{t+1p}) = s_{1p} c_{4p} (K_{t+1p} - K_{tp}) + s_{3p} \qquad when\ K_{t+1p} > K_{tp} \tag{4.41}$$

$$S(K_{tp}, K_{t+1p}) = s_{2p} c_{4p} (K_{tp} - K_{t+1p}) + s_{4p} \qquad when\ K_{tp} > K_{t+1p} \tag{4.42}$$

Where s_{1p} and s_{2p} represent the percentage of the initial installment cost of one unit of capacity. In the case of increasing capacity, s_{1p} is generally negative due to the need of cash outflows, whereas in the case of decreasing capacity, s_{2p} could either be negative due to clean up costs or positive due to the salvage value of machinery. In addition, s_{3p} and s_{4p} represent fixed switching costs and c_{4p} is the cost of installing one unit of capacity.

Other related costs include transportation costs from the plant to the market region, l_{pm}, as well as fixed operating cost, F_p, which is incurred when a plant is operated for production regardless of the production quantity. Moreover, variable production cost, P_p is also considered, this cost is directly related to quantity of products manufactured at plant p.

4.6 Recursive Dynamic Programming

Once the product life cycle has been formed, the expected discounted after tax profit can be calculated using recursive dynamic programming. Calculations begin at the end of the lattice and work backwards to the present. And since capacity levels are unknown, all possible capacity levels are considered at each node. The option value will incorporate the possibility of switching from one regime to the other. The expected after tax profit in regime j with capacity level K at time t is obtained using equation (4.43)

$$NPV(\theta_t, j, \vec{K}, t) = \max[\pi^*(\vec{e}\ ,\theta_t, \vec{K}) + S(K_{tp}, K_{t+1p}) + EV(\theta_t, j, \vec{K}, \vec{e}, t)]. \tag{4.43}$$

Where θ_t represents the total demand of all the markets at t, k represents a given capacity level at t, and $\vec{e}$ represents a set of given exchange rates at t. $EV(\theta_t, j, \vec{K}, \vec{e}, t)$ is the expected future profit when a switch to the candidate capacity level in $\vec{K}$ takes place. Since the form of EV differs across the different regimes, EV equations are constructed for all three regimes as follows.

4.6.1 The Growth Regime

The expected discounted after tax profit in the growth regime at time t is equal to the expected discounted after tax profit when staying in the growth regime at time $t+1$ plus the expected discounted after tax profit when switching to the maturity regime at time $t+1$ plus the expected discounted after tax profit when switching directly to the decay regime at time $t+1$.

$$EV(\theta_t, g, \vec{K}, \vec{e}, t)$$

$$= e^{-rt}\{[1-p(t)-q(t)][\pi_{g,u}\sum_{i=1}^{5} p_i NPV(e^{3\phi}\theta_t, g, \vec{K}, \vec{e}_i, t+1) + \pi_{g,m}\sum_{i=1}^{5} p_i NPV(\theta_t, g, \vec{K}, \vec{e}_i, t+1)$$

$$+ \pi_{g,d}\sum_{i=1}^{5} p_i NPV(e^{-3\phi}\theta_t, g, \vec{K}, \vec{e}_i, t+1)] + p(t)[\pi_{m,u}\sum_{i=1}^{5} p_i NPV(e^{2\phi}\theta_t, m, \vec{K}, \vec{e}_i, t+1) +$$

$$\pi_{m,m}\sum_{i=1}^{5} p_i NPV(\theta_t, m, \vec{K}, \vec{e}_i, t+1) + \pi_{m,d}\sum_{i=1}^{5} p_i NPV(e^{-2\phi}\theta_t, m, \vec{K}, \vec{e}_i, t+1)]$$

$$+ q(t)[\pi_{d,u}\sum_{i=1}^{5} p_i NPV(e^{\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1) + \pi_{d,m}\sum_{i=1}^{5} p_i NPV(\theta_t, d, \vec{K}, \vec{e}_i, t+1)$$

$$+ \pi_{d,d}\sum_{i=1}^{5} p_i NPV(e^{-\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1)]\} \qquad (4.44)$$

where

$p(t)$ = Probability of switching to maturity

$q(t)$ = Probability of switching to decay

$1 - p(t) - q(t)$ = Probability of staying in growth

4.6.2 The Maturity Regime

The expected discounted after tax profit in the maturity regime is at time t is equal to the expected discounted after tax profit when staying in the maturity regime at time t+1 plus the expected discounted after tax profit when switching to the decay regime at time t+1.

