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Real Options Analysis in Global Value Chains

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Abstract

Global value chains have become an imperative for modern firms. Fragmenting the value chain across national boundaries based on economic benefits provides firms with key advantages that are necessary to maintain competitiveness. At the same time, extended supply chains expose firms to new sources of risks and increased uncertainty. It is important for firms to include in their investment decisions the inherent benefits provided to them through the operational flexibility of global value chains in order to avoid undervaluing risky projects.

In this thesis we present the argument that in comparison to standard project valuation methods such as NPV, Real Options analysis provides a better means to value projects in global value chains under increased uncertainty. We analyze the available literature to determine the causes for under-utilization of real options analysis in corporate decision making and conclude that the mathematical complexity of standard option valuation methodology as well as its dissimilarity with current valuation methods is a significant impediment towards wider adoption. It is argued that a streamlined adoption of the underlying decision framework of real options can help firms in quantifying the operational flexibility of global value chains as a real option.

This is demonstrated using a Monte Carlo simulation based spreadsheet model that simulates the decision process for a firm operating a global value chain across different regions. The model calculates the value of different capacity expansion projects in the global value chain, including the real option value of operational flexibility in the presence of uncertainty. An extension to the model simulates the effect of positive and negative changes in duty rates on the firm's overall profits. The results of the model are compared to valuations using standard NPV with stochastic parameters and a linear programming model using deterministic parameters. It is shown that passive NPV valuations with fixed strategies unduly penalize projects in the face of uncertainty while explicitly considering operational flexibility as a real option in global value chains provides a more accurate valuation for such projects.

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1. Introduction

The current reality of global trade is one centered on global value chains. Production of goods is now a fragmented process taking place over many different locations around the globe. Global operations provide key benefits to firms in terms of larger markets, greater economies and increased innovation. More importantly, the flexibility afforded by the global nature of supply chains provide firms with a competitive advantage that is otherwise not achievable. Consequently supply chains face an imperative to extend themselves beyond previous boundaries.

This globalization of the value chain has two counteracting impacts. While it increases the potential for a risk event in a single part of the chain to propagate, it also allows a greater ability to diversify risk across regions and markets (Lessard, 2013). It is important for firms to capitalize on the benefits of their global flexibility if they want to avoid being paralyzed by the increased risks facing their extended value chains. Investments in global value chains require an expanded view that incorporates the increased benefits of flexibility in order to offset the deleterious effects of the increased risk.

Despite this reality, firms still rely on traditional methods, such as Net Present Value, to evaluate investment decisions related to their global operations. These methods are inherently biased against uncertainty, hence inadequate for evaluating investments in global value chains. They use higher discount rates to model uncertainty which unduly penalizes such projects while being unable to account for the additional decision making flexibility. This results in an overvaluation of the risk while undervaluing the benefits of flexibility (Miller and Park, 2002). There is a need for better decision support tools to aid investment decisions related to global value chains.

Modeling investment decisions as real options has been forwarded as a potential panacea to decision making in increased uncertainty (Dixit and Pindyck, 1994; Luehrman, 1998a; Millar and Park, 2002). This relies on imagining investment decisions as being similar to buying an option on the uncertain future value of the project thus providing a means to quantify the decision making flexibility and the uncertainty in value that characterizes investments in global value chains. Conceptually real options have the potential to replace existing investment valuation methods, especially for situations with high uncertainty such as in global value chains. However despite an ever increasing range of academic research, the corporate adoption of real options remains slow while the literature remains disjointed and hopelessly complex for most practitioners (Copeland and Antikarov, 2005). Common methodologies are based on financial option valuation which is vastly different from the Discounted Cash Flow methods typically used. A better understanding of real options, the benefits of its application towards global value chains and easier implementation can vastly improve the ability to exploit the operational flexibility inherent in global value chains.

The objective of this thesis is to argue that real options analysis presents a better means to value projects in global value chains than standard project valuation methods. We achieve this in three parts. Firstly we use existing literature to argue that operational flexibility is a key component of the value of global value chains and real options analysis provides a means to explicitly value it. Secondly we review the literature on real options to present a streamlined framework for solving a capacity expansion problem for a firm operating in multiple regions. Thirdly we formulate a spreadsheet based Monte Carlo simulation based on his framework to provide a real options valuation for a capacity expansion project for a firm operating across different market regions in the presence of uncertainty in demand, cost, price and macroeconomic factors. The model's results are compared to deterministic valuations and passive valuations that do not model flexibility as a real options or do not consider flexibility as part of the valuation process respectively. This comparison is used to demonstrate the comparative benefits of real options to traditional valuation methods, for modeling operational flexibility in global value chains.

2. Literature Review

In order to demonstrate why operational flexibility is important to the value of projects in global value chains and how operational flexibility can be added to the valuation process, we need to begin by understanding the concept of global value chains and what makes them different from older models of global firms. This question is answered through the first section of literature review. In section 2.1 we begin by explaining the basic concept of global value chains and how they create value. Subsection 2.1.1 uses the early literature on the subject to define the factors that are important for successful management of global value chains. Subsections 2.1.2 and 2.1.3 discuss the meaning of risk and the centrality of risk management to global value chains. Subsection 2.1.4 demonstrates how operational flexibility is the factor that allows global value chains to effectively manage the increased risk and create greater value through their global operations. Subsection 2.1.5 provides the conclusion to this discussion and introduces real options as a possible method to integrate operational flexibility into project valuation.

The next question that needs to be answered is whether real options analysis can actually fulfill this task. This question is tackled in section 2.2. We start by introducing the theory behind real options. Subsection 2.2.1 discusses the deficiencies of current valuation methods and their inability to consider flexibility. Subsection 2.2.2 introduces the different types of real options in literature. Subsection 2.2.3 provides an overview of the different applications for which real options have been applied in academic literature in global supply chain contexts. Subsection 2.2.4 uses empirical studies to show the importance of real options thinking in incorporating operational flexibility in global value chains and the positive effect it has on firm behavior and outcomes.

Through the literature review we demonstrate that without properly adjusting for operational flexibility, firms cannot deliver on the true potential of their global value chains. Investments in global value chains should thus be assessed on an appropriate measure that actively takes operational flexibility into consideration. Real options analysis potentially provides the solution to this. Real options encapsulates a framework that can include the value of flexibility in decision making and has proven to help managers in exploiting the benefits of operational flexibility in global value chains. Chapter 3 will then discuss the difficulties in applying real options analysis and guidelines to formulate a model for a capacity expansion problem in global value chains.

2.1. Global Value Chains

The old paradigm of international trade was centered on the trade of finished goods between different nations across the globe. This relatively simpler model of trade has been gradually replaced by a more complex web of trade in intermediate inputs and activities (Sydor, 2011). Alternatively this changed reality has been explained as a shift from a trade in goods towards a trade in “tasks” that add value to the final products (Grossman and Rossi-Hansberg, 2008). These interactions, together, are referred to as Global Value Chains. According to the GVC Initiative at Duke University (Frederick, 2016),:

> “A global value chain describes the full range of activities undertaken to bring a product or service from its conception to its end use and how these activities are distributed over geographic space and across international borders.”

The task approach to trade reimagines the production process as a sequence of stages that together make a final good. This different conception of international trade has led to major changes in the understanding of how global trade operates by academics and policymakers as well as leading to the development of new value-added measures of trade such as the OECD-WTO’s Trade in Value Added (TiVA) database and the World Input-Output Database (WIOD) among others. This shift is also supported by statistics as sales by Multinational enterprises (MNEs) increased from US$6 trillion to US$31 trillion between 1990 and 2008 while employing 79 million people (UNCTAD, 2010).

However the concept of production as a fragmented process is not entirely new and has been present in both the literature on organizational strategy for quite some time (Kogut, 1984; Porter, 1986). Porter’s value chain model (1986) played a major role in helping explain the separation of the different activities undertaken by a firm. He defined a number of primary (Inbound Logistics, Operations, Outbound Logistics, Marketing and Sales and Service) and support activities (Organization, Human Resources, Technology and Purchasing) that either add value to the product or support this value creation. The heterogeneity in these tasks provided the conceptual basis for their spatial separation leading to the global separation of tasks across countries. The reduction in the costs of transportation along with faster and more efficient modes of communication has made it increasingly convenient for firms to not only spatially separate the different tasks in their value chain but also to outsource them entirely. This has led to the increased prevalence of the value chain as a cross-disciplinary idea.

The Global Value Chain concept has gained importance firstly due its centrality in explaining the nature of modern trade as a trade in intermediate goods but also due to its effectiveness in understanding the incentives and methods through which value chains are sliced up and distributed around the world. In this regard the Global Value Chain is not only a means to increase sales and global reach for a firm’s products but can also be the source of creating a competitive advantage (Kogut, 1984). Global value chains thus present both new challenges and opportunities to firms. In order to fully understand how global value chains are different from older models of global firms and the key factors in their successful management, we will begin by discussing the different rationales for global operations in subsection 2.1.1.

2.1.1. Nature of global value chains

Understanding the nature of global value chains can help us determine the parameters on which their competitive success depends. The development of the literature on global value chains and global strategies provides important insight into these parameters. As mentioned earlier, the development of Porter’s value chain model (1986) provided the conceptual basis for the geographic separation of different tasks along the value chain. The uniqueness of each task made it obvious that the different tasks in the value chain were differently suited towards either international integration or national differentiation

(Porter, 1984). Hence there was an imperative for firms to create a global value chain that optimized the flow and placement of these tasks in order to gain the greatest overall advantages.

Kogut (1985a) used the value chain framework to propose that the global strategy of firms should have two principal tasks: deciding where to break the value chain across borders and deciding which activities of the value chain to focus on. According to Kogut (1985a) the answers to these questions are based on the comparative advantage of countries in certain tasks and the competitive advantage of firms across their value chains. He further suggested that while these two concepts can offer different policy guidelines in certain cases, effective global strategy should be based on their interaction with each other in order to create a benefit above the market norm. The impetus for a globally integrated value chain is thus based on the cost as well as the market value of each link in the value chain and how they could be exploited to create a competitive advantage. Thus the global value chain represents not only a means to improve sales and revenue, instead its existence and proper management could be a source for creating competitive advantage for firms.

Ghoshal (1987) improved on this framework by adding another layer of complexity. He observed that managing global value chains can be difficult for firms since corporate objectives can be multidimensional and contradictory. Thus there is a need for a framework that weighs the different costs and advantages of different alternatives. He asserted that any multinational organization has 3 broad goals and 3 different tools to achieve each one of them. The goals include achieving efficiency in current operations, managing the risks that come with those operations and developing capabilities and knowledge that can allow it to innovate and adapt with changes in the future. The tools available to global value chains for these goals include exploiting the market differences in the countries that are part the value chain, profiting from the larger economies of scale that result from global operations and making use of synergies that accrue from operating in diverse locations and environment. The effective use of these tools in service of the goals creates competitive advantage for a global firm. Table 1 illustrates these goals and tools.

Strategic Objectives	**Sources of Competitive Advantage**		
	National Differences	**Scale Economies**	**Scope Economies**
Achieving efficiency in current operations	Benefiting from differences in factor costs – wages and cost of capital	Expanding and exploring potential scale economies in each activity	Sharing of investments and costs across products, markets and businesses
Managing risk	Managing different kinds of risks arising from market or policy-induced changes in comparative advantages of different countries	Balancing scale with strategic and operational flexibility	Portfolio diversification of risks and creation of options and side-bets
Innovation learning and adaptation	Learning from societal differences in organizational and managerial processes and systems	Benefitting from experience – cost reduction and innovation	Shared learning across organizational components in different products, markets or businesses

Table 1: Global strategy: an organizing framework (from Ghoshal, 1987)

It is clear from this framework that proper assessment of decisions in global value chains must be based on evaluating the efficiencies gained, the learning potential unlocked as well as the effective management of risks. Thus any new investments should be judged on all three of these criteria. Simply judging a project in the global value chain on the basis of its own short term profitability without consideration of its effect on the larger chain can lead to suboptimal investment decisions.

This framework is important in explicitly identifying the centrality of risk management to the management of global value chains. While earlier researchers had focused on the potential for efficiencies and learning that arise from global value chains, the framework of Ghoshal (1987) indicated that these benefits must be balanced with the costs of the new risks being undertaken. While all operations face certain risks, the implication is that global value chains face increased risks compared to local operations.

Subsection 2.1.1 discusses this assertion in greater detail explaining the different risks and risk factors facing global value chains. Subsection 2.1.2 presents an overview of how these risks are commonly managed and the importance of operational flexibility in counteracting these risks. Subsection 2.1.3 discusses how operational flexibility can be modeled as a real option providing a means to include risk management into the evaluation of investment decisions.

2.1.2. Risk and Uncertainty

The concept of risk and uncertainty have seen considerable research in the domain of supply chain management (Park et al., 2013). However, the meaning of the terms themselves can be confusing. The terms risk and uncertainty have been used in different contexts in distinct academic fields. In a general sense both risk and uncertainty are used to refer to variations in performance or variables such as revenues, profits, market share etc. Additionally the sources of this variance have also been referred to as risks as in the cases of political or competitive risk (Miller, 1992).

In the field of Economics, where the terms are used extensively, they have very standardized definitions. Uncertainty is used to refer to situations where a number of different resulting scenarios are possible, but where no definite probability can be used to define these outcomes. On the other hand if specific probabilities can be attached to the different possible resulting scenarios then these situations are referred to as risk

(Lessard, 2013). Uncertainty has also been used to refer to an unpredictability in variables related to organizational performance or the incompleteness of information in regards to these variables (Duncan, 1972). If risk is defined in terms of the unpredictability of variance in performance, then Miller (1992) defines the relationship between risk and uncertainty such that uncertainty with regards to the corporate environment and organizational variables increases risk.

In a supply chain context, Juttner and Peck (2003) summarize that risk refers to a potential mismatch between supply and demand. The sources of risk can be considered as uncertainties, or any variables that affect supply chain outcomes and cannot be predicted with certainty. Hence one of the aims of a global strategy is to reduce the sensitivity of firm performance to the uncertainty in its environment. It is important to mention that while the variance in performance can theoretically be in either direction, in the strategic management literature and among managers the term risk is generally associated with negative outcomes (March and Shapira, 1987).

When identifying different kinds of risks, researchers generally create a certain typology. Park et al. (2013) suggest that the spatial source of risks with respect to the central firm provides the most widely used categorization. Thus risks are defined as either operational or internal to the firm, supply risks from upstream components of the value chain, demand risks that arise from a failure to adequately fulfill the current demand and environmental risks that do not fall into any of the first three categories. Environmental risks can often morph into other kinds of risks. In a similar vein, Sodhi and Tang (2012) provide a typology that considers both the cause and effect of a risk source, categorizing them as either global or local. Miller (1992) divided all possible uncertainties in international business into 3 broad categories based on the spatial characteristics of the variables that are affected: general environment, industry related and firm specific. The impacts of these different sources of uncertainties are not consistent across firms or even projects within firms. Table 2 lists these different types of uncertainties.

General Environmental Uncertainties	Industry Uncertainties	Firm Uncertainties
<u>Political uncertainties:</u> • War • Revolution, • Coup d'état, • Democratic changes in government • Other political turmoil	<u>Input market uncertainties:</u> • Quality uncertainty • Shifts in market supply • Changes in the quantity used by other buyers	<u>Operating uncertainties:</u> • Labor uncertainties • Input supply uncertainties – raw materials shortages, quality changes, spare parts restrictions • Production uncertainties – machine failures, other random production factors
<u>Government policy uncertainties:</u> • Fiscal and Monetary reforms • Price controls • Trade restrictions • Nationalization • Government regulation • Barriers to earnings repatriation • Inadequate provision of public services	<u>Product market uncertainties:</u> • Changes in consumer tastes • Availability of substitute goods • Scarcity of complementary goods	<u>Liability uncertainties:</u> • Product liability • Emission of pollutants
<u>Macroeconomic uncertainties</u> • Inflation • Changes in relative prices • Foreign exchange rates • Interest rates • Terms of trade	<u>Competitive uncertainties:</u> • Rivalry among existing competitors • New entrants • Technological uncertainty – Product or Process Innovations	<u>R&D uncertainty:</u> • Uncertain results from research and development activities
<u>Social uncertainties</u> • Changing social norms • Social unrest • Riots • Demonstrations • Small-scale terrorist movements		<u>Credit uncertainty:</u> • Problems with collectibles
<u>Natural uncertainties:</u> • Variations in rainfall • Hurricanes • Earthquakes • Other natural disasters		<u>Behavioral uncertainty:</u> • Managerial or employee self-interested behavior

Table 2: Risks in international business (Miller, 1992)

At the same time, uncertainties and risk in global value chains have also been categorized based on other typologies that are more focused towards possible countermeasures. Sodhi and Tang (2012) provided a typology based on the severity of impact, with risks being categorized as either “delays” or “disruptions”. Kleindorfer and Van Wassenhove (2004) proposed that there are two broad categories of risks in the global supply chain: disruption risk in supply channels and supply-demand coordination risk. In the most generalized scenario for manufacturers, Billington et al. (2002) also identify the same two sources suggesting that the greatest risk is from uncertainty in the demand for outputs and the supply of inputs.

Lessard (2013) provides a framework to categorize risks in the global supply chain that considers both the spatial characteristics of uncertainty as well as providing insights into possible countermeasures. He categorizes six sources of risk in the global supply chains of today: national factors, consumer dynamics, natural disruptions, man-made disruptions, innovation and macroeconomic dynamics. All these sources are nested within each other making a complex system where the location of the risk source determines what action is best to mitigate its effect. National systems, supply chains and consumer dynamics are the inner parts of the system where managerial interventions can control the risk while global regimes and the global macro-economy represent the outer nests where financial hedging might be required to mitigate risk factors. However, a certain part of the supply chain can be vulnerable to different sources of risk at the same time. A case in point is sourcing where all layers of the nest can have an impact.

The different categorizations of risks all lead to the common conclusion that extending value chains over greater distances increases their exposure to risks. The spatial breadth of global value chains makes them vulnerable to environmental and national risks from a number of different regions while the functional diversity of the firms in the value chain makes them more vulnerable to market based risks of different industries. The lengthening of supply chains directly increases disruption risks by increasing possible points of impact. Sodhi and Tang (2012) conclude that the overextension of global value chains increase their risk exposure in three ways: a higher number of firms in the supply chain means a higher number of possible points of disruption, the longer length of supply chains decreases visibility along the chain making it harder to detect individual risks and lastly the network nature of a supply chain means that locally optimal decisions can lead to globally suboptimal results. In order to manage these risks firms formulate risk management frameworks that help identify risk sources, assess their possible impacts and suggest countermeasures. The next subsection will discuss this in more detail.

2.1.3. Risk Management in Global Value Chains

In the supply chain management literature, the term supply chain risk management (SCRM) is used widely to designate a process of identifying the different sources of risks, assessing them and selecting an appropriate counter measure. Lessard (2013) characterizes this 3 step SCRM process as *identify, characterize* and *mitigate*. A range of risk assessment tools have been developed to properly gauge the risks facing a value chain. These tools can be categorized as decision analysis, case study or perception based (Manuj and Mentzer, 2008). Decision analysis approaches are the only category that provide some quantitative insight into the risk being faced by firms, however there is no single consensual tool that is applicable to all situations. Furthermore researchers have noted that the results of risk assessment efforts are not always put into practice (Juttner, 2005; Tang, 2006).

Once risks have been identified and characterized, firms can begin the risk mitigation process. Researchers from a number of different fields agree that there are a limited number of options available to firms in terms of their risk management strategies. Park et al. (2013) categorized these responses as risk avoidance, risk acceptance or risk mitigation. These measures can be targeted towards different aspects of the supply chain as shown in Table 3. From these only risk avoidance and risk mitigation can be considered as active risk management responses.

		Risk Response		
		Avoidance	**Mitigation**	**Acceptance**
Risk Management Approach	Supply management	Divestment, auditing, vertical integration	Contract strategy, multiple/local sourcing	No strategy
	Demand management	Divestment, vertical integration	Stockpiling, pricing, marketing	No strategy
	Product management	Divestment	Postponement	No strategy
	Information management		Joint business planning, vendor managed inventory	No strategy

Table 3: Matrix of risk management strategies categorized by risk response and management approach (Park et al. (2013))

Other categorizations for response types can also be found in the literature. Lessard (2013) also presents three potential response types for firms. Firms can either "shape the risk" which refers to changing the probability distribution of outcomes, they can use real options and real pooling which refers to improving the consequences for the realization of a risk event and they use financial diversification or hedging to redistribute the risk. Mascarenhas (1982) had used the terms prediction, insurance, avoidance, control and flexibility to refer to the same types. Control measures are a form of shaping the risk where the firm tries to control the environmental uncertainty, insurance is a form of hedging while flexibility is a means to improve the consequence of risk realization. Prediction does not constitute a risk response as much as a risk identification and assessment tool. Avoidance measures generally constitute leaving the market altogether.

The two strategies of control and flexibility can be somewhat opposite to each other in function. Control strategies try to limit the uncertainty in the environment of the firm that can have negative effects on the firm while flexibility measures increase a firm's ability to change and adapt to the changes in its environment. In this regard, flexibility can be seen as a more robust counter towards environmental uncertainty than control as well as potentially allowing firms to benefit from volatility.

This conclusion is further backed by looking at the specific actions that constitute control measures. Forward and backward integration, government lobbying, making questionable payments, promotions and advertising to influence customers, longer term contracts, formation of cartels and increasing the barrier to entry for competitors are some of the measures that have been highlighted in literature as examples of control strategies (Mascarehas, 1982; Miller, 1992). These measures require either larger upfront costs, activities that fall outside the core competencies of the firm and even some activities that are ethically questionable.

Another common way to categorize responses towards the uncertainty in global value chains is provided by Miller (1992) who divides all responses into either financial or strategic measures. Financial risk mitigation measures include financial tools such as futures and forward contracts, swaps and options. Firms have particularly used financial derivatives, contracts with fixed commodity prices or interest and exchange rates to transfer risk from the buyer to the seller or vice versa (Boyabatli and Toktay, 2004). Theoretically these measures provide means for firms to hedge their risks from uncertainties by locking in prices and are referred to as financial hedging. However, adequate financial tools are not available in all markets and scenarios hence financial risk management tools are not enough by themselves to create an effective response to uncertainty (Miller, 1992; Guay and Kothari, 2003).

From the discussion regarding operational hedging in the fields of operations management, finance and strategy, it can be seen that such strategies work well both individually and as a complement to financial hedging, require larger upfront costs but provide longer term hedges and can provide unique value creation opportunities that are not possible through financial hedges alone (Boyabtli and Toktay, 2004). Operational hedging is thus required to minimize risks in cases where financial hedging is not possible. Moreover, operational flexibility is a better risk response since it also provides benefits of its own to firms in global value chains. In contrast to financial measures that can only restrict the effects of environmental variability on firm performance, operational flexibility can actually provide a means to generate greater value (Lessard, 1986). It was in this respect that Kogut (1984) recognized operational flexibility as one of the main sources of competitive advantage for global firms. Incorporating operational flexibility into global operations is crucial for firms to properly benefit from their global value chains. The next subsection will discuss how operational flexibility goes beyond a hedging measure to provide global value chains with a competitive advantage. Subsection 2.1.4 will discuss the concept of operational flexibility in more detail.

2.1.4. Operational Flexibility

Since risk mitigation in international business has financial, strategic and operational dimensions, the benefits of operational flexibility for global value chains have been studied by researchers from all three fields.

Huchezermeier and Cohen (1996) define operational flexibility as the ability to switch between different global manufacturing options. In the existing literature on flexibility in global value chains, product and market diversification is the most often cited example of operational hedging (Miller, 1992). Mascarehas (1982) identified the use of general purpose equipment that can handle different inputs and outputs, selling products in multiple markets, the use of more flexible contractual commitments in overseas markets such as through franchising and sub-contracting and decentralization of decision making as actions that provide firms with strategic flexibility. Miller (1992) also identified multiple sourcing, strategic stockpiling of inputs and workforce flexibility in this category. From the perspective of operations management for global firms, flexibility in production options and network structures based on uncertainties in demand or exchange risk is the main source of operational flexibility.

Operational flexibility and operational hedging in global value chains have also been discussed outside the operations management literature. Geographical diversification as a form of operational hedging has been mentioned by researchers from finance. Firms can maintain the ability to use both local and foreign means of production to sell to foreign markets which provides them the ability to hedge against uncertainty in exchange rates, prices and demand (Chowdry and Howe, 1999; Hommel, 2003).

From a corporate strategy point of view, Kogut (1985b) discussed the impact that operational decisions can have on managing the risk profile of firms. Using the sourcing decision as the basis of his analysis, he mentioned that firms can create a speculative, hedged or flexible risk profile. The speculative profile is based on leveraging economies of scale in one location, betting that the favorable costs will outweigh any future macroeconomic changes. The hedged profile consists of sourcing from multiple locations to create a hedge against exchange rate fluctuations. Finally a flexible profile consists of the firm using multiple sourcing locations as well as keeping excess capacity or using flexible technology in order to move production to counter exchange rate movements. In this case operational hedging is differentiated from operational flexibility, however many authors consider the two terms interchangeable. This operational flexibility is also often referred to as providing firms with a real option.

Kogut (1984) had originally cited the flexibility of firms to shift production and product lines in response to fluctuations in relative factors costs as being one of the main competitive advantages of operating globally. It was referred to as the “hallmark feature” of global value chains that they can transform the uncertainty between global markets into a source of competitive advantage and increased profits. Thus operational flexibility, beyond its risk minimization benefits, is one of the main benefits of international business and an important source of competitive advantage for managers of global value chains. Kogut

(1984) referred to these beneficial opportunities created through operational flexibility as "real options".

Huchzermeier (1991) noted that "Operational hedging strategies … can be viewed as real (compound) options that are exercised in response to demand, price and exchange rate contingencies faced by firms in a global supply chain context." Boyabatli and Toktay (2004) mention that in some literature all forms of operational hedging are referred to as real options. Their own opinion is that all forms of operational hedging in global value chains cannot be considered as real options since real options are used not only to protect against downside risks but also create greater value for the firms from environmental volatility. Hence real options are understood better as means of managing risks in the global value chain rather than as risk hedging strategies only. An example of an operational hedge that is not a real options is moving production entirely to a foreign location to minimize the risk from exchange rate differences since it does not create the flexibility to benefit from later changes.

2.1.5. Summary

From this discussion it is evident that global value chains present both unique challenges and opportunities to firms. While extending supply chains over longer distances exposes the firm to increased risks, the global value chain also provides firms with a novel way to not only protect from some of these risks but also to benefit from them. Environmental volatility, rather than being a source of risk, can become a source of value for properly managed global value chains. Thus evaluation of individual projects in the global value chain needs to explicitly recognize the benefits of operational flexibility at the planning stage. This operational flexibility has been considered as a real option by a number of different researchers. Using a real options framework to evaluate strategic decisions for global value chains can provide a means to achieve this goal.

The next section will discuss the concept of real options in greater detail. After an initial introduction regarding financial options and their similarity to real world projects we will discuss the types of real options and some of the literature in the context of relating real options, global value chains and operational flexibility. The subsections will answer some of the most important questions regarding adoption and application of real options.

2.2. Real Options

The term Real Options was first used by Stewart C. Myers (1977) when he proposed them as an alternative for Present Value Calculations, commonly referred to as Discounted Cash Flow (DCF) techniques, when valuing investments. However, this was not an entirely new concept as Myers was transitioning a concept that had already existed in Capital Markets theory towards Corporate Finance. The theory of real options is based in the theory of financial options or any option that is held against an underlying asset being traded in a market. In Finance an option provides the holder the right, without the obligation, to buy or sell an underlying asset at a pre-determined price at the end or during a maturity period. This underlying asset can be any financial asset; such as common stock, commodities and bonds. Thus the value of the option relies on the changes in the value of the underlying asset. The specified price at which the option can be exercised is called the exercise or strike price while the specified date is called the expiration date or maturity date.

There are two basic kinds of financial options. The "Call Option" provides the holder the right to buy the underlying asset while the "Put Option" provides the holder the right to sell it. Both options present a right to buy or sell but not an obligation, meaning that the holder can choose not to exercise this right and let the options lapse. Thus owning a financial option provides a level flexibility to a decision maker, where the investment or divestment decision can be delayed until more information has been obtained. This flexibility can be considered equivalent to the managerial flexibility to alter strategies based on future events and the resolution of uncertainty. The proponents of real options analysis argue that real world projects often have characteristics that are akin to options or options can often be built into projects to provide greater flexibility. Thus real options analysis is a method of treating a real world investment opportunities as financial options and evaluate them using financial option valuation methods.

In order to better understand the concept of real options and its wide applicability we will start by discussing the comparative deficiencies of Discounted Cash Flow methods that are currently used for valuation in subsection 2.2.1. In the next subsection, 2.2.2, we will discuss the types of real options present in the literature. Subsection 2.2.3 will provide an overview of the literature on real option in a supply chain context. Subsection 2.2.4 will argue that real options can be crucial in unlocking the potential of operational flexibility for global value chains.

2.2.1. Real Options and Discounted Cash Flow

When evaluating investments, corporate planners mostly rely on methods such as Net Present Value (NPV) or Discounted Cash Flow (DCF), Internal Rate of Return (IRR) and the payback method (Miller and Park, 2002). While modifications to these methods are possible, traditional DCF analysis has remained the preferred method for capital budgeting decisions (Ryan and Ryan 2002). All these methods assume a known deterministic cash flow accruing from investment into a project as well as a fixed discount rate.

However DCF has been shown to have a number of limitations. In their ground breaking work, Dixit and Pindyck (1994) asserted that the limitations of the DCF method are a result of unrealistic assumptions. They suggested the method implicitly assumes that either the invested amount can be recovered in case of unconducive market conditions or that the initial decision to invest can only be made at a certain point in time. These conditions hold true only for a limited number of investments.

Trigeorgis (1996) and Miller and Park (2002) went further in suggesting that the DCF method is fundamentally ill-equipped for evaluating strategic investments. Trigeorgis (1996) justified this with a historic perspective suggesting that starting from its development after the Second World War, DCF was fundamentally different from strategic planning as a method of resource allocation. While the former was suited for more decentralized project planning with measurable cash flows the latter was focused on comparatively intangible benefits and has been done using more qualitative tools.

Miller and Park (2002) limit the efficacy of DCF to cost reduction problems with relatively deterministic cash flows as opposed to strategic investments that more commonly have uncertain cash flows. According to them there are three limitations to the DCF methodology. Firstly, the selection of an appropriate discount rate for the investment is difficult. As uncertainty increases the discount rate is also increased thus penalizing more uncertain investments. Secondly the DCF method ignores the inherent flexibility of managerial action as more information is revealed about the investment. Lastly they mention the inability of DCF to consider the option to delay investments.

Kogut and Kulatilaka (1994b) suggested that DCF works effectively only in stable environments which makes it inherently weak for strategic investments especially where the investment is meant to create further growth opportunities in the future. As discussed earlier, operational flexibility is incredibly important for investments in global value chains. Using standard budgeting tools such as DCF, which fail to evaluate the value of flexibility in investments, to analyze global value chain decisions can lead to bad decision making. Thus real options analysis can be a crucial aid in making effective decisions when managing global value chains.

2.2.2. Types of Real Options

In the literature, real options analysis has been most heavily applied towards investments in resource extraction and Trigeorgis (1996) used the example of an investment into an oil extraction and refining operation to categorize real options into eight types. The same categories have come to be widely used for real options in other literature (Schulmerich, 2010).

i. Option to Defer Investment

This option is also termed as the learning option (Schulmerich, 2010). The option to defer investment applies to situations where the exact timing of an investment can be delayed until more information is obtained. An upfront cost must be paid which creates a window of time in which the option holder can decide to either make full commitment or to allow the option to lapse. The option to defer is present naturally in many investment situations where an initial investment allows the opportunity for a larger follow up investment. For global value chains, a smaller initial investment in an uncertain foreign market that allows for a much bigger presence later can represent such an option.

ii. Time-to-build Option (Staged Investment)

This option is useful is situations where the investment can be divided into stages and at the end of each stage the option holder retains the right to abandon the project. Thus each stage of investment in the project is considered an option on the value of the next stage. The time-to-build option is a bundle of sequential options and is valued as a compound option. This option can most commonly be utilized in industries with long and resource intensive research and development phases, such as pharmaceuticals as well as in venture capital. This option is dependent on the nature of the project and not necessarily tied to its global or local character.

iii. Option to Expand

The option to expand provides the holder the right to increase the operating scale of the project if the resolution of future uncertainty is favorable. These options are valuable as a means to expand the upside potential of an investment in a highly uncertain market. The investment is then considered as the initial project plus a call option on future expansion. While these options are common in a variety of industries, they are particularly useful for investments into new technologies and markets that have potential of providing future growth opportunities.

iv. Option to Contract

The option to contract works as the inverse of the option to expand whereby the holder can contract the scale of a project if the resolution of uncertainty turns out to be unfavorable. These options are used to limit the downside potential of an investment in a highly uncertain environment. In some literature, the options to expand and contract are presented as a single category of real options to alter the operating scale. Both these options are a function of the nature of the project and not particular to global value chains.

v. Option to Abandon for Salvage value

The option to abandon for salvage value gives the holder the opportunity to recoup some or all of the investment that was initially made. The value that is recovered from the sale is called salvage value. This value that can be recovered is generally greater for more generic investments and lower for more specific assets. The real option is modeled as a put option. When exercising the option, the salvage value of the investment needs to be compared with the potential loss of organizational capabilities.

vi. Option to Abandon and Restart

This option provides the holder with the right to temporarily stop operations and restart them at a more favorable time. It is useful for cases where the uncertainty in prices and costs can lead to a temporarily unfavorable situation and operations can be stopped without any significant cost in terms of goodwill.

vii. Option to Switch Use

The options to switch use is a broad category of possible opportunities where the holder gains some measure of operational flexibility in terms of the input and/or output factors. Schulmerich (2010) refers to this as the “classical real option” since this option is most readily comparable to the concept of operational flexibility for a global firm. In many real world projects it is possible for an investment, such as a manufacturing plant, to produce multiple different outputs or take different inputs. This flexibility has to often be purchased at some initial cost. Many different decisions can be modeled using this options including the use of technologies that allow alteration in the scale of production, the product mix, the nature of feedstock, as well as the use of subcontractors and multiple suppliers. The option to switch between different product, market and production combinations in a global value chain is also modeled as an option to switch use.

viii. Growth Options

Growth option are decisions that do not directly derive their value from the current investment but from the potential for growth that it results in. These are strategically important and unlock future capabilities that would not be possible without the initial investment. They have many applications in Research and Development as well as in cases of new market entry and for product development using a new technology. Growth options are the clearest example of the benefits of real options against NPV since simple NPV calculation cannot evaluate the benefits from such opportunities. From the perspective of global value chains, modeling investments into new territories as growth options for the entire value chain instead of as a self-contained project can drastically change management's evaluation of such investments.