$$EV(\theta_t, m, \vec{K}, \vec{e}, t)$$
$$= e^{-rt}\{[1-r(t)][\pi_{m,u}\sum_{i=1}^{5} p_i NPV(e^{2\phi}\theta_t, m, \vec{K}, \vec{e}_i, t+1) + \pi_{m,m}\sum_{i=1}^{5} p_i NPV(\theta_t, m, \vec{K}, \vec{e}_i, t+1)$$
$$+ \pi_{m,d}\sum_{i=1}^{5} p_i NPV(e^{-2\phi}\theta_t, m, \vec{K}, \vec{e}_i, t+1)] + r(t)[\pi_{d,u}\sum_{i=1}^{5} p_i NPV(e^{\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1)$$
$$+ \pi_{d,m}\sum_{i=1}^{5} p_i NPV(\theta_t, d, \vec{K}, \vec{e}_i, t+1) + \pi_{d,d}\sum_{i=1}^{5} p_i NPV(e^{-\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1)]\} \quad (4.55)$$

where

$r(t)$=Probability of switching to decay

4.6.3 The Decay Regime

When demand switches to the decay regime by time t, the expected discounted after tax profit in the decay regime is

$$EV(\theta_t, d, \vec{K}, \vec{e}, t)$$
$$= e^{-rt}\{[\pi_{d,u}\sum_{i=1}^{5} p_i NPV(e^{\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1) + \pi_{d,m}\sum_{i=1}^{5} p_i NPV(\theta_t, d, \vec{K}, \vec{e}_i, t+1)$$
$$+ \pi_{d,d}\sum_{i=1}^{5} p_i NPV(e^{-\phi}\theta_t, d, \vec{K}, \vec{e}_i, t+1)]\} \quad (4.56)$$

The expected after tax profit is calculated working backward to present. The after tax profit will be given in the initial node of the lattice for each one of the regimes.

CHAPTER 5

NUMERICAL EXAMPLE AND RESULTS

5.1 Numerical Example

This chapter presents a numerical example to illustrate the solution procedure of the mathematical models presented in Chapter 4. Demand is governed by the stochastic product life cycle lattice developed in Chapter 4. Exchange rate fluctuations are modeled by the exchange rate lattice which is also presented in Chapter 4. The supply chain optimization model is used to determine the optimal scenarios that must be considered to maximize the firm's after tax profit. The expected discounted after tax profit will be calculated using recursive dynamic programming.

A globally operated firm wants to maximize the discounted after tax profit from its operations in regions 1, 2, and 3. Regions 1, 2, and 3 correspond to Mexico, US and Canada, respectively. The firm is only concerned with the production and the distribution of a single product among the three countries. The total time horizon for the problem is 3 years. Each time interval is one month, which implies T= 36 months. In the product life cycle, the switch from the growth regime to the maturity regime takes place with probability, $p(t)$, equal to the cumulative normal distribution function, with a mean of 9 months and a standard deviation of 1 month. The switch from the growth regime to the decay regime occurs with probability, $q(t)$, equal to the cumulative normal distribution function, with a mean of 18 months and a standard deviation of 1 month. The switch from the maturity regime to the decay regime happens with probability, $r(t)$, equal to the cumulative normal distribution function, with a mean of 27 months and a standard deviation of 1 month. The growth phase of the product life cycle has a mean of 10% and a volatility of 12 %. The maturity phase has a mean of 0 and a volatility of 10%; and a mean of -20% and a volatility of 8% for the decay phase. The total initial demand is 250 units, and the fractions of the total demand representing demands in markets 1, 2, and 3 are $\gamma_1 = 0.25$, $\gamma_2 = 0.40$ and $\gamma_3 = 0.35$. The price of the firm's output in Mexico, US and Canada is $r_1 = 2700\,peso$, $r_2 = \$400$ and $r_3 = C\$385$. Corporate tax rates in Mexico, US and Canada are equal to 5%, 8% and 10%, respectively.

The project value is maximized by evaluating two levels of capacities at the production plants, the minimum and maximum capacities. Minimum capacity levels at the plants are $K_1 = 60$, $K_2 = 90$ and, $K_3 = 90$. Maximum capacity levels at the plants are $K_1 = 110$, $K_2 = 140$ and, $K_3 = 150$ and the fixed operating costs are $F_1 = 143{,}535\,peso$, $F_2 = \$23{,}475$ and, $F_3 = C\$30{,}000$. Variable production costs at the plants are $P_1 = 1{,}722\,peso$, $P_2 = \$192$ and, $P_3 = C\$200$. The cost of installing one unit of capacity for the three countries is as follows: $c_{41} = 287{,}070\,peso$, $c_{42} = \$37{,}560$, $c_{43} = C\$50{,}000$. The switching cost parameters are presented in Table 5.1. Logistic costs per unit are presented in Table 5.2.

In regards to exchange rates data, the initial set of exchange rates is (0.939, 9.569), i.e., 1 Canadian dollar = 0.939 US dollars and 9.569 Mexican pesos. The American exchange rate has a mean of -0.98% and a volatility of 3.46%, whereas, the mean of the Mexican exchange rate is equal to -0.57% and its volatility is equal to 3%. The Canadian dollar is the numeraire currency meaning all values are indicated in Canadian dollars. The correlation between the Mexican peso and the US dollar is 0.7. The stretch parameter $\omega = 1.1$ is used to ensure non-negative probabilities for the exchange rate lattice. The riskless rate of interest is 10%. Tables 5.3-5.7 summarize the input data explained above.

Table 5.1: Switching costs.

	s_{1p}	s_{2p}	s_{3p}	s_{4p}
Mexico (Peso)	-1.0	0.8	-1,914	-1,435
USA ($)	-1.0	0.85	-272	-183
Canada (C$)	-1.0	0.9	-300	-200

Table 5.2: Logistic costs per unit.

Country	Canada	USA	Mexico
Canada (C$)	-	20	40
USA ($)	17	-	26
Mexico (C$)	287	191	-

Table 5.3: Product life cycle parameters.

Demand parameters	Growth	Maturity	Decay
Mean	0.1	0	-0.2
Standard deviation	0.12	0.1	0.08

Table 5.4: Product demand information.

Country	Fraction of the demand (γ_{mt})
Canada	0.35
USA	0.40
Mexico	0.25

Table 5.5: Monthly capacity levels and fixed costs.

Country	Min and Max Capacity Levels (K_p)	Fixed cost	Variable production cost
USA	90, 140	$23,475	$192
Canada	90, 150	C$30,000	C$200
Mexico	60, 110	143,535peso	1,722peso

Table 5.6: Product price and corporate tax.

Country	Product Price	Corporate tax (%)
USA ($)	400	8%
Canada (C $)	385	10%
Mexico (Peso)	2700	5%

Table 5.7: Exchange rates data.

Country	Mean	Standard Deviation
USA	-0.98%	3.46%
Mexico	-0.57%	3%

5.2 Results and Discussion

In this section, varying sets of input parameters are tested to better understand their effect on the profit. The optimal network obtained in the seed node of the lattice for all the regimes is presented in Figure 5.1. The expected after tax profit for the growth, maturity, and decay regime is C$ 28, 3856, C$ 27, 536, and C$ 23, 1937 respectively. These results are based on the default parameters presented in the previous section.

As demonstrated in Figures 5.2 and 5.3, profits increase with higher product price values. Also, higher profit values are achieved throughout the product's entire life cycle regardless of the regime. However, it is apparent that higher product price values in the American market have a greater impact on profits when compared to the Canadian market. This may be due to the fact that the American market constitutes a bigger fraction of the overall demand than the Canadian market. Moreover, American tax rates are lower than Canadian tax rates which may cause production to be more profitable in the American market.