It is worth noting that in actual investments, multiple real options of the same kind or many different kinds of real options can often be present at the same time. These opportunities have to be evaluated as compound options.

2.2.3. Real Options Literature

Discussion over real options has existed in the literature since the late 1970s when the term was originally introduced. Over time the concept, its uses and methodologies have expanded immensely. While earlier applications focused only towards investments in natural resources, since at least the early 1990s real options researchers have been forwarding it as a general alternative to discounted cash flow in capital budgeting. This has resulted in a wide variety of applications for real options. Natural resource exploration remains the most common area of application for real options due to the easy availability of valuation parameters through the futures markets for oil and gas. Research and development has also seen wide applications, especially in highly uncertain and long development cycle industries such as pharmaceuticals. Real options analysis has mostly been used to value investments into individual projects but a number of researchers have also shown applications in valuing business strategies. Trigeorgis (1996, 2005) and Millar and Park (2002) provide a more detailed overview of the different scenarios for which real options have been applied and the considerable literature on the topic.

A large number of researchers have used real options analysis, either as a formal capital budgeting tool or a strategic framework, to model a number of separate decisions related to global supply chains. Minimizing supply risk in over stretched supply chains is one of the major challenges in global value chains. Carbonara et al. (2014) proposed a real options framework to model the costs and benefits of a number of supply chain risk mitigation strategies. These strategies included product postponement, strategic stock, multiple sourcing, the decision to make and buy the same product, contractual incentives for supply contracts and flexible transportation. Pochard (2003) and Costantino and Pelligrino (2010) demonstrated applications for real options in accessing dual sourcing strategies to minimize supply risk in global supply chains.

Global value chains have allowed managers to break their value chains across different territories and activities and outsource certain activities in order to improve efficiencies. Thus the outsourcing decision is one of the most important decisions in managing global value chains. Nembhard and Shi (2003) modeled product outsourcing as a real option and used Monte Carlo simulation to demonstrate the applicability of real options in better assessing the outsourcing decision. Datta (2005) undertook an in-depth discussion of the outsourcing process to demonstrate how current rationales for outsourcing do not provide any normative value to decision makers while a real options framework can remedy this. This is particularly important since an outsourcing relationship entails an increased level of uncertainty which is resolved as the relationship proceeds over time. Thus the outsourcing of a task presents the firm with a “real call option” to bring back this task inhouse in the future as more information becomes available. For outsourcing decisions, real options can be used both to design firm strategy towards outsourcing as well as evaluating and measuring the efficiency of the strategy once it is implemented.

Avanzi et al. (2013) demonstrated how a real options framework could help a firm in exploiting the embedded flexibility in its supply chain by means of decisions related to postponement, contraction, expansion, switching and abandonment. They used the case of an actual Swiss firm, Maillefer Extrusion, and its decision to utilize the flexibility in its supply chain to counteract cost based competition. Through real options analysis the authors were able to provide a monetary value for increased flexibility gained from postponement that could then be compared with the cost savings from offshoring production.

It is difficult to empirically prove the effectiveness of real options since specific case studies can only show whether the outcome was positive without definitively proving the effectiveness of the process itself. A number of researchers however have demonstrated the potential empirical benefits of real options thinking as a cause for corporate success. Lavoie and Sheldon (2000) used real options as an explanation for the differences in how U.S. and European firms invest in biotechnology. They argued that American companies have dominated the biotechnology sector without possessing any traditional comparative advantage against European companies. For the year 1996, U.S. biotechnology firms invested $7.9 billion on R&D, employing 118,000 workers across 1,287 firms. In contrast all of Europe combined had only 716 firms employing a meagre 27,500 workers and invested $1.2 billion. In that year, U.S. firms earned $14.6 billion in revenue while the European firms made only $1.4 billion. According to the authors, this disparity in fortunes was not a result of any comparative advantage that benefitted firms operating in the United States. Instead it accrued from an understanding on their part that investments in R&D should be analyzed as real options. Their research did not refer to any actual case where a U.S biotechnology firm had used real options analysis when making these investments instead using it as an explanatory tool for the actual observed reality

Manufacturing flexibility has been modeled as real options in a large variety of literature and is one of the most repeated application of real options analysis. Bengtsson (2001) provides a comprehensive review of these applications. The option value of global manufacturing flexibility in particular has mostly been modeled as a switching option. A number of authors have used dynamic programming to evaluate these options. Kogut and Kulatilaka (1994a) created a dynamic programming model to evaluate the real option value of having the flexibility to shift production in a global manufacturing network under exchange rate uncertainty. Huchzermeier and Cohen (1996) and Cohen and Hucherzmeier (1999) provide a combination of dynamic programming and lattice based models to evaluate the value of global operational flexibility in response to exchange rate changes.

The above discussion shows the vast range of potential applications for real options in global value chains and towards supply chain applications in general. In the next subsection we will demonstrate the particular application of real options as a means to unlock the potential for operational flexibility in global value chains.

2.2.4. Unlocking operational flexibility through real options

It is evident that global firms operating in a number of countries can benefit from operational flexibility and this flexibility has been recognized as a real option since Kogut (1984) used the term in this context. However the potential to benefit from operational flexibility does not mean that it is always possible for firms to practically do so. It needs to be established that firms with global value chains are able to practically benefit from operational flexibility and that treating this flexibility as a real option provides tangible benefits. There have been a number of empirical studies that have demonstrated that global value chains are not always able to use the inherent potential for operational flexibility and using a real options framework helps in delivering on this potential.

Rangan (1998) studied whether firms with global value chains actually exhibit operational flexibility in order to cope with exchange rate uncertainty. He formulated three different hypothesis regarding the behavior of firms reflecting an optimistic, pessimistic and realistic attitude towards flexibility. These orientations can be interpreted as a highly flexible response, highly inflexible response and an intermediate response that is dependent on the internal configuration of the firm respectively. The research used data from European, Japanese and American multi-national enterprises during the 1980s and indicated that firms did exhibit a statistically significant level of flexibility but not directly correlated to the changes in the exchange rates. Thus it could be concluded that while operations across the globe can confer real options of flexibility to firms, they might not always be able to benefit from these options.

This is an important insight and is supported by a number of earlier theoretical frameworks. Kogut (1985b, 1989) suggested that the potential to operate flexibility requires an appropriate management system in order to translate into actual operational flexibility. Volberda (1997) had also previously suggested that flexibility needs to be designed into firms both on the organizational and managerial levels. Thus operating in multiple countries does not allow firms to benefit from flexibility by itself. This needs to be designed into the managerial and operational policies of the firm.

Since then, a number of other researchers have empirically shown in a variety of contexts that multinational operations provide firms with the potential for flexibility but not necessarily the ability to effectively make use of this flexibility. Research by Chung et al. (2010) studied the behavior of 52 Japanese firms and their 1519 subsidiaries during the Asian economic crisis that started in 1997. The study showed that in reaction to economic shocks, subsidiaries that had across country real options were more likely to show flexibility than those with within countries real options. Thus it is necessary for firms to orient their real options as a hedge against the most likely risks facing their global operations.

Driouchi and Bennett (2011) used a survey of 278 firms operating globally to gauge the effects of multinational operations and awareness of real options on the downside risk of firms. Downside risk was taken as a downside outcome in terms of annual return measures such as ROA, ROE and ROIC compared to the industry standards for that time period. The results showed that firms with real options awareness and multinational operations were able to reduce their downside risk significantly more than firms without real options awareness. This reflects that knowledge of real options can act as the driving force behind managers’ ability to effectively use the operational flexibility to hedge against uncertainty. This is an important observation when seen along with the earlier conclusion of Howell and Jagle (1997) that the intuitive understanding of managers is not always in line with the results from real options analysis. Hence it can be concluded that a natural understanding of flexibility is not enough to operationalize it without a framework such as real options analysis.

It can be observed from the literature that real options analysis has both vast applications and potential benefits for decision makers in global value chains. While managers have been aware and making use of the flexibility inherent in global operations even without the real options terminology, the growth of real options thinking has had an important impact on the quality of these decisions. It has not only helped managers communicate the benefits of this flexibility in better terms but it has also made firms more aware of these opportunities as well as more willing to exploit them (Triantis and Borison, 2001). Additionally, the observation that flexibility in global value chains, while potentially present, still needs a moderating framework for its successful application means that real options analysis can be crucial in providing firms with the required tools to deliver on that potential. Especially since it has been shown that even managers that are aware of real options are often unable to value these options properly (Howell and Jagle, 1997).

Firms operating globally have the potential to use their operations to reduce risk and create a competitive advantage. It is crucial for successful global value chains to benefit from this flexibility. However simply the presence of global operations or even the management of global operations as an integrated global value chain is not enough to actually deliver on this potential. Operational flexibility needs to be explicitly recognized from the start and designed into both the management and operation of global value chains in order to reap this benefit. Recognizing and assessing projects in the global value chain as real options provides firms with the ability to do this.

3. Real Options Modeling and Valuation

In the preceding section we have shown that global value chains require a different framework for investment valuation. This framework must explicitly include the benefits of operational flexibility. We have also shown that real options analysis has been suggested as a means to value flexibility in decision making over a wide variety of applications and empirical studies have also demonstrated its effectiveness in helping managers benefit from the operational flexibility of global value chains.

In this section we will discuss the actual valuation process for real options as well as the difficulties being faced currently in adoption of real options by practitioners. This discussion will help in providing the guidelines for the model to be formulated in section 4. The first subsection will introduce the basic methodology for option valuation as well introduce the most common solution methods. Subsection 3.2 will discuss the challenges in using real options as a valuation tool. Subsection 3.3 will focus specifically on literature that models the operational flexibility of global value chains as real options. Subsection 3.4 will present the main conclusions and guidelines on which we base the model presented in the succeeding chapter.

3.1. Overview of Methodology

The basic idea of real option valuation is derived from the standard method for valuation of financial options. As mentioned previously, an option provides the holder the right without the obligation to buy or sell a specified asset by paying a set price on or before a specified date. The underlying for financial options can be any financial asset, such as common stock, commodities and bonds. Over time as the price of the underlying changes, the value of the option changes concurrently. The specified price at which the option can be exercised is called the exercise or strike price while the specified date is called the expiration date or maturity date.

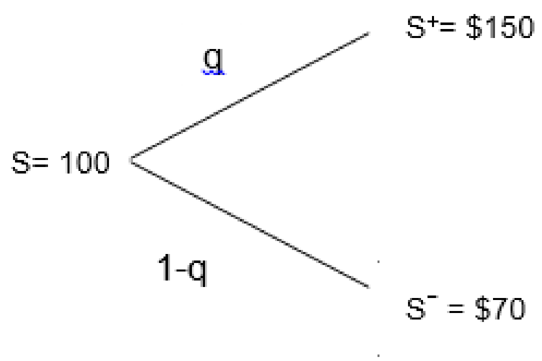
The option to sell the underlying asset for the pre-determined strike price at or before the expiration date is called a put option. If the market price of the underlying falls below the strike price, it would be favorable for the option holder to exercise the option and sell the underlying for a higher price than its current price in the market. If the price of the underlying does not decrease below the strike price by the expiration date, then the option will expire without being exercised.

Conversely, the option to buy the underlying asset at or before the expiration date is called the call option. If the market price of the underlying increases above the strike price then it will be favorable for the option holder to buy the underlying asset at the lower strike price. At all points in time when the option yields value to the holder it is considered to be "in the money". From this discussion it is clear that the value of an option depends on the current price of the underlying, the strike price of the option, the time to maturity and the volatility in the price of the underlying asset. Black and Scholes (To explain the idea behind the valuation methodology, we will use the following notation:

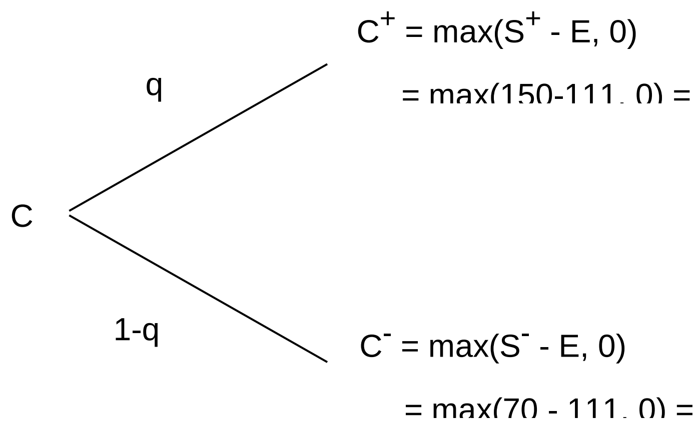
C = value of a call option
S = price of the underlying asset
P = value of a put option
T = maturity (expiration date of the option)
τ = time to expiration (expiration date – current date)
E = exercise (strike) price of the option
r = risk-free interest rate
u = upward movement multiplicative factor
d = downward movement multiplicative factor

Option valuation is made possible by assuming that it is possible to construct a portfolio of 'N' number of shares of the underlying asset and '$B' of bonds. The portfolio will track exactly the payoff from the option at all future states in time and hence must have the same current value as the option to prevent arbitrage.

Consider an underlying asset, a common stock in this case, of current price S=$100. In the next period the price of this asset can either increase or decrease. There is 'q' probability that the price of this asset will increase to S^{+}= $150 with an up movement multiplicative factor of u = 1.5 and a 'q-1' probability that it will decrease to S^{-}= $70 with a down movement multiplicative factor of d = 0.7. This movement in the actual price of the asset is shown below.



The value of an option on this asset will depend on the movement of the asset price based on the tree above. A call option of current value C can have either an increased value C+ or a decreased value of C-, again with the probabilities of q and 1-q respectively. If the exercise price E= $111, then the value of the option at the end of this period can be shown by the following tree.



To find the current value of this option we will construct a replicating portfolio comprised of N shares of the underlying stock at current stock price and borrowing $B at the riskless rate through bonds. The net cost of this portfolio is given by the expression:

Cost of replicating portfolio = NS-B

In order for the cost of this replicating portfolio to be the same as the call option, its returns in all states must match the returns from the call option. Hence, for a risk free interest rate of 8% (r = 0.08), the portfolio can have the following two value at the end of the period:

$$Up\ State = NS^{+} - (1+r) \times B$$
$$= \mathrm{N} \times (\$150) - (1+\mathrm{r}) \times \mathrm{B} = 39$$
$$= C^{+}$$

$$Down\ State = NS^{-} - (1-r) \times B$$
$$= N \times (\$70) - (1+r) \times B = 0$$
$$= C^{-}$$

Solving these two equations together yields the values:

N = 0.49 shares

B = $37.76

For the given values, the value of the call option can be calculated by equating it with the value of the replicating portfolio:

Value of Call Option = Value of Replicating Portfolio

C = NS – B = 0.49 * (100) – 37.76

C = $11.24

This replicating portfolio concept lies behind the methodology of option valuation. Black and Scholes (1973) originally showed that with a few simplifying assumptions, exact option values can be obtained using a closed form equation that has come to be known as the Black and Scholes formula. The calculation assumes that the stock prices follow a stochastic diffusion Wiener process of the form:

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

Where ά is the instantaneous return on the stock and σ is the instantaneous standard deviation of stock returns.

The restrictive assumptions of the Black and Scholes formula means that it is rarely applicable to the real projects for which real options are used. Most of the literature also does not rely on the Black and Scholes formula except for a few exceptions (Luehrman, 1998a). These assumptions will be discussed in more details in the subsection 2.3.2. The more common methodology for real options valuation uses the multiplicative binomial tree. This methodology assumes that over a single period the asset price can take only one of two possible values. It can be shown that at the end of the first step the value of a call options is given by:

$$C = \frac{p * C^{+} + (1-p) * C^{-}}{1+r}$$

Where p and (1-p) are risk-neutral probabilities given by the following expression:

$$p = \frac{(1+r)-d}{u-d}$$

The values of *u* and *d* are expressed in terms of the volatility (σ) in the asset price. This process can be repeated over and over to create a discrete time binomial tree that replicates the payoffs from a real option. Thus the option can be valued if the volatility in the returns and the time to expiration are known.

In addition to the multiplicative binomial tree, a number of different approaches have been used to value real options. The specific approach used is also often dependent on the context with certain kinds of options being valued through one family of solution methodology. There is relatively little consensus on a single best approach for all cases. Broadly the approaches can be distinguished between discrete-time and continuous-time approaches (Miller and Park, 2002). Table 5 lists down the different approaches and their advantages and disadvantages. An alternative way to categorize valuations methodologies is presented by Schulmerich (2010) dividing all methodologies into either Analytical or Numerical methods. In addition to these, there has also been some effort to use real options analysis in conjunction with decision analysis techniques such as decision tree analysis.