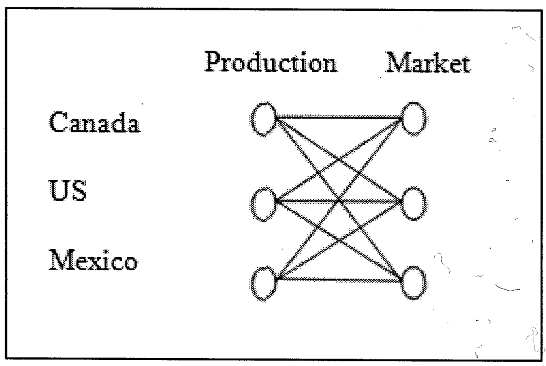


Figure 5.1: Optimal network configuration

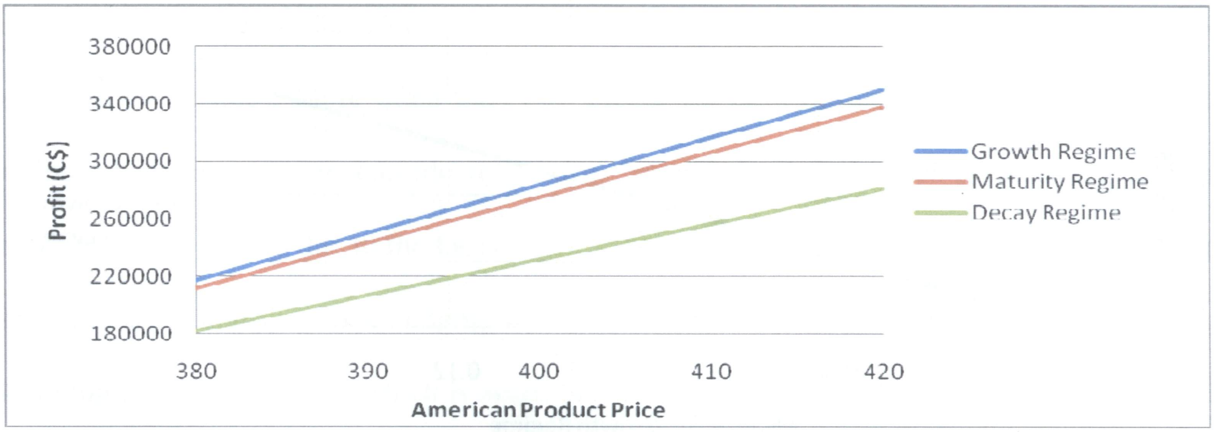


Figure 5.2: Profit values for different American product prices.

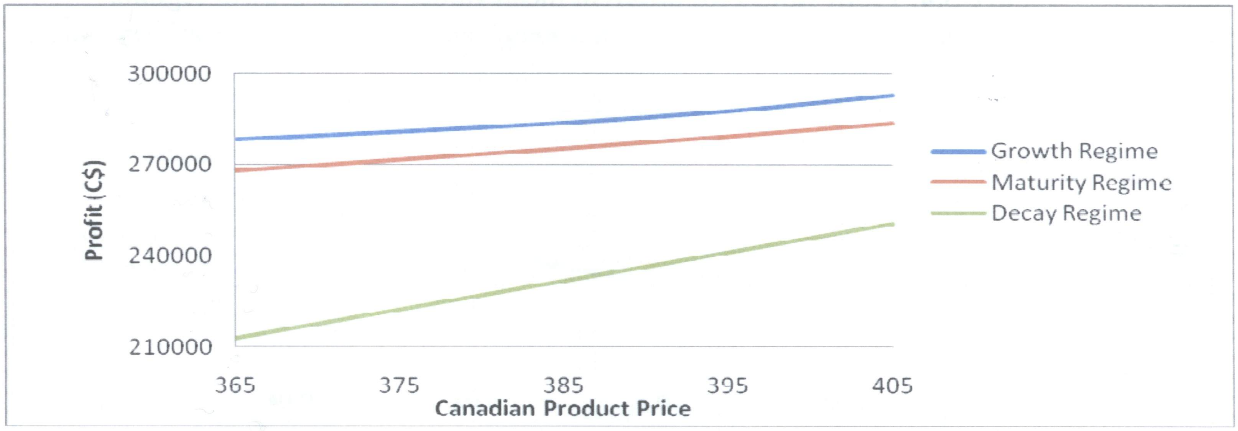


Figure 5.3: Profit values for different Canadian product prices.

The mean values of the demand have proven to have an effect on profits. Figure 5.4 illustrates those greater mean values of the demand in the growth regime result in higher profits. Figure 5.5 also reveals that greater mean values of the demand in the maturity regime also result in greater profits. However, the trend of increasing profits in figure 5.5 is not as dramatic as the increasing trend in figure 5.4 due to the nature of plateau demands in the maturity regime. Figure 5.6 depicts the higher the mean value of demand in the decay regime, the higher the profits.

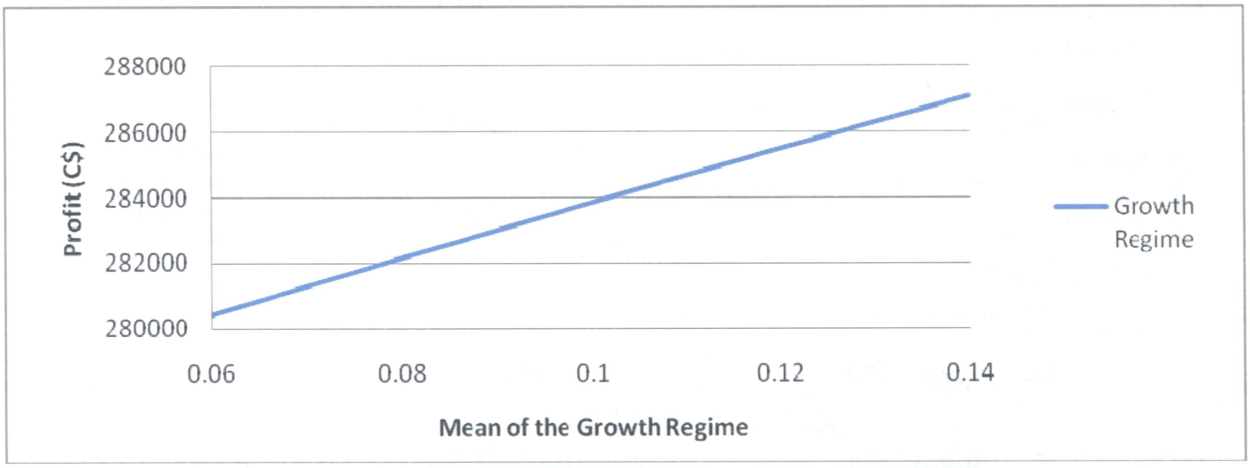


Figure 5.4: Profit values for different mean values for the growth regime.

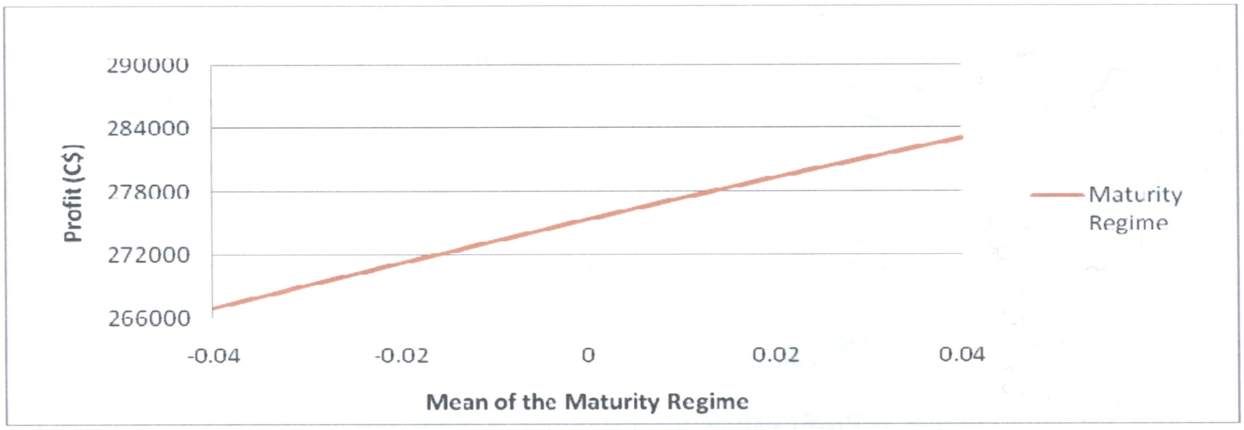


Figure 5.5: Profit values for different mean values for the Maturity regime.

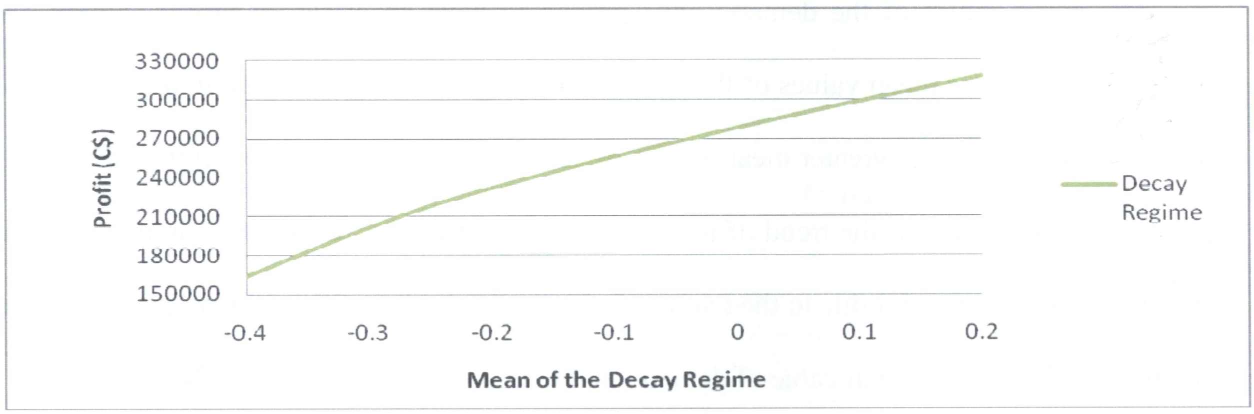


Figure 5.6: Profit values for different mean values for the decay regime.

Unlike mean values, higher standard deviation values of the demand result in lower profits in all regimes. More often than not, higher standard deviation values result in greater profits when demands are considerably large. Nevertheless, figure 5.7 illustrates a declining trend in profits. This is due to the fact that the capacity levels chosen for this numerical example limit the user's ability of risk hedging in this particular case. As for figure 5.8, a less dramatic declining trend is observed, which is again due to the nature of plateau demands in the maturity regime. Figure 5.9 reveals that, when standard deviation values are increased in the decay regime, profits are decreased due to higher uncertainty in an environment of declining demands.