Discrete Time	**Continuous Time**		
Multinomial Lattice	Closed Form	Stochastic Differential Equations	Simulation
Advantages: • Intuitively Appealing • Flexible • Easy Implementation	Advantages: • Simplified Calculations • Straightforward	Advantages: • Model flexibility • Mathematically accurate	Advantages: • Adaptable • Broad Applicability
Disadvantages: • Cumbersome • Labor Intensive	Disadvantages: • Limiting Assumptions • Limited Applicability	Disadvantages: • Approximate Solutions • Complicated	Disadvantages: • Requires Special Skills • Potential Misuse

Table 4: Real Options Analysis Modeling approaches (Miller and Park, 2002)

In a survey conducted in 2007 it was observed that Binomial lattices, risk adjusted decision trees and Monte Carlo simulations were the most common methodologies used by businesses in that respective order (Block, 2007). The Black-Scholes option pricing model, which is the predominant option pricing methodology for financial options, was used by only 1 firm among the 40 firms that were using real options at the time. Similar results were also obtained by Triantis and Borison (2001). They also suggested that among practitioners there is no single preferred methodology, instead the industry and the nature of the problem determines which methodology is best suited.

3.2. Challenges

While considerable literature exists on the subject, the application of real options analysis for global value chains faces a number of difficulties related to the valuation methodologies. Real options analysis as a general field suffers from a lack of consensus regarding methodology and the underpinning assumptions. There also exist two distinct ways in which real options analysis has been utilized in the literature with authors highlighting the inapplicability of opposing approaches. We will tackle these issues in the next subsections. Subsection 3.2.1 will provide an overview of the problems that have been highlighted by practitioners when using real options analysis. Subsection 3.2.2 will discuss the contrasting ways in which real options have been applied in the literature to draw conclusions regarding its appropriate use. Subsection 3.2.3 will discuss the different modeling challenges faced in real options valuation.

3.2.1. Insight from practitioners

The actual adoption of real options among corporate managers has been slow even if gradually increasing. A number of different reasons have been highlighted for this phenomenon. In an exploratory study conducted in the UK, Busby and Pitts (1997) found that almost none of the 44 respondents had any formal procedures for the use of real options in their companies. This was despite the fact that the majority of respondents agreed to the importance of flexibility and the presence of options in their managerial decisions. Research conducted in 2000 for Bain and Company showed that from a sample of 451 senior executives only 9% were currently using real options (Teach, 2003). Around the same time 205 CFOs from Fortune 1000 firms were surveyed for the basic capital budgeting tools they used most often as well as supplemental tools that were being employed by Ryan and Ryan (2002). While the most popular capital budgeting tool was recognized as NPV, being used for a majority of budgeting decisions by 96% of respondents, real options analysis was only being used as a supplemental budgeting tool by 11.4% of respondents. This made it the least used supplementary budgeting tool among the 13 tools on the survey. The situation has gradually improved over the years with the formal adoption of real options gradually growing. In a study conducted among Fortune 1000 companies in 2007, 14.3% of the firms that responded were using real options (Block, 2007). This translated into 40 firms out of 279 respondents.

The most common reason cited for the slow adoption of real options has been the lack of support from higher management, mostly due to their inability to follow the complex methodology (Triantis and Borrison, 2001). This has also been backed up by repeated results that show wider adoption in industries with a greater engineering focus and hence more analytically trained senior executives. In research by Block (2007), 37 of the 40 firms that were using real options represented just 5 industries: technology, energy, utilities, healthcare and manufacturing respectively.

Other research has also indicated that the adoption of real options has been more prevalent in certain industries. Miller and Park (2002) mentioned Merck & Co. and Hoffman-La Roche as companies in the biotechnology sector that have been using real options analysis as a guide for their investments. Stuart (1999) quoted an executive at Amgen, a U.S. based pharmaceutical company, as mentioning real options providing the basis for a higher than standard bid for its acquisition of the cancer drug Abarelix. This was only one of a number of mergers and acquisitions that were mentioned for using real options valuation to identify and value targets.

The study conducted by Block (2007) showed that the use of real options is most prevalent in the areas of new product introduction, research and development and mergers. This suggests that the most commonly used type of real options are growth options. This had also been highlighted in the exploratory survey by Busby and Pitts (1997). These are opportunities for which other quantitative methodologies can be particularly ineffective. Triantis and Borison (2001) also concluded that real options were mostly used in industries with large one time investments and highly uncertain environments, leading towards the conclusion that instead of replacing current capital budgeting methods real options are being used to perform analysis that is difficult with pre-existing tools.

The discussion regarding the adoption of real options among corporate practitioners provides a few key conclusions with respect to the barriers towards a greater adoption of real options in decision making. Firstly that the use of real options is not as widespread as many of the early researchers expected. A number of researchers have observed greater adoption in specific industries compared to others (Triantis and Borison, 2001;

Block, 2007). Considering that useful applications of real options have been demonstrated by researchers in a wide range of contexts, it can be argued that the industry specific adoption is due to the knowledge base in these specific industries being more familiar with the methodology rather than the limited applicability of the concept itself. This conclusion is also backed by research that has pointed towards the difficulty in understanding the methodology as one of the major reasons for the slow adoption of real options (Block, 2007). Thus there is a need to find easier ways to demonstrate the benefits of real options thinking without delving into the complex mathematics of financial option valuation in order to increase its adoption.

A second important conclusion that can be drawn is that in firms where it is being used, real options is seen as a supplemental aide to guide investment strategy rather than as the primary budgeting tool for a majority of decisions (Ryan and Ryan, 2002; Block, 2007). The literature on real options analysis can be divided between research that forwards it as a valuation tool and research that proposes it as a strategic framework. This distinction is also present in how real options analysis is being used among corporate practitioners. Busby and Pitts (1997) and Triantis and Borison (2001) reported wide disparity in how different firms approach real options. The latter showed that real options usage was divided into 3 classes. Firstly there are firms that use real options as a qualitative framework or way of thinking. Secondly there are firms that use real options as an analytical tool for evaluations of projects using a specific valuation methodology. Lastly real options are being used as an organizational process that helps identify strategic options in the industry. This distinction has led to confusion among practitioners regarding the best way to apply real options as well as creating a hurdle towards its greater adoption. One of the most important research questions with regards to real options is whether it should be used as a budgetary tool or as strategic framework. This distinction will be explored in more detail in the next subsection.

3.2.2. Real Options as Strategic Framework

Most literature on real option analysis begins by explaining the concept of using options thinking towards investment decisions and only later discussing a specific methodology to achieve a financial valuation. There is almost unanimous acceptance that the first part of this holds significant appeal for managers. The majority of criticism for real options analysis is rooted in methodological issues (Luehrman, 1998a). As discussed earlier, the majority of challenges in terms of real world adoption are also a result of methodological difficulties. Thus it stands to reason that removing the valuation methodology while keeping the concept of real options is an attractive alternative.

This has created a distinction in how real options are perceived among researchers. Most of the literature discussed so far uses real options analysis as a tool to provide exact valuations for specific investment decisions. On the other hand there is also a growing body of literature that perceives real options as a purely strategic framework and severely limits its applications as a budgetary tool. This section will discuss a few of these applications.

Janney and Dess (2004) referred to these uses as informal and formal uses of real options. They actively suggested that managers should look at real options as a framework instead of a decision-modeling tool while also warning that not all decisions that reduce the uncertainty in a managerial decision should be considered real options. They defined real options as decisions comprising two parts where one decision creates the opportunity to take the next decision without an obligation and used an entry and exit perspective to divide all options into four types as shown in Figure 1: Immediate Entry, Immediate Exit, Delayed Entry and Delayed Exit.

	Immediate Action	Delayed Action
Action to Enter	**Immediate Entry** **Advantage: Early Involvement**	**Delayed Entry** **Advantage: Avoid irreversible uncertainty**
Action to Exit	**Immediate Exit:** **Advantage: Commitments are reversible**	**Delayed Exit** **Advantage: Delay making full commitment to an exit**

Figure 1: The Four Types of Real Options (Janney and Dess, 2004)

In this classification, an "immediate entry" option allows a firm to make a smaller initial commitment at some smaller cost that provides the opportunity for a full commitment later as more information becomes available. In contrast to this the "delayed entry" option allows a firm to simply buy the right for an entry at some later stage, without actually making a commitment at the first stage. The two options apply to different kinds of investment opportunities. The first is more applicable to cases where it is possible to break the investment decision into parts while the latter is used when the investment decision can be delayed but must all be made in one go.

The "immediate exit" option works in reverse of the "immediate entry" option, with a firm fully committing initially but buying the opportunity to reverse this commitment with an exit. The "delayed exit" option then buys the opportunity to delay making full commitment towards an exit. Here again the nature of the decision decides the applicability of the option. A number of these options related to the same decision can be bundled either as a portfolio, increasing the opportunities available, or as a sequence making compound options where exercising one options creates another. The authors do not provide any quantitative framework to formally evaluate these decisions, instead suggesting that internal consistency between valuation parameters and decision rules is enough to provide guidance to decision makers without necessarily providing a verifiable number.

Kogut and Kulatilaka (1994b) discussed a specific kind of strategic investment called platform investments. These are investments made to expand organizational capabilities providing firms with the means to expand into new markets. They suggested that no other framework can capture the benefits associated with this form of investment as well as real options. The authors argue that current heuristics for investment decisions suffer from short-sightedness and a focus on short term benefits making them ill-suited for investment decisions. Compounding the problem is a mix of environmental factors from the demands of financial institutions to the division of Strategic Business Units (SBUs) that incentivizes short term thinking. They observed that while formalization of the real options analysis process is possible for many platform investments, it will more often only be possible to use as a framework for analysis to guide decision-making. In this regard they suggested that the real option value of a platform investment should be evaluated on four factors: uncertainty, opportunity, time dependence and discretion.

Amram and Kulatilaka (2000) limited the definition of real options significantly to focus on only market priced risk. This provided a clearer distinction between investments that should not be quantitatively assessed using real options and those that should be. However, they also concluded that even in cases where a complete quantitative evaluation is not possible, real options thinking still provides valuable insight into the largely qualitative strategic analysis aided by other decision tools.

Some researchers have also attempted to primarily use the real options as a strategic framework while significantly simplifying the mathematical rigor of the valuation process. Luehrman (1998b) forwarded the idea that firm strategy as a whole can be modeled as a sequence of real options. This follows the important observation that strategy is meant as a guide for future actions rather than a detailed long-term plan to be followed “mindlessly”. Current strategy formulation methods rely mostly on qualitative tools and real options can provide a quantitative guide to strategic decision making that is currently missing. Thus different projects and decisions available to a firm form a portfolio. This portfolio of real options needs to be actively managed over time and profitable options executed at the right time.

To make quantitative sense of this portfolio, a framework was provided in his earlier work (Luehrman, 1998a). This framework used concepts from the Net Present Value methodology as well as from Financial Options in order to quantify the two sources of extra value that make real options a better tool than NPV: time and volatility.

To explain the current state of a strategic option, two new metrics were defined (Table 4). The first of these is referred to as NPVq. NPVq is obtained mathematically by dividing the value of the project’s assets by the present value of the expenditure required to obtain these assets. The crucial difference here is that NPVq assumes the firm can defer its investment decision until a later time. Hence we are earning the time value of money on the expenditure. There is no direct relationship between NPVq and the traditional NPV. Instead NPVq is the quotient form of “modified NPV” which is obtained by subtracting the present value of the future expenditure from the value of the project’s assets. The modified NPV is always either equal to or greater than traditional NPV. The relationship between NPVq and modified NPV is that when the modified NPV is positive, NPVq will be greater than 1 while it will be lesser than one for negative values of modified NPV.

The second metric is called cumulative volatility and is a measure of the uncertainty in the future value of the project. Mathematically this is the product of the standard deviation in the returns from the project and the square root of the time until the option expires. Luehrman (1998a) relates all these project characteristics to the components of financial options pricing including stock price, exercise price, time to expiration, risk-free rate of return and the variance of returns on stocks. The actual values of these metrics are then calculated using the Black-Scholes Option Pricing Tables for financial options.

Metrics	Mathematical representation	Theoretical Explanation
Value to cost (NPVq)	$S \div PV(X)$	Present Value of Project's profits divided by Present Value of required investment
Cumulative Volatility	$\sigma\sqrt{t}$	Standard deviation in the returns from the asset multiplied by square root of the time until option expires

Table 5: Metrics for Options Space

Using these metrics, Luehrman (1998b) creates "option space", a rectangular plot between NPVq (on the x-axis) and cumulative volatility (on the y-axis). Every strategic option can be placed in this option space based on the respective value of the two metrics. The space itself is divided into regions denoting the suggested course of action as shown in Figure 2. Options that fall towards the top of option space, in regions 1 and 6, are at a stage where either all the volatility regarding their expected returns has been resolved or no more time remains before a decision has to be made. Hence immediate decisions need to be taken based on their NPVq values. The bottom right and left sections need to be further divided based on the current NPV values. In region 2 fall projects that have both NPV and NPVq values as positive. Exercising these options right now would lead to favorable returns even if there is still time remaining until a final decision cannot be delayed further. In region 3 fall projects that have a negative NPV value but an NPVq value greater than 1. These projects should not be exercised right now since they will lead to negative returns however they can be cultivated in a way that future resolution of volatility makes them profitable. While all options falling on the left side should definitely not be exercised right now, those in Region 4 have a greater chance of becoming profitable in the future than those in region 5.

The option space created by Luehrman (1998b) provides a good visual indicator of the value of different strategic real options as well as providing a guide towards future action.

In addition Luehrman (1998b) also suggests that managers can actively try to navigate options into more favorable regions by changing the project's characteristics.

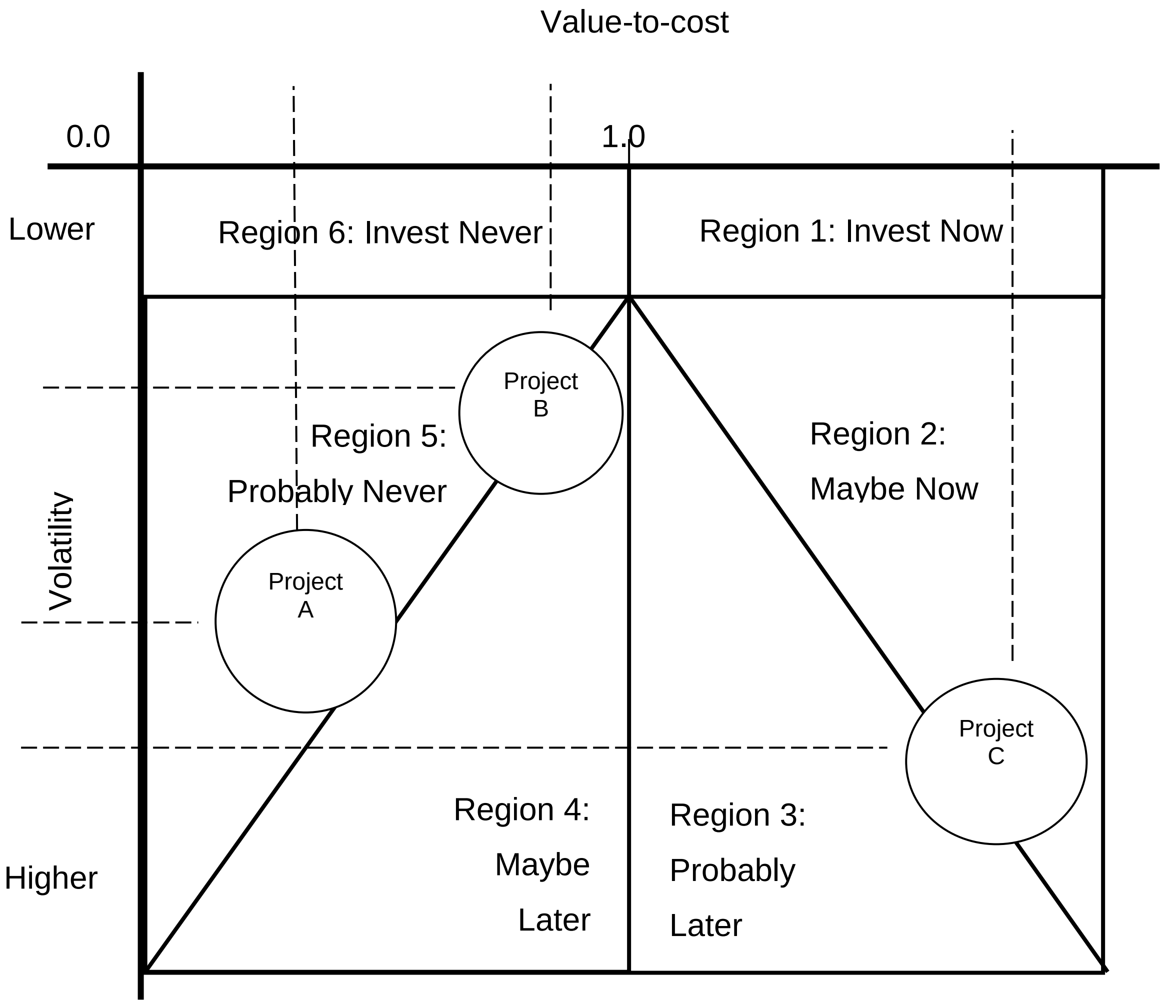


Figure 2: Options space (Luehrman, 1998b)

It is clear that using real options thinking to guide strategy can have major benefits for decision makers. The insights that real options analysis can provide are not entirely dependent on the quantitative rigor of the process or the exact number obtained. The exact method to apply real options thinking depends on the users and the application for which it is being used. While it is clear that certain contexts are more amenable to real option valuation than others, the flexibility of how real options analysis can be applied should be seen as a strength of the concept rather than a weakness. A deeper discussion of the challenges faced when modeling certain types of projects as options will be undertaken in section 2.3.2.