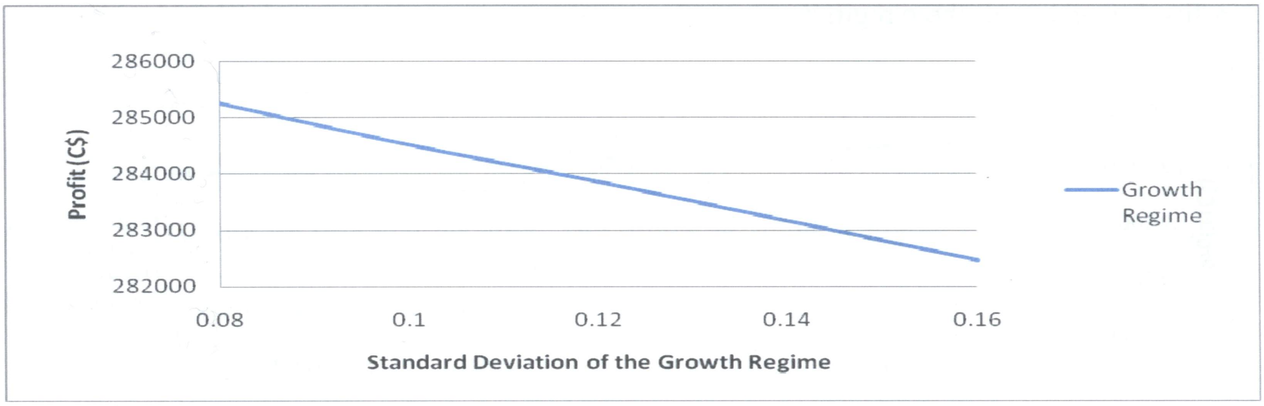


Figure 5.7: Profit values for different standard deviation values for the growth regime.

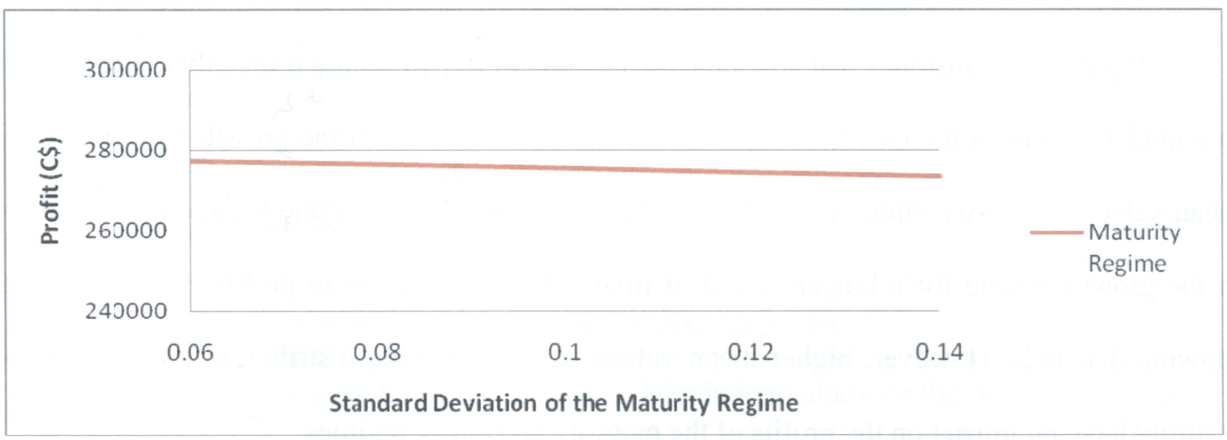


Figure 5.8: Profit values for different standard deviation values for the Maturity regime.

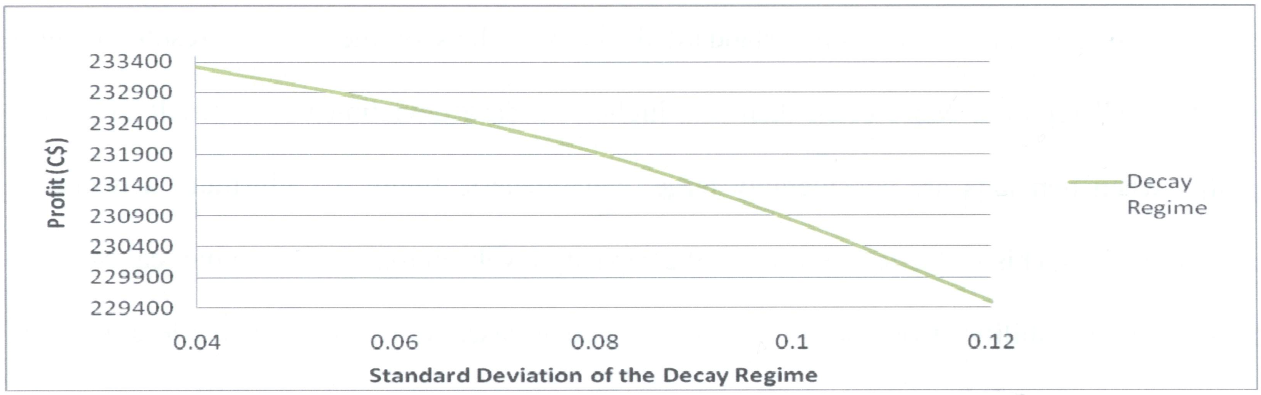


Figure 5.9: Profit values for different standard deviation values for the decay regime.

As shown in figure 5.10, it is apparent that higher tax rates in Mexico lead to a drop in profits throughout all three regimes.

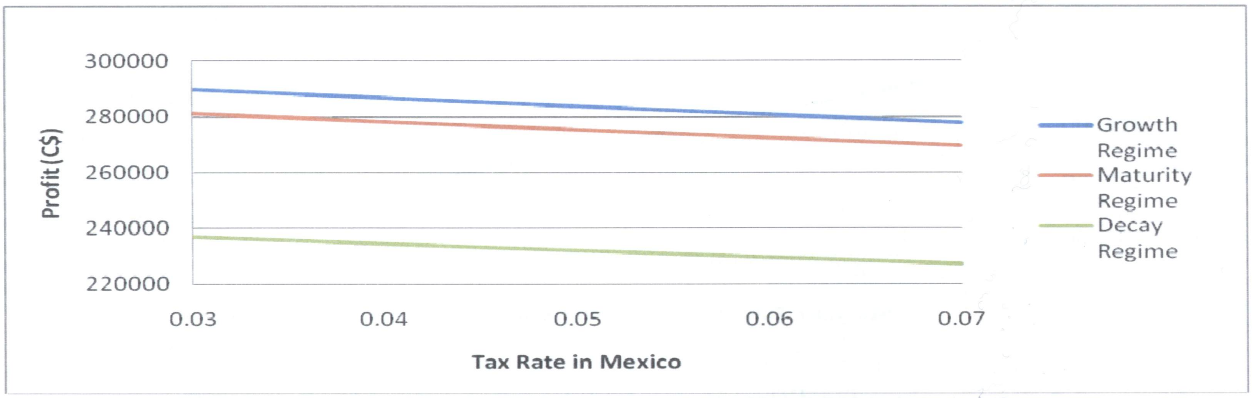


Figure 5.10: Profit values for different tax rates in Mexico.

Figure 5.11 illustrates that when the mean value of the switching probability from growth to maturity regime is increased, a slight raise of profits is noticed in the growth regime. Higher mean values of the switching distribution imply that the product life cycle is expected to remain in the growth regime for a longer period of time. Thus, an increase in profits is resulted from growing demands. However, higher mean values of the switching distribution from growth to maturity have no impact on the profits of the maturity and decay regimes

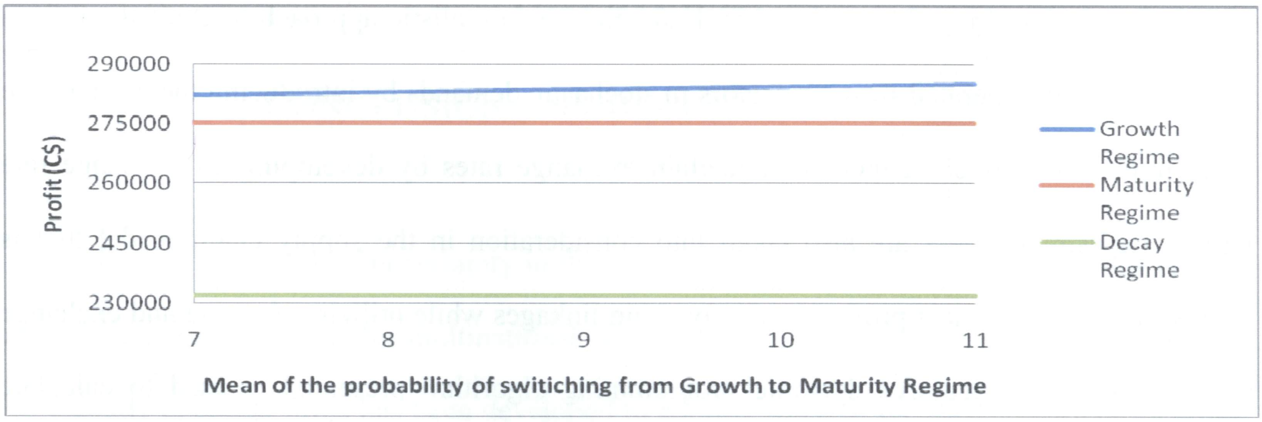


Figure 5.11: Profit values for different mean values of the switching probabilities from growth to maturity regime.