This flexibility of use has also been recognized by a number of researchers. Real options are often wrongly considered as an entirely new and self-contained method of investment valuation. Instead, much like many of the corporate users mentioned in the previous section, the use of real options as a supplement to more well-known budgetary methods such as NPV has been advocated as the best way to use real options by a number of the foremost researchers in the field (Trigeorgis, 2005; Van Putten and MacMillan. 2004). Trigeorgis (1996, 2005) provided the following formulation for how real options can be understood as a complement to traditional NPV analysis:

Expanded (or strategic) NPV = passive NPV + Option Premium (ROV)
(Flexibility value + Strategic Value)

Here the option premium consists of both operational options that provide value above passive NPV by considering management's ability to use operational flexibility and strategic options that provide value through interaction effects with competition and inter-project dependence. The strategic component of option value is hard to quantify and is best understood qualitatively while real options valuation is meant to quantify the flexibility value of the option premium. Millar and Park (2002) suggested that real options analysis should be treated as a decision support tool rather than a tool to evaluate the exact value and it is in this context that we propose its use for investment valuation. Real options analysis thus provides expanded insight into standard NPV valuations.

Another important conclusion from this discussion is that future research into real options must not further complicate methodology, instead seeking to use real options thinking to supplement already existing tools to better evaluate the value of managerial flexibility. In the next subsection we will discuss the particular factors that make current real options valuation methodology so challenging.

3.2.3. Modeling Challenges

The common Real Option valuation methodologies are adapted from financial option pricing and hence present a number of challenges when applied to real projects. Moreover, different researchers have used widely varying and often conflicting methodologies to overcome these challenges (Borison, 2005).

i. The Underlying Asset

In financial option valuation, the identification of the underlying asset is important from two perspectives. Firstly the movement in the value of the underlying asset indicates the stochastic process to be used in order to model the option. For financial options, the underlying asset is a stock or market traded security hence making it easy to identify the stochastic process followed by its value. This is much more difficult for real options since the underlying asset is often a real world project. Secondly, the tradability of the underlying is an important assumption for the valuation procedure. It is self-evident that real world projects are not traded in markets and do not fulfill this criteria. These difficulties have led to some simplifying assumptions.

When determining the underlying stochastic process, common Real Option methodologies assume Geometric Brownian Motion (GBM). The GBM is one of the assumptions in the original Black-Scholes equation since it is common to model the movement of stock prices using GBM and is used as such in most Real Option valuations. Further discussion of the assumptions in this regard is contained in the section on volatility.

The tradability of the underlying asset is a much more widely discussed issue in real options literature. For financial option valuation, it is necessary to assume that the underlying asset can be bought and sold in complete markets. In the field of real options different projects, plants and even strategies have often been considered as the underlying asset, none of which are traded on markets. It is this area where the literature on real options diverges into competing assumptions.

One popular assumption is the existence of a security that correlates perfectly with the real asset in value. This security is often referred to as a “twin” security. Trigeorgis (1996) explains this as a security that is traded in financial markets and possesses the same risk characteristics as the underlying asset of the real option. This approach is rationalized by comparing it with the traditional NPV method which similarly assumes a twin security that is either perfectly or highly correlated with the project characteristics. However in practice it can be difficult to find such twin security. Borison (2005) argues that in principle it is difficult to rationalize that a single investment, such as a manufacturing plant, would be highly correlated with any specific stock. It is also worth mentioning that while the Black-Scholes method requires a twin security that has the same return in all states, the twin security in the DCF method merely requires the same risk characteristics, or the same beta, as the investment being considered.

Miller and Park (2002) suggest that the twin security approach is only practically used for three scenarios. Firstly this approach is used for options related to investments in natural resources, such as oilfields, where the value of the project is based on the price of commodities that are traded in futures markets. Secondly in cases where a specific division of the firm can be considered as the underlying asset and the stock of a competing company can be used as the twin security. Lastly, when the project is considered to have enough of an impact on the market value of the firm that its own stock can be used as a twin security.

An alternate approach was first presented by Mason and Merton (1985) that assumed that the project should be treated as if it were traded in the market itself. This approach was later extended by Copeland and Antikarov (2001) for cases where no perfectly correlated twin security exists coining the term “Marketed Asset Disclaimer” or MAD. The MAD approach assumed that the value of the project itself, in its original state without real options, is the best estimate for the value of the twin security.

The MAD approach has allowed a much wider usage of real options analysis. Another alternative suggestion is to use different approaches for different cases. For valuing options for which a traded security can be found, such as those related to natural resources, the twin security approach is used while for other cases the MAD approach or approaches based on decision analysis methods can be used. Borison (2005) also states that the value calculated using the two methodologies represents somewhat different outcomes.

ii. Selecting the appropriate discount rate

The replicating portfolio technique used to value financial options results in all the risk being hedged away. Hence it is appropriate to use the risk-free rate for these calculations. When transferring the methodology over to real assets, this assumption needs to be given some consideration. From a general perspective, the approaches of Trigeorgis (1996), Mason and Merton (1985) as well as the MAD approach of Copeland and Antikarov (2001) all assume that the underlying is a tradeable asset and hence the risk-free rate is used. In some of the approaches based in decision analysis methodologies, the Weighted-Average-Cost-of-Capital (WACC) is used to discount the option value representing the ability of shareholders to access investments with a comparable risk profile.

One key discussion with regards to the discount rate and the risk characteristics of the underlying is with respect to market risks and private risks. In financial theory, market risks are a characteristic of the macro environment including the economy and competitive structure of the market while private risks are a characteristic of the firm and the project. Borison (2005) noted the lack of consideration given to private risk in most real options analysis techniques as a major weakness. However this distinction has been used in several papers where the private and public parts of the risk associated with a real option are treated separately. For example, Kamrad and Ernst (2001) considered mining ventures and presented the uncertainty in the price of the mined resource as public risk while the uncertainty in the quantity of the resource at the mining site was presented as a private risk.

Smith and Nau (1995) forwarded a new terminology of “partially complete markets” to account for the inability to completely hedge the private risks involved in a real project while hedging the market risk. They used a novel approach towards real options valuation that combines decision analysis methodology with standard real options analysis. Smith and McCardle (1998) expanded on this method and also compared the values obtained through both the decision analysis based utility function approach and the risk free rate. They conclude that the former method undervalues the option while the latter overvalues it due to the assumption that all the risk associated with the project can be diversified.

Amram and Kulatilaka (2000) limited the definition of real options to only those strategic options that were dependent mostly on market-priced risk. In their formulation the ability to accurately identify risks is crucial to the application of real options valuations methodologies. For investments dominated by private risk they proposed decision tree methodology to value the real option. This definition however severely limits the applicability of real options. We can conclude that to the extent possible, the uncertain parameters and the discount rate chosen should be based on market data. In cases where a directly related commodity, firm or project can be found with market data, valuation methods should incorporate it. However, the absence of market priced information does not mean that real options analysis loses all value as a decision support tool for investment valuation.

iii. Volatility

In order to perform the calculations for option valuation it is necessary to know the expected volatility, expressed by the standard deviation, in the returns from the underlying asset. This is done using historical data on the movement of stock prices for financial options. For most real options, no historical data exists for the project returns to gain this information.

For the approaches that utilize the twin security concept, this problem is overcome by using the historical returns of the traded security. This is most often used for natural resources that are traded in futures markets. This approach often also leads to simplifications of reality. In some of the research for switching options it is assumed that the switching decision in entirely inherent on the changes in the price of a single traded commodity, such as oil (Kulatilaka and Trigeorgis, 2004) or that the effect of all the changes in the environment can be captured through a single parameter such as changes in the exchange rate (Huchzermeier and Cohen, 1996).

An alternative to this is the approach introduced by Copeland and Antikarov (2001) that utilizes Monte Carlo simulation in order to calculate the expected volatility. This approach uses Monte Carlo simulation to simulate the expected changes in the prices of the inputs and outputs for a project over a number of periods. The volatility is then taken as the standard deviation of the project's return. This approach also theoretically overcomes the challenge of considering multiple sources of uncertainty. At the same time, it is crucial that the correlations between the different sources of uncertainty is considered and modelled effectively. Copeland and Antikarov (2005) argue that for their approach different sources of uncertainty can be considered together as long as they vary through time together and their covariance is modeled correctly. Hence this approach is not suitable when one source of uncertainty is continuous while the other is discontinuous.

iv. Exercise Price, Date and Dividends

In addition to identifying the underlying asset and its current price, the volatility in its returns and the appropriate discount rate; the exercise price and exercise date is also needed in order to calculate the real option value. While these parameters also pose certain challenges when compared with financial options, the challenges are more easily manageable and no separate approaches have been designed for them. In terms of exercise price, the challenge stems from the fact that the exercise price for a real option is often not in the form of a single amount. In many cases exercising the option leads to a number of outlays over a period of time. Mostly this is assumed to either be an aggregated payment, or each outlay is considered as an option towards the next outlay.

Similar issues need to be considered for exercise dates. Miller and Park (2002) point out a number of ways in which the exercise date of a real option is different from that of a financial option. Since real options are mostly real world projects, the exact exercise date might not be easy to know in advance or contingent upon the resolution of some other source of uncertainty. Another feature that differentiates the exercise date of real options from financial options is the span of time between the payment of the price and its effects. Most real options need considerable time to exercise after the exercise price has been paid, such as constructing a new plant and drilling at a mine, which can increase the uncertainty. Neither exercise price nor exercise date seem to have received much discussion in the literature.

Dividends is a final factor that needs to be considered before a real option valuation can be made, even though they do not form part of the calculation formula themselves. For a financial option, a dividend being paid out on the stock changes the value of the stock and hence the option value – increasing the option value for a put option and decreasing it for a call option. For real options any continuous payments, such as rents, royalties, insurance or maintenance fees, must be considered as a leakage in the value of the asset.

3.3. Real Options and Global Value Chain Models

Operational flexibility in global value chains can best be modeled as switching options. As mentioned previously, a switching option is the option to switch between different input and output configurations or modes of operation. Hence these options find common applications in manufacturing and supply chain contexts. Switching options are considered much more difficult to model than other kind of simple options. This difficulty is introduced due to the presence of switching costs, which are the costs incurred each time that the mode of operation is changed. The result is that the optimal switching policy is path dependent. At each node of the binomial tree, the optimal decision is not based only on the comparison between the costs of the two alternate modes but on a calculation of all optimal switching decisions at future nodes as well (Copeland and Antikarov, 2001). Thus it becomes very difficult to model switching options using lattice models. Kulatilaka and Trigeorgis (2004) demonstrated that in the presence of switching costs it becomes necessary to use stochastic dynamic programming to model switching options.

Stochastic Dynamic Programming models can be seen as an alternative to common methodologies for real options valuation. Kulatilaka (1995) provided a methodology that utilized a stochastic dynamic program to model switching options for a production system that can use different inputs. He further suggested that the same methodology can be used to model all other real option types. However switching options have remained the primary type of option modeled using stochastic dynamic programming (Kulatilaka and Trigeorgis, 2004; Kulatilaka, 1988; Triantis and Hodder, 1990; Kogut and Kulatilaka, 1994; Huchzermeier and Cohen, 1996; Pochard, 2003; Goh et al., 2007) while multiplicative binomial trees are commonly used for almost all other types of real options.

Common models for the real option value of operational flexibility in global value chains are also modeled using stochastic dynamic programming. Operational flexibility in this context is defined as a global firm's ability to co-ordinate its activities within its global value chain network and make the optimal decision with regards to allocation of product or production to different market regions.

Kogut and Kulatilaka (1994) were the first to model this flexibility as a real option to switch production locations. They referred to this as the "option value of multi-nationality". Their model analyzed the case of a firm that can transfer production between two alternate production locations to minimize costs, hence providing the firm with a real option. The value of this option depends on the changes in the exchange rate between the two nodes of the global supply chain network. This model considers the difference between the exchange rates of the two alternate production locations as the only source of uncertainty. The exchange rate process itself is modeled as a mean-reverting diffusion process. The model showed that significant value can be derived by operating plants in two countries by shifting production based on changes in the exchange rate and that the value was related to both the value of the exchange rate and its volatility. If the starting exchange rate was closer to 1, flexibility had greater value as there was a greater chance of change in the optimal production location in future periods. They also demonstrated that in the presence of switching costs, a hysteresis band of inaction develops, in which the firm declines the switching decision due to the probability of reversing this decision in future periods. The width of this band is proportional to the degree of uncertainty and switching costs. Another important observation was that the real option value was in effect a result of excess production capacity in the system.

Huchzermeier and Cohen (1996) provided a dynamic programming hierarchical model for global manufacturing strategy. In the first step, a lattice model is created that simulates future exchange rate movements. Then the available configuration options for the global supply chain network are defined. This model is based on a 3 stage supply chain with 3 location options for each stage. The specific strategic configuration options that are possible are defined beforehand. For each exchange rate scenario, each of the configuration is solved as a linear program. Once each strategic configuration has been solved for each of the possible exchange rate scenarios in the lattice model, these values are used as inputs for a multi-period stochastic dynamic programming formulation to determine the after-tax profit or loss for each possible configuration. This allows the computation of the real option value of operational flexibility as the difference between the base case profit with no switching allowed and the case where switching between configurations options is allowed during the planning horizon.

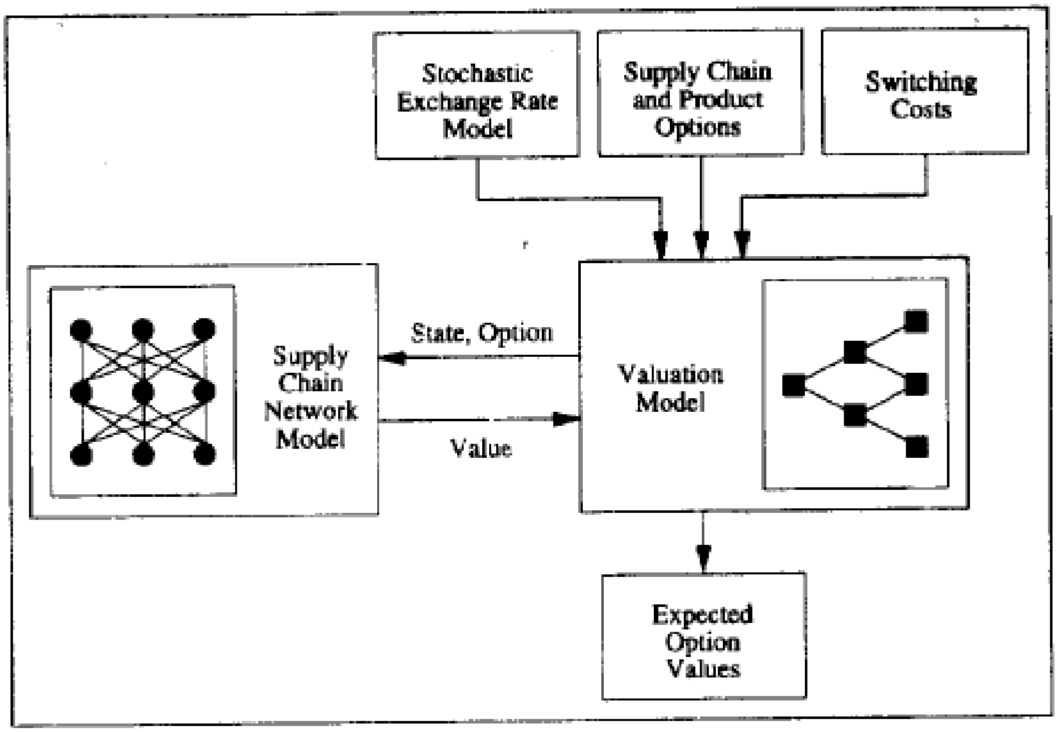


Figure 3: Modeling Framework from Huchzermeier and Cohen (1996)

This is a vastly expanded model that allows different configurations in terms of sources of supply, plant capacities, different product to market allocations and supply linkages within the global supply chain network. This model also considered exchange rate volatility as the only source of uncertainty and is modeled using a multinomial approximation model. The exchange rate between countries is modeled as following a geometric Brownian motion. The results again showed significant benefits from operational flexibility as well as hedging effects. The same model was extended to capture the uncertainty in demand using a stochastic scenario formulation in a later work (Cohen and Huchzermeier, 1999). A Harvard case study (Flaherty, 1985) was used to demonstrate how excess capacity can be justified when the network is analyzed considering real option values even when a deterministic analysis was suggesting significant reduction in the existing capacity.

These dynamic programming models provide a powerful means to model the value of operational and managerial flexibility inherent in global value chains. However the models also present a high level of complexity for managers and decision makers. The assumptions in the models are opaque and require familiarity with both stochastic dynamic programming principles as well as multiplicative lattice models. They are also restrictive in terms of the sources of uncertainty that can be considered together. This is a major hurdle when positioning real options analysis as an alternative or even a complement to traditional DCF methods. DCF methods use simplistic mathematics that is easy to follow and can be easily manipulated to provide valuations for different scenarios. Furthermore the two methodologies are so vastly different that it is difficult to use them to complement the insight gained from each other.

3.4. Designing a new modeling approach

The discussion on the different modeling and methodological challenges faced in translating financial option valuation methodology towards real options is important in understanding the consistent criticisms that are raised against it and the difficulties in its wider adoption. It is difficult for most common practitioners to grasp the assumptions of the models let alone understand their consequences towards valuations. While Stochastic Differential Equations are particularly complicated for practitioners even simpler methods such as binomial lattice models are relatively unknown outside corporate finance. Thomas Copeland and Vladimir Antikarov have been two of the foremost champions of real options valuations as an alternative to NPV. However by their own admission “The academic literature about real options contains what, from a practitioner’s point of view, is some of the most outrageously obscure mathematics anywhere in finance. Who knows whether the conclusions are right?” (Copeland and Antikarov, 2005).

In the next chapter we will present a capacity planning problem for firm with a global value chain and propose a new modeling approach that uses Monte Carlo Simulation to calculate the real option value of operational flexibility. Our suggested modeling approach is based on three key conclusions from the discussion in the preceding chapters.

Firstly, a more simplified approach appears to be necessary in order for more practitioners to benefit from the insights that real options can provide for project valuations in global value chains. We have already discussed how there is no single best fit methodology for all cases. For most option types, lattice models provide the easiest solution but they are not suitable for all applications. Switching options with multiple uncertainties in particular are difficult to model using lattice models. A less mathematically rigorous methodology that uses concepts already familiar to practitioners while also being able to incorporate decision making flexibility can add significantly to the valuation process.

Secondly, the underlying assumptions should be easier to follow. Dynamic programming models, stochastic differential equations and even lattice based models can appear as black box solutions for most practitioners. While all these methods can provide valuations for a wide range of real options, the actual methodology through which they arrive at those numbers are not easy to understand. This is important since the prescriptions from real options based thinking are often in favor of taking more risky projects with greater volatility in parameters. Without a better understanding of the methodology, it is difficult to convince executives to act against the basic business aim of minimizing risk.

Thirdly, our proposed approach is based on the conclusion that using a real options framework can itself have an impact on investment decisions and managerial outlook without relying on any of the valuation methodologies. Utilizing real options as a decision support tool to guide investment decisions is a viable first step towards a better understanding of operational flexibility. In this regard, the insight from real options thinking is more important than the exact valuation itself. As Luehrman (1998b) suggested, the benefit of real options is in providing financial foundations for strategic decisions at an earlier stage.

With these key conclusions, the basis of our proposed methodology is to forego the translation of different problems into the same fixed lattice models or differential equations. Instead we suggest reformulating the decision process of the firm for the specific context being considered while explicitly incorporating the flexibility available to managers in a standard NPV framework and using Monte Carlo simulation to add uncertainty in parameters. Somewhat similar methods have been used to model certain supply chain risk management strategies as real options (Carbonara et al., 2014; Constantino and Pelligrino, 2010).

4. Modeling capacity expansion in a Global Value Chain

We will use a capacity expansion decision in a global value chain to demonstrate our approach. In the literature review we showed that the ability of a firm to co-ordinate its activities within its global network provides the firm with added value in terms of flexibility to respond towards environmental volatility. This flexibility is akin to owning a real option as the firm gains the right, without the obligation, to use this flexibility. In the following case, investment in excess capacity in any region beyond its local demand provides the firm with flexibility with regards to its distribution decisions. The firm can choose to use the extra capacity to fulfill demand in other regions without the obligation to do so. The model will be used to demonstrate the effect that analyzing the decision process as a real option can have on the final valuation. As a comparison, we will setup a model with no uncertainty, using deterministic inputs. This will allow us to demonstrate the effect that considering this decision as a real option can have on decision making by comparing the value of flexibility in a deterministic versus stochastic setting. We will develop the real options based model in subsection 4.1 and the deterministic model in subsection 4.2.

Consider a firm that is marketing and selling a single generic product in three different market regions. Manufacturing plants are operated in two of these regions while the firm has a policy to use the excess capacity, after local demand is fulfilled, in its largest plant to supply the remaining region. The firm follows this as a fixed policy without considering the profitability of the link hence its current distribution schedule is not optimized. We designate the region without a plant as Region A and the regions with existing plants as Region B and Region C. The initial network configuration for the firm is shown in Figure 4. The firm anticipates that growing demand in all three regions over the next 6 periods, particularly in Region A, will require additional capacity. The firm has decided to add additional capacity in exactly one of the three regions.

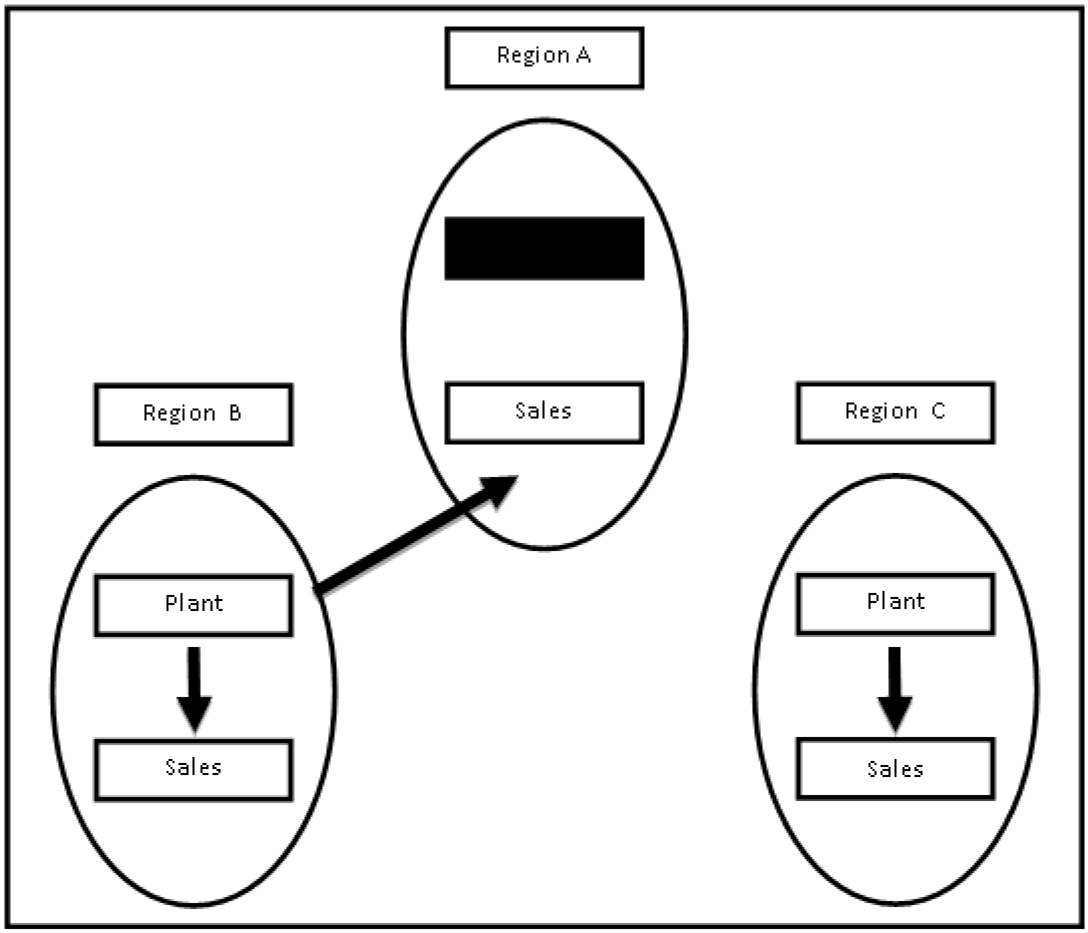


Figure 4: Initial network configuration

There are two parts to the decision facing the firm. Firstly it needs to decide which region would be the best for the additional investment in capacity. We designate each of these choices as the three possible projects. Project 1 is an investment in Region A, Project 2 an investment in Region B and Project 3 an investment in Region C. The second decision relates to the additional capacity being added. The firm will make this decision based on the profitability of each of the three projects at different levels of capacity.

Traditionally the profitability of a specific project is evaluated using the Net Present Value method. The NPV method calculates the profit for each period in the planning horizon and then discounts them to the present using a given discount rate. The initial cost of investment is then subtracted from the profits to calculate the Net Present Value.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - I$$

Here C_t refers to the net cash flow in period t. I is the initial investment. r is the discount rate. We consider it to be the WACC (Weighted Average Cost of Capital) for the firm taken as 10%. In the proposed model we will use a real options framework to calculate the net cash flow accruing from the different projects. In the next subsection we will present the profit function for the firm and the methodology used to model the firm's decision as a real option.

4.1. Real Option Model of Operational Flexibility

The firm's profit function is fairly complex. Each region has its own selling price, production cost, duties and tax rates that change over time. The model does not consider the exchange rates between the different regions instead all prices and costs are expressed in a single numeraire currency. Consider that the index of supply regions is i and the index of market regions is j while t denotes the time period. $PRICE_{j,t}$ denotes the selling price in region j for period t.The total production cost comprises two components: a region dependent component (referred to as $PRODUCTION\ COST_{i,t}$ and reflective of regional factors such as labor cost) that differs for each region and a raw material dependent component ($RAW\ MATERIAL\ COST_t$) that is the same across all regions but changes over time. The distribution costs ($DISTRIBUTION\ COST_{i,j}$) depends on whether the product is being shipped within the region of its production or to a different region while staying constant over time. Each region has a different tax rate ($TAX_{j,t}$) and import duty ($DUTY_{j,t}$) that are expressed as percentages. The import duty is assumed to be the same for imports into a specific region and not dependent on where the imports originate from. The tax rate charged is based on the region where the sales are being made. The profit function $PROFIT_{i,j,t}$ for a single shipped product shipped between a plant and market in period t is given by:

$$PROFIT_{i,j,t} = \left(1 - TAX_{j,t}\right)[PRICE_{j,t} - \{\left(1 + DUTY_{j,t}\right)\left(PRODUCTION\ COST_{i,t} + RAW\ MATERIAL\ COST_t\right) + DISTRIBUTION\ COST_{i,j}\}] \quad (1)$$

One of the ways in which a global value chain benefits firms operating across countries with different tax rates is through utilizing transfer pricing to optimize profits. Theoretically a firm, shipping products from one location to another can show profits in whichever of the two locations has a lower tax rate by using the appropriate transfer price, thus minimizing its tax burden. In practice this is subject to a number of international laws and legal constraints. In our model, we assume that the firm has a choice to lower its tax burden using transfer pricing. If TAX_i refers to the corporate tax rate in the region where the plant is based and TAX_j refers to the tax rate in the region where the sale is made, then our modified profit function is provided by:

$$PROFIT_{i,j,t} = \left[1 - \min(TAX_{j,t}\ ,\ TAX_{i,t})\right][PRICE_{j,t} - \{\left(1 + DUTY_{j,t}\right)\left(PRODUCTION\ COST_{i,t} + RAW\ MATERIAL\ COST_t\right) + DISTRIBUTION\ COST_{i,j}\}] \quad (2)$$

The firm expects that the demand in each region, the selling price and production cost will change in each of the subsequent periods. The firm has forecast a trend for these changes but the exact values are uncertain. Specifically, the firm forecasts that demand, prices and production costs will all follow a general upward trend with an estimated mean growth rate. The actual growth rate is modeled as a normally distributed random variable.

Stochasticity of these parameters is achieved by modeling the annual growth rates for demand, prices and costs as a normally distributed random variable. Thus, the actual value of the selling price in a period would be given by:

$$PRICE_{j,t} = PRICE_{j,t-1} + \left(GROWTH\ RATE_j\right) * (PRICE_{j,t-1}) \quad (3)$$

Here the term $GROWTH\ RATE_j$ is a normally distributed random variable whose value depends on the forecasted mean growth rate for prices in region j and its the co-efficient of variation.

Our model works in three steps. First we setup a Monte Carlo simulation that picks random values for the different parameters based on the starting values and the given distribution. In each trial of the simulation, a set of values are selected for all the stochastic parameters in each of the periods. Based on the realization of these values, the profit function is calculated for every possible demand region – supply region link. In the next step, the profits for the different links are compared using a hierarchy-based decision logic, based on certain simplifying assumptions, to make the final distribution decision. Lastly the profits for the distribution schedule in each period is totaled and discounted to the present to provide a final value for the project being considered.

4.1.1. Hierarchy-based decision logic

The hierarchy-based decision logic to compare the profits on each demand region-supply region link and make distribution decisions is given in Figure 5. This figure indicates the way the supply from region *i* to region *j* is calculated. In this calculation, region *i* is the region with the expanded plant, while regions *j* and *k* are the two possible markets where the products can be shipped. The process is based on a few simplifying assumptions.

Firstly, only the supply from the expanded plant, or in other words the project under consideration, is considered to be contributing towards the operational flexibility of the network. Thus the decision process given in Figure 5 is used only when making distribution decisions from the plant being expanded. Other plants are used only to fulfill local demand. This is a major simplification and significantly limits the degree of flexibility in the network. However it can be justified since expansion is being considered due to capacity limits on the existing network. The expanded capacity is meant to fulfill the growing demand and it makes sense to use only the expanded capacity for this purpose.

The second simplification concerns the local region of the plant where additional capacity is being added. The model always prefers to fulfill local demand before making a decision regarding shipping to foreign markets. Theoretically this implies that even in cases where it is more profitable to ship to a foreign market than fulfilling local demand, the firm will choose the less optimal decision to first fulfill all the demand in the local market and only decide to ship the excess capacity left to foreign markets. This simplification reflects a service priority set by management to first satisfy local demand.

Thus, the distribution decision is greatly simplified. It becomes a decision between choosing two shipment options originating from the region where the capacity expansion is being added. After local demand is fulfilled, the decision process determines if excess capacity remains and which region to ship it first. The basis of these decisions are the link specific profits that have been calculated already.

Thirdly we assume that the firm incurs no switching cost each time it switches from supplying on one link to another. All extra costs incurred to allow this switching are incurred at the start as a form of setup costs and no extra costs are associated with the individual decision to switch in each succeeding period.

For each project the capacity level is decided ex-ante while the ex-post decision is regarding the best distribution flow contingent on the realization of demand, price and cost scenarios. The model determines the logistics distribution schedule for each period and calculates the after-tax profits. Since we assume that there are no switching costs to switch between different distributions strategies, the sum of annual profits provides the global after-tax profits for the firm. The model is solved for different capacity levels in each project.

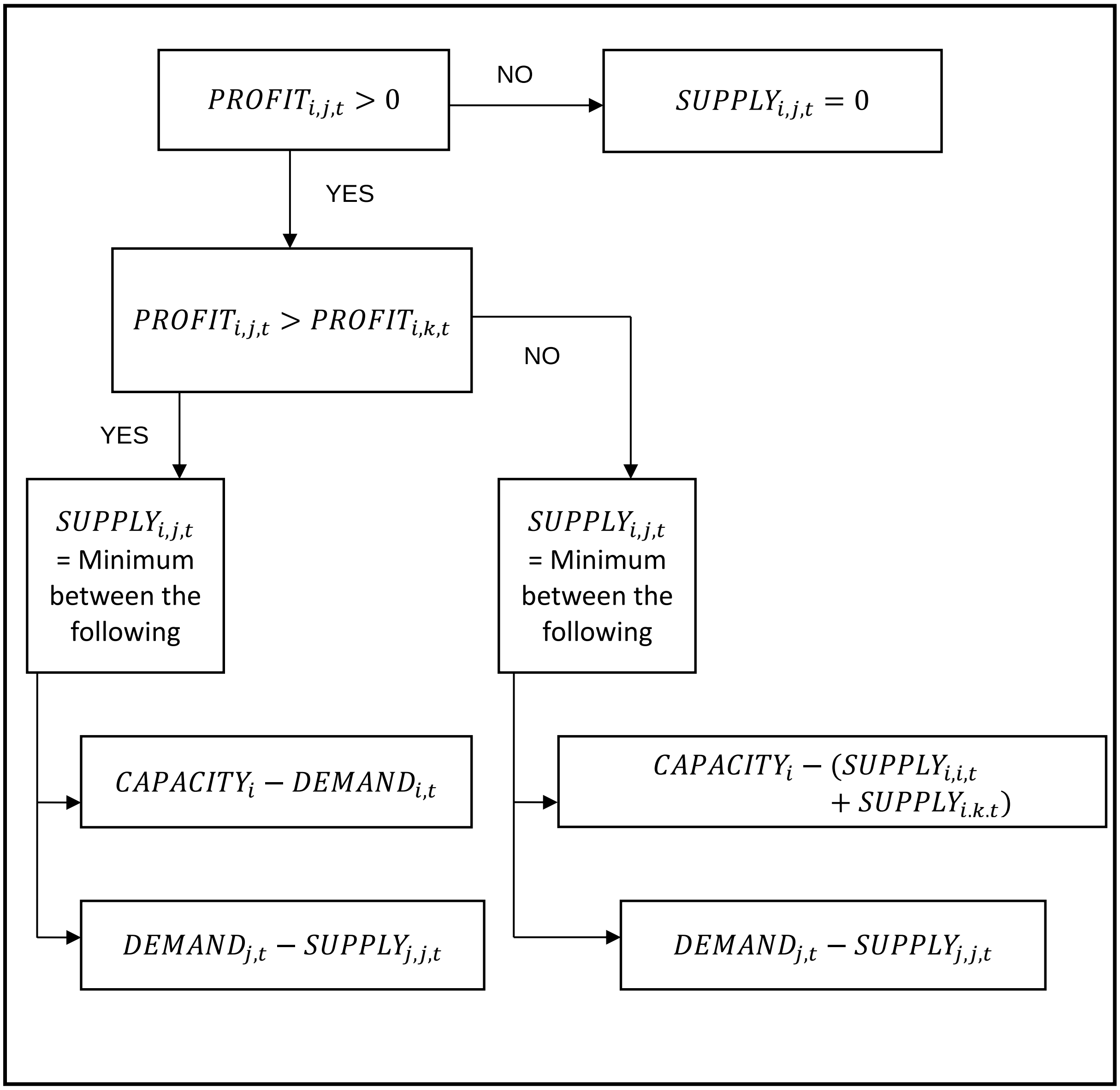


Figure 5: Decision Process to determine the shipping quantity from region i to region j

For each project, the Net Present Value is calculated at different capacity levels. This value of NPV is the expanded NPV that takes into account both the passive NPV and the value of operational flexibility. The relationship is given as follows (Trigeorgis, 1996):

Expanded (or strategic) NPV = passive NPV + Option Premium (ROV) (Flexibility value) (4)

The extra value above the passive NPV as provided by the model is the flexibility value component of the option premium. In addition we will also calculate a passive NPV for each trial of the simulation and compare the values with the expanded NPV. The passive NPV in this case is the NPV calculated using a fixed policy without considering flexibility. A fixed policy is one where the distribution decision is taken in advance without consideration of the absolute or relative profitability of the link. Since there can be more than one fixed policies we will denote the passive NPV with the specific fixed policy that it relates to.