Figure 5.12 depicts that greater profits are achieved with higher standard deviation values for the American exchange rate with respect to the Canadian dollar. The exchange rate follows Brownian motion and, with more uncertainty, more profit can be achieved with the proposed solution framework by utilizing hedging. The proposed solution framework allows the user to hedge risks by having the ability to switch between options and or capacity levels.

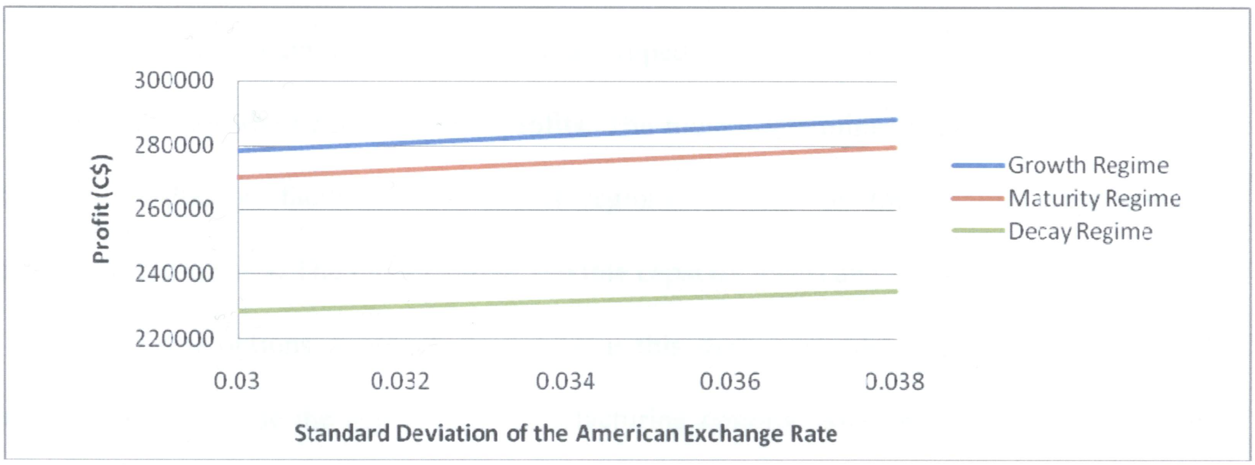


Figure 5.12: Profit values for different standard deviation values for the American exchange rate.

Concluding from the results, this thesis presents a realistic approach to evaluate options faced by globally operated firms. It factors in stochastic demands by introducing the product life cycle model. Moreover, it includes uncertain exchange rates by developing an exchange rate lattice. Adjustment costs are also taken into consideration in the supply chain model that is created to obtain the most profitable supply chain linkages while utilizing demand and exchange rates. Finally, the recursive dynamic programming algorithm presented is used to calculate expected profit values.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Due to the reality of uncertainty in the competitive global market, flexibility has become one of the most vital tools for multinational corporations. In this thesis, a modeling framework for globally operated firms has been developed to address some of the gaps in current literature. The solution framework presented extends previous research on global supply chain by factoring in a number of uncertainties. The solution framework is comprised of several models. The product life cycle lattice portrays stochastic demands in the global market. It characterizes demand into three regimes: growth, maturity, and decay. Because in real life demands are never constant, it is essential to formulate a lattice representing the true realistic nature of demands. The proposed exchange rate lattice is a key component of the overall solution framework. Exchange rates have always and will continue to fluctuate over time and since that is inevitable, factoring in an exchange rate lattice is vital for a realistic evaluation of options.

The supply chain network model is developed to utilize uncertain demands and exchange rates to maximize the firm's after tax profits. The model determines the most optimal linkages between production facilities and market regions, as well as the optimal production and distribution quantities. The model allows flexible capacity levels and factors in adjustment costs.

The real options approach discussed in this thesis provides the user with the needed information to choose the appropriate manufacturing options based on an incorporated view of the actual market. A recursive dynamic programming algorithm is used to calculate expected after tax profit.

This thesis addresses many of the limitations that have been observed in current literature. Major contributions of this research include providing the decision maker with a valuation procedure for globally operated firms under demand and exchange rate uncertainty. Also, the proposed solution framework enables users to hedge against risk by utilizing two types of flexibility: switching capacity levels and changing the supply chain network.

Future research can be done by extending the proposed model to a three echelon supply chain. Future research can also factor in financial contract options as part of the solution framework. The proposed solution framework can also be improved by considering multiple products. However, factoring in multiple products can be computation demanding and time consuming. It is also suggested that future research should factor in gas price uncertainty rather than adopting the assumption of constant transportation costs.

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