Owning the real option of operational flexibility also provides the firm with some strategic value that is more difficult to quantify. Some of this strategic value is provided by limiting the risk faced by the firm or minimizing the uncertainty in profits or by providing it future opportunities to grow. Ideally the strategic value should also be included in the expanded NPV however it is much harder to quantify than the flexibility value. To provide a measure for this we will compare the coefficient of variation for the passive and expanded NPV valuations for each project configuration evaluated.

4.2. Deterministic Model of Operational Flexibility

As mentioned previously we will also present a deterministic model of operational flexibility to present a comparison to the real options model. The deterministic model does not consider the project parameters to be uncertain, rather it will use the mean value for the uncertain parameters. This results in a fixed set of values for the demand, selling prices and costs for every period in the planning horizon. The results of this model will be used to compare the effect of valuing projects using a fixed passive policy against a valuation that determines the optimal distribution schedule in each period using a linear program. For this purpose we adapt the model provided by Huchzermeier (2005).

$$\max \sum_{i=1}^{m} \sum_{j=1}^{n} \left[1 - \min\left(TAX_i\ ,\ TAX_j\right)\right]\left[PRICE_j - \{\left(1 + DUTY_j\right)(PRODUCTION\ COST_i + \ RAW\ MATERIAL\ COST_t) + DISTRIBUTION\ COST_{i,j}\}\mathrm{VOL}ij \right. \tag{5}$$

Subject to $\sum_{j=1}^{n} \mathrm{VOL}ij \leq \ \mathrm{CAPACITY}i \qquad i = 1 \ldots m$

$\sum_{i=1}^{m} \mathrm{VOL}ij \leq \ \mathrm{DEMAND}j \qquad j = 1 \ldots n$

$\mathrm{VOL}ij \ \geq 0 \qquad i = 1 \ldots m, j = 1 \ldots n$

The model considers a firm with *m* plants, denoted by the index *i*, serving *n* market regions, denoted by the index *j*. $\mathrm{DEMAND}j$ refers to the demand in market region j and $\mathrm{CAPACITY}i$ refers to the capacity of the plan in region i. The decision variable for the model is the flow of products from a specific plant to a specific market region denoted by VOL*ij.* The model optimizes the profit to the firm by deciding the quantity of products flowing on each plant – market link in a given period. The constraints in this model ensure that production in each plant is never more than the capacity of the plant, the shipped volumes to each region are never more than the demand for that period and all shipped volumes are non-negative. The solution to the above LP provides a distribution schedule that maximizes the firm's profits for a single period.

This model provides a single period optimized logistics distribution schedule for a firm operating across a number of regions. If the price, cost, tax rates and duties are known in advance, the model can be solved for a number of different periods. If we assume that there are no switching costs incurred when the firm switches between different distribution configurations then the discounted sum of these annual profits provides a net present value for the network as a whole.

$$NPV = \ \sum_{t=1}^{T} \frac{LP_t}{(1+r)^t} - I \tag{6}$$

Here LP_t refers to the profits obtained by solving the linear program (4) for period t. I is the initial investment. This model can be solved for different configurations of the global value chain, in terms of the plants to keep open and the capacity to maintain in each. It is important to note here that this model allows a greater degree of flexibility than the real options model we have formulated since the firm can use any plant to deliver to any regions in all periods instead of flexibility in just the expanded plant.

5. Results and Analysis

The firm has made forecasts for demand, market price and cost parameters based on their current values and the historic trend. The firm predicts that demand, production costs and prices will follow an increasing trend for each region in the next 6 periods. A single period is equal to a year. This is modeled using an annualized growth rate for each parameter-region combination. There is uncertainty regarding the exact growth rates though the mean values of growth can be predicted. Actual annual growth rates are predicted to represent a normal distribution around these mean values. Using the mean growth rates, deterministic values for the demand, costs and price over the planning horizon can be calculated. Table 6 lists the forecasted deterministic demand, Table 7 lists the forecasted deterministic production and raw material costs while Table 8 lists the forecasted deterministic prices and the associated growth rates for each region respectively. The firm does not expect the raw material costs to grow over the next 6 periods but to fluctuate around the current values. Hence its deterministic value is modeled as being constant. The tax rates, import duties and distribution costs are assumed to stay constant throughout the planning horizon and are listed in Table 9 and Table 10.

Demand							
Regions	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**	**Growth Rate**
Region A	850,000	1,020,000	1,224,000	1,468,800	1,762,560	2,115,072	20%
Region B	2,000,000	2,100,000	2,205,000	2,315,250	2,431,013	2,552,563	5%
Region C	1,125,000	1,293,750	1,487,813	1,710,984	1,967,632	2,262,777	15%

Table 6: Forecasted demand by region

Production Cost							
Regions	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**	**Growth Rate**
Region A	$ 3	$ 3.1	$ 3.2	$ 3.4	$ 3.5	$ 3.6	4%
Region B	$ 4.5	$ 4.6	$ 4.7	$ 4.8	$ 4.9	$ 5.0	2%
Region C	$ 3.5	$ 3.6	$ 3.7	$ 3.8	$ 3.9	$ 4.1	3%
Raw Material Cost							
	$ 5.5	$ 5.5	$ 5.5	$ 5.5	$ 5.5	$ 5.5	0%

Table 7: Forecasted production and raw material cost by region

Selling Price							
Regions	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**	**Growth Rate**
Region A	$ 10.00	$ 10.30	$ 10.61	$ 10.93	$ 11.26	$ 11.59	3.0%
Region B	$ 11.50	$ 11.62	$ 11.73	$ 11.85	$ 11.97	$ 12.09	1.0%
Region C	$ 10.25	$ 10.51	$ 10.77	$ 11.04	$ 11.31	$ 11.60	2.5%

Table 8: Forecasted selling prices by region

Regions	**Duties**	**Tax Rate**
Region A	5%	20%
Region B	15%	35%
Region A	10%	30%

Table 9: Duty and Tax rates by region

Unit Distribution Costs	
Same region	$ 1.00
All other regions	$ 1.50

Table 10: Unit Distribution costs

In addition to the potential profits, the firm must also consider the associated costs of capacity expansion. For the existing plants, capacity costs are a function of the extra number of units added only. Each extra unit of capacity has a fixed and known cost. For the new plant capacity costs have a variable component based on the number of units as well as a fixed component that must be spent regardless of the amount of new capacity being added. Table 11 lists the existing capacity in each region, the fixed costs of additional capacity and the variable or per unit cost of additional capacity.

Capacity			
Regions	**Existing Capacity**	**Fixed Cost**	**Variable Cost/unit**
Region A	0	$ 2,500,000.00	$1.00
Region B	2,100,000	$ -	$3.00
Region C	1,200,000	$ -	$1.50

Table 11: Existing capacity and costs of additional capacity by region

The deterministic model uses these exact values to calculate an optimized logistics schedule for each period. The real options model considers the growth rates to be stochastic, hence the exact values are calculated by running a Monte Carlo simulation. For each project, the Net Present Value is calculated at different capacity levels. The capacity levels are considered in jumps of 100,000 units for the sake of convenience. In the next sections we will list only the results for the capacity levels that provide overall insights for the investment decision. For all projects we will list the results for the case where no new capacity is added and the cases with the highest NPV. A few other capacity levels will also be provided for comparison.

5.1. Deterministic Model Results

We begin by providing the results of the deterministic model. For each project and at every capacity level we calculate passive NPV using a fixed policy, the expanded NPV using the model provided in subsection 4.2 and the flexibility value as the difference between the two valuations.

a. Project 1: Add new capacity in Region A

Project 1 considers adding a plant in Region A. The passive case considers using the capacity in each region to fulfill only local demand. Hence this is a case with no flexibility. The expanded NPV considers using the extra capacity to add to the overall operational flexibility of the network using all possible links in the network. Hence this is a case with full flexibility. Table 12 lists down the passive NPV, expanded NPV, flexibility value and the flexibility value as a percentage of the expanded NPV.

Capacity	Passive NPV (No Flexibility)	Expanded NPV (Full Flexibility)	Flexibility Value	Flexibility Value as percentage of Expanded NPV
No Investment	$5,429,122.32	$5,429,122.32	$0.00	0.0%
1,400,000	$5,516,156.70	$5,527,177.68	$11,020.98	0.2%
1,600,000	$5,609,774.58	$5,631,024.21	$21,249.63	0.4%
1,700,000	$5,636,796.83	$5,664,599.18	$27,802.35	0.5%
1,800,000	$5,640,655.24	$5,670,427.74	$29,772.50	0.5%
1,900,000	$5,605,808.26	$5,640,842.90	$35,034.64	0.6%

Table 12: Passive and Expanded NPV for Deterministic Project 1

b. Project 2: Add new capacity in Region B

Project 2 considers adding extra capacity in Region B. Two passive cases are modeled. The first considers a fixed policy of using all the capacity left over after fulfilling local demand to be shipped to Region A. This considers a single degree of flexibility. The second case considers using all available to fulfill only local demand. This would result in abandoning Region A and is used as a comparison to check if only the increase in local demand in enough to justify capacity expansion. The results are provided in Table 13.

Extra Capacity	Passive NPV 1 (1 degree of flexibility)	Passive NPV 2 (No flexibility)	Expanded NPV
No Investment	$5,247,304.14	$5,429,122.32	$5,429,122.32
100,000	$4,716,186.61	$5,228,128.76	$5,228,128.76
200,000	$4,046,675.46	$5,001,648.83	$5,001,648.83

Table 13: Passive and Expanded NPV for Deterministic Project 2

c. Project 3: Add new capacity in Region C

Project 3 considers adding extra capacity in Region C. Again two passive cases are modeled. The first considers a fixed policy of using all the capacity left over after fulfilling local demand to be shipped to Region A. This considers a single degree of flexibility. The second case considers using all available to fulfill only local demand. This would result in abandoning Region A and is used as a comparison to check if only the increase local demand in enough to justify capacity expansion. The results are provided in Table 14.

Extra Capacity	Passive NPV 1 (1 degree of flexibility)	Passive NPV 2 (No flexibility)	Expanded NPV
No Investment	$5,364,349.60	$5,429,122.32	$5,429,122.32
100,000	$5,288,262.30	$5,443,325.58	$5,443,325.58
200,000	$5,131,509.33	$5,435,766.82	$5,435,766.82

Table 14: Passive and Expanded NPV for Deterministic Project 3

5.2. Analysis of Deterministic Model Results

Based on the results of the model we can observe a few key conclusions. Firstly, the firm’s current strategy of using excess capacity in Region B to fulfill demand in Region A is sub-optimal. If the firm chooses to make no new investment, it would be optimal to abandon Region A rather than fulfilling its demand from another Region. This is because on a per unit basis shipping products from Region B or Region C results in a negative value for the profit function. Each unit shipped actually increases the losses for the firm. Thus the expanded NPV provides the same value as the No-flexibility case of passive NPV. There is no flexibility value to be gained from investing in capacity expansion in either Region B or Region C. Additionally we observe that for Project 2, even the No-flexibility passive NPV is decreasing with increases in the capacity for this region. The project to install extra capacity in Region B cannot be justified at any capacity level. In contrast to this, the No-flexibility passive NPV has the highest value for Project 3 at an additional capacity of 100,000 units. Hence there is enough extra local demand to justify an expansion of 100,000 units at Region C to serve the local market only.

The best project to undertake across all considered capacity levels for all the projects is a new plant in Region A with a capacity level of 1,800,000 units. The local demand in Region A is not forecasted to reach this level until period 6, hence Project 1 will have excess capacity to allocate flexibly to other regions for 5 periods. However the benefit of this flexibility is limited. The Expanded NPV is not significantly larger than the passive NPV at any capacity level as shown in Table 12. The flexibility value is only 0.5% of the expanded NPV. Figure 6 compares the passive NPV and expanded NPV valuations for different capacity levels. It can be observed that as capacity levels rise the flexibility value, seen as the gap between the passive and expanded NPV valuations, increases but it is not enough to alter the best case project between the passive and expanded valuations.

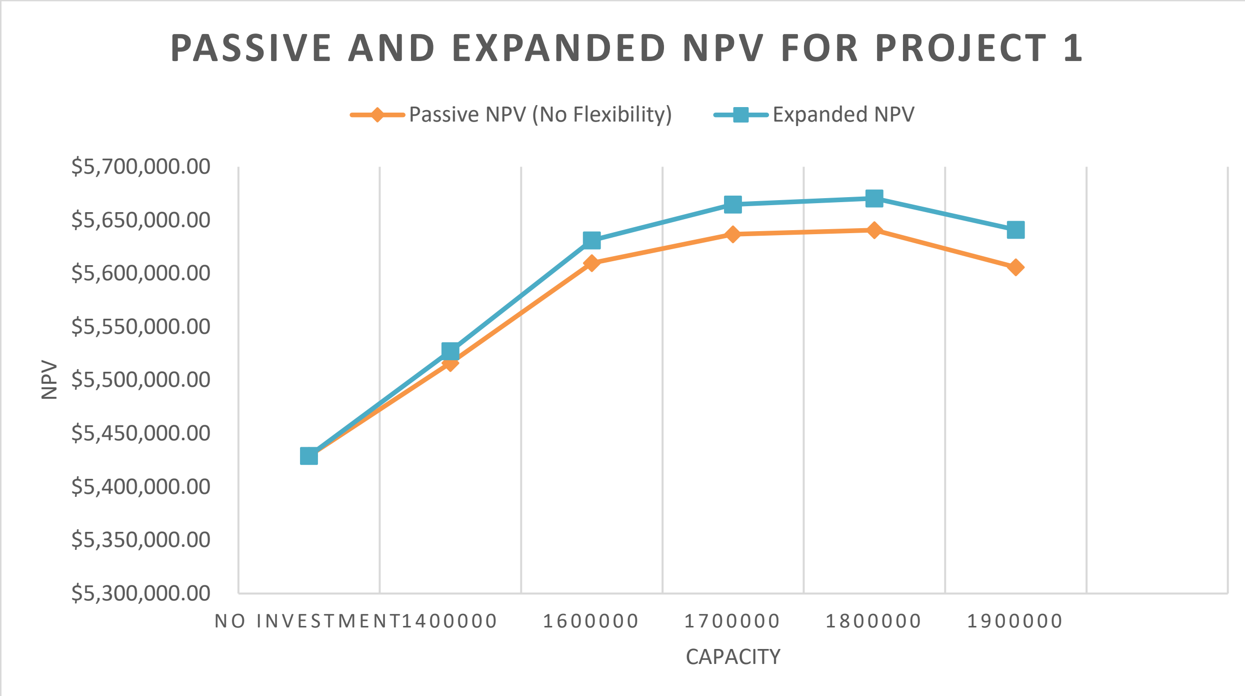


Figure 6: Comparison of Passive and Expanded NPV for Project 1

It is also worth noting that in cases where the extra value gained from flexibility is so low, it might not be worth making the extra investment due to the added managerial complexity. In this case, the firm must build effective co-ordination mechanisms between the different regions as well as designing its supply chain in such a way that decision makers can postpone the distribution decision until the uncertainty regarding market parameters has been resolved. The firm can expect to incur some extra costs, in terms of developing co-ordination mechanisms, in order to exploit the operational flexibility of its global value chain. Regardless of the monetary cost, this can be a difficult process for global firms. Since the upside of operational flexibility is so small these additional costs and efforts will be difficult to justify and the firm might be better served concentrating on passive projects only.

This deterministic valuation provides a basic idea of how considering the overall value of a project to the value chain provides a better indicator of a project's true value. However this perspective does not take into account the effect of uncertainty on the firm. The deterministic valuation shows that for this network it appears that there is limited value of considering flexibility and only one of the three projects considered provide any value from flexibility at all. In the next section we will use the real options model to see the effect of including uncertainty on the valuation.

5.3. Real Options Model Results

Using the steps outlined in section 4.1 we set up a simplified spreadsheet based Monte Carlo simulation model to simulate the effects of this uncertainty and provide a real options valuation for each of the projects. The logic based decisions defined in Figure 5 are modeled using nested "IF" functions in a spreadsheet in Microsoft Excel. The working of the model is explained in greater detail in Appendix B. We use the Analytic Solver Basic add-in for Microsoft Excel by Frontline Solvers to run the Monte Carlo simulations. The simulation runs 5000 trials for each capacity level scenario. The model determines a distribution schedule for each realization of random parameters using calculations explained in Section 4.1.1 and calculates the total profits for the firm across all periods.

The model will take into account stochastic random parameters that have the same mean as the values used in the deterministic model but show variation around that following a normal distribution. Specifically, the growth rates for the demand, selling price and production costs are modeled as a normally distributed random variable with a coefficient of variation of 10%, i.e. the ratio of the standard deviation to the mean is 10%. The raw material costs are also modeled as a normally distributed random variable but the variation is modeled directly using a standard deviation of 5%. The mean growth rates and the standard deviations are listed in Appendix A.

For each project and for every capacity level we will again calculate the passive NPV using a fixed policy, the expanded NPV and the real option value (ROV) as the difference between the two valuations.

a. Project 1: Add new capacity in Region A

For project 1 we are considering opening a new plant in Region A. The passive case uses a fixed policy of fulfilling only local demand in the region of the plant. The expanded case allows the new plant in Region A to use all capacity above local requirements of Region A to be used to supply either Region B, Region C or both. The ROV values are calculated as the difference between the passive and expanded values. Table 15 lists the expected (or mean) values and their standard deviations for the passive NPV, expanded NPV and ROV at different capacity levels for Project 1.

	Passive		**Expanded**		**ROV**
Capacity	**Expected Value**	**Standard deviation**	**Expected Value**	**Standard deviation**	
No Investment	$5,344,165.96	$3,121,519.36	$5,430,304.17	$2,948,898.12	$86,138.21
1,600,000	$5,513,712.82	$4,751,631.62	$5,654,684.37	$4,607,421.45	$140,971.55
1,700,000	$5,534,955.34	$4,796,653.20	$5,691,256.77	$4,674,583.21	$156,301.43
1,800,000	$5,538,288.28	$4,828,252.18	$5,708,998.29	$4,711,526.74	$170,710.01
1,900,000	$5,510,965.08	$4,822,270.51	$5,698,904.69	$4,748,989.46	$187,939.61

Table 15: Monte Carlo Simulation Results for Project 1

Figure 7 displays the distribution of output values as well as a few key measures for the distribution for the passive NPV at the capacity with the highest expected value (1,800,000 units). Figure 8 displays the output curve and key measures for the distribution for the expanded NPV at the same capacity.

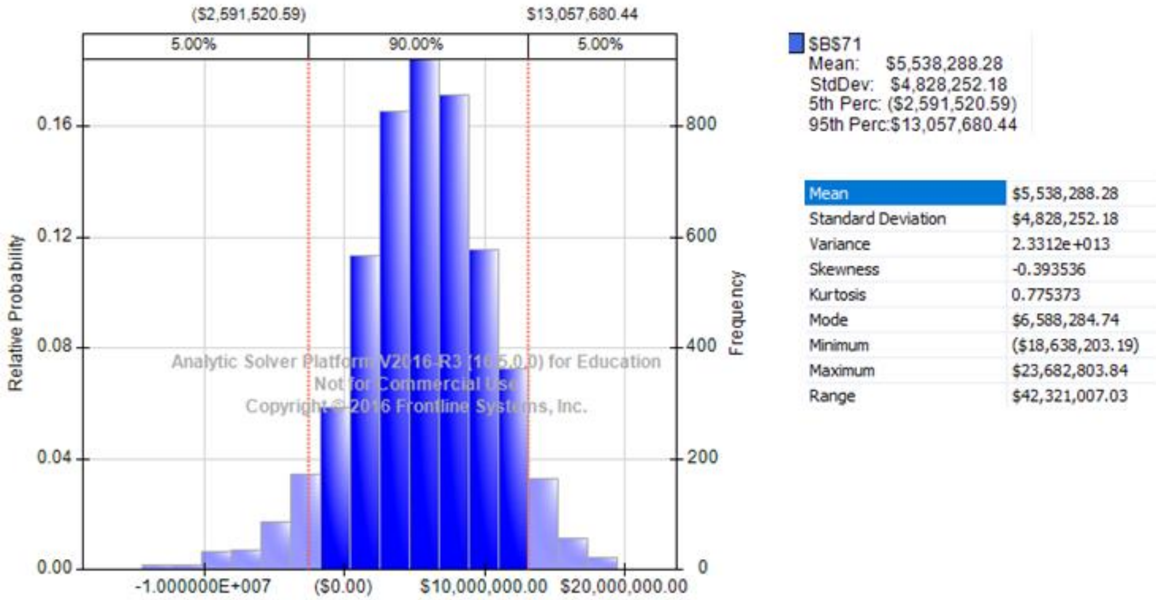


Figure 7: Output curve for passive NPV for best case Project 1 (1,800,000 units)

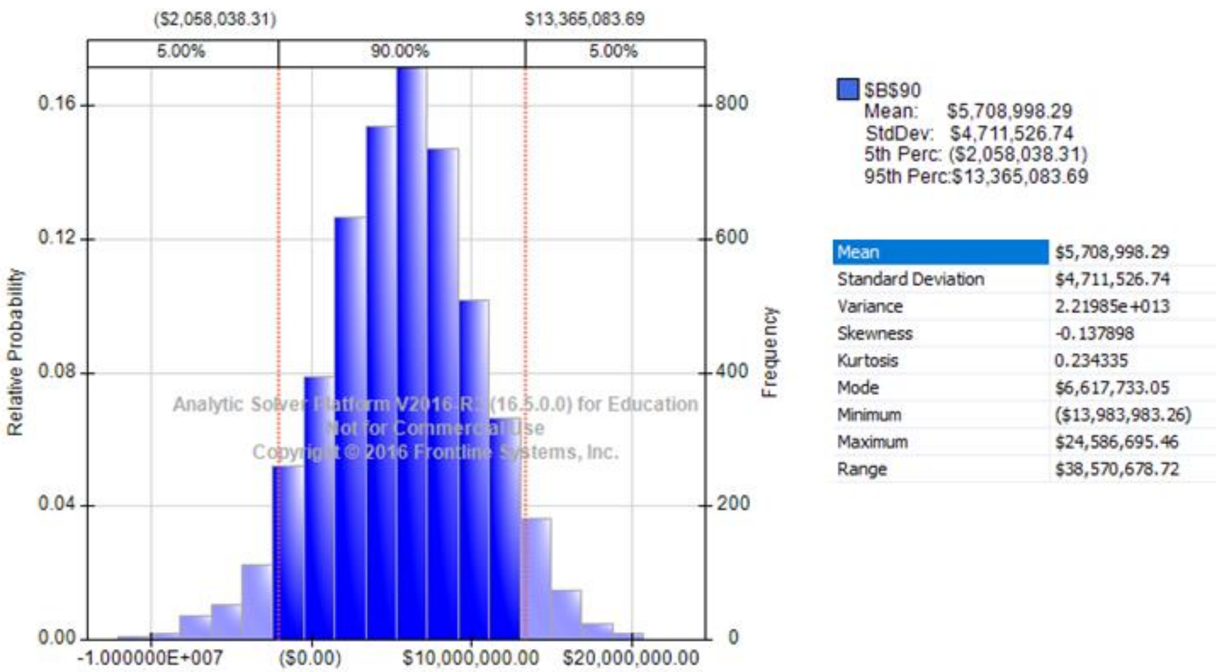


Figure 8: Output curve for expanded NPV for best case Project 1 (1,800,000 units)

b. Project 2: Add new capacity in Region B

Project 2 considers adding extra capacity in Region B. Two passive cases are modeled. The first considers a fixed policy of using all the capacity left over after fulfilling local demand to be shipped to Region A. The policy is followed regardless of profitability. This considers a single degree of flexibility. The second case considers using all available capacity to fulfill only local demand. This would result in abandoning Region A and is used as a comparison to check if only the increase in local demand is enough to justify capacity expansion. The ROV values are calculated as the difference between the more profitable of the two passive cases and expanded values. Table 16 lists the values expected (mean) values for both cased of the passive NPV, expanded NPV and ROV as well as the standard deviations for the passive and expanded NPV.

	Passive NPV 1 (1 degree of flexibility)		Passive NPV 2 (No flexibility)		Expanded NPV		ROV
Extra Capacity	Expected Value	Standard deviation	Expected Value	Standard deviation	Expected Value	Standard deviation	
No Investment	$5,146,462	$3,178,614	$5,334,177	$3,178,172	$5,423,655	$2,999,255	$89,478
100,000	$4,621,409	$3,242,675	$5,137,723	$3,225,363	$5,229,407	$3,037,052	$91,683
200,000	$3,939,327	$3,427,088	$4,896,399	$3,366,625	$4,997,166	$3,161,274	$100,767

Table 16: Monte Carlo Simulation Results for Project 2

c. Project 3: Add new capacity in Region C

Project 3 considers adding extra capacity in Region C. Again two passive cases are modeled. The first considers a fixed policy of using all the capacity left over after fulfilling local demand to be shipped to Region A. This considers a single degree of flexibility. The second case considers using all available capacity to fulfill only local demand and would result in abandoning Region A. The ROV values are calculated as the difference between the more profitable of the two passive cases and expanded values. Table 17 lists the values expected (mean) values for both cased of the passive NPV, expanded NPV and ROV as well as the standard deviations for the passive and expanded NPV.

	Passive NPV 1 (1 degree of flexibility)		**Passive NPV 2 (No flexibility)**		**Expanded NPV**		**ROV**
Extra Capacity	**Expected Value**	**Standard deviation**	**Expected Value**	**Standard deviation**	**Expected Value**	**Standard deviation**	
No Investment	$5,279,390	$3,133,479	$5,344,163	$3,133,479	$5,428,506	$2,969,292	$84,343
100,000	$5,203,178	$3,205,304	$5,360,781	$3,203,734	$5,443,800	$3,038,910	$83,019
200,000	$5,034,350	$3,376,061	$5,338,566	$3,358,496	$5,433,528	$3,163,233	$94,961
300,000	$4,868,568	$3,457,419	$5,329,473	$3,419,324	$5,421,667	$3,235,000	$92,193

Table 17: Monte Carlo Simulation Results for Project 3

5.4. Analysis of Real Options Model Results

The Monte Carlo simulation based real option model does not change the basic prescriptions for each project from the deterministic model. The more profitable project is still Project 1 with a capacity level of 1,800,000 units. Project 2 is not feasible at any capacity level and the more profitable configuration for Project 3 is an extra capacity of 100,000 units. However there is significant difference in the valuations for the different projects. Project 1 in particular shows a much higher valuation now than the deterministic model. In the next subsections we analyze the key results of the case. We can also observe in Figure 7 and Figure 8 that it is possible for the firm to have a negative NPV. This means that for certain realizations of costs, demands and selling prices the firm will not be able to recoup its investments in capacity during the 6 year period. Since the results from the deterministic model used mean values, they failed at conveying the possibility of a loss. Thus the real options model provides a more realistic picture of the risks present in the investments being discussed.

5.4.1. Effect on Passive NPV

For passive valuations, introducing uncertainty has the effect of decreasing the expected (mean) values below the values calculated using deterministic parameters. While all the uncertain variables have the same mean values as those used for deterministic valuations, the expected NPV is lower for every level of capacity considered. This suggests deterministic valuations are unable to convey accurately how uncertainty will affect the profitability of the project and consistently underestimate the negatives of passive management. This is because fixed policies mean that the firm will stay committed to a distribution schedule even when it results in losses. As we include uncertainty into our valuation, we see the effect of these downside scenarios on the valuation. However, since the policy is fixed, the potential upside from increased shipments to more regions cannot be captured. This effect of uncertainty on fixed policies cannot be observed through a deterministic valuation and hence the valuation is higher.

Table 18 compares the passive NPV values from the deterministic model with the expected passive NPV values from the Monte Carlo Simulation model for Project 1. The same comparison using only the No-flexibility passive NPVs for Projects 2 and 3 is provided in Table 19.

Capacity	Passive NPV (No Flexibility) - Deterministic	Expected Passive NPV - (Monte Carlo Simulation)
No Investment	$5,429,122.32	$5,344,165.96
1,600,000	$5,609,774.58	$5,513,712.82
1,700,000	$5,636,796.83	$5,534,955.34
1,800,000	$5,640,655.24	$5,538,288.28
1,900,000	$5,605,808.26	$5,510,965.08

Table 18: Comparison of passive NPV for Project 1

	Project 2		Project 3	
Extra Capacity	**Passive NPV – No Flexibility (Deterministic)**	**Expected Passive NPV - (Monte Carlo Simulation)**	**Passive NPV – No Flexibility (Deterministic)**	**Expected Passive NPV - (Monte Carlo Simulation)**
No Investment	$5,429,122.32	$5,334,177	$5,429,122.32	$3,133,479
100,000	$5,228,128.76	$5,137,723	$5,443,325.58	$3,203,734
200,000	$5,001,648.83	$4,896,399	$5,435,766.82	$3,358,496

Table 19: Comparison of passive NPV for Projects 2 and 3

5.4.2. Effect on Expanded NPV

In contrast to the passive NPV valuations, the expected values for the expanded NPV are much closer to their deterministic valuations for all of the three projects. For Project 1 we observe expected expanded valuations from the Monte Carlo Simulation model exceeding the deterministic valuations at higher levels of capacity (Table 20). This is an important result since the Monte Carlo simulation model does not allow the same level of flexibility to the firm as the deterministic model. Despite this, the model provides higher valuations for the expanded NPV. This result reflects the ability of firm managers to better protect against downside risks while at the same time exploiting the increased upside potential from volatility. Analysis of operational flexibility as a real option shows us how uncertainty in the environment can be positive for the firm and recommends larger investments. At the same time we can observe how using mean values of uncertain variables puts an unfair penalty on the valuations.

Capacity	Expanded NPV - Deterministic	Expected Expanded NPV - (Monte Carlo Simulation)
No Investment	$5,429,122.32	$5,430,304.17
1,600,000	$5,631,024.21	$5,654,684.37
1,700,000	$5,664,599.18	$5,691,256.77
1,800,000	$5,670,427.74	$5,708,998.29
1,900,000	$5,640,842.90	$5,698,904.69

Table 20: Comparison of Expanded NPV for Project 1

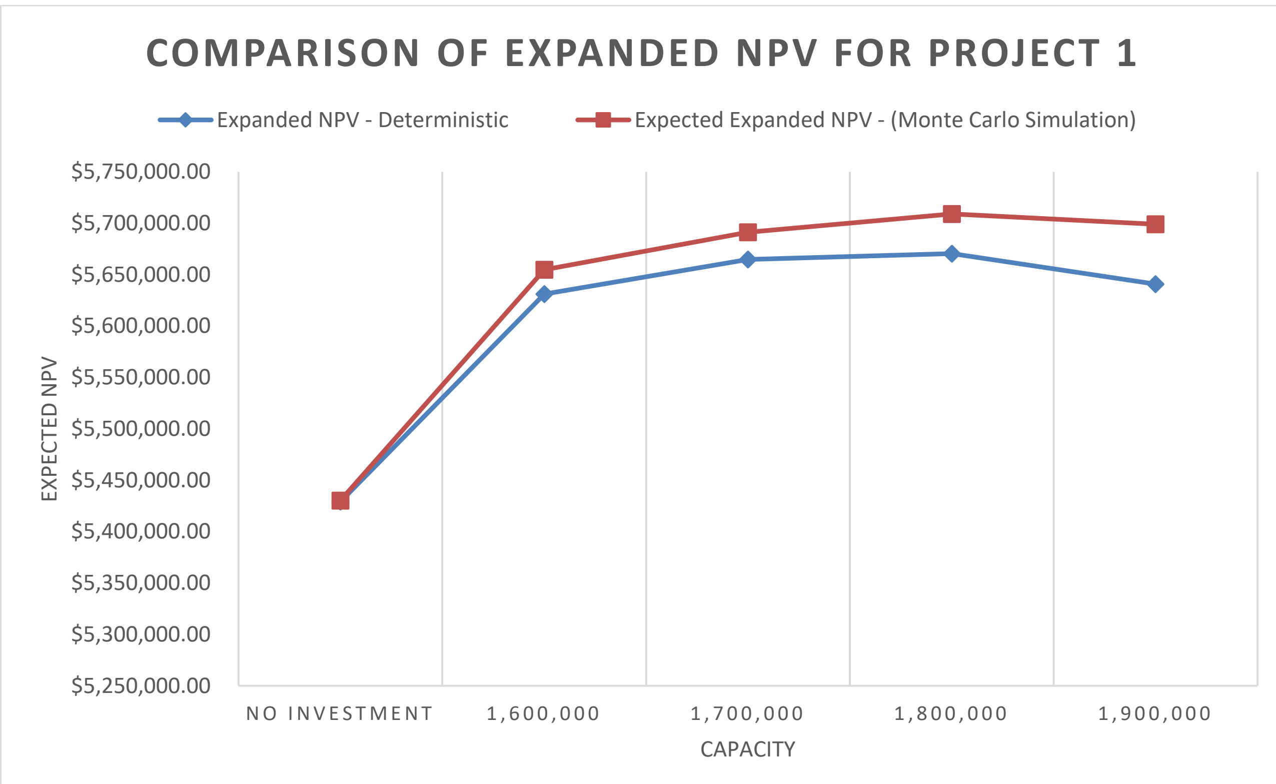


Figure 9: Comparison of Expanded NPV for Project 1

Figure 9 shows the comparison between the deterministic and Monte Carlo simulation model based expanded NPV visually. We can observe that the deterministic expanded NPV curve decreases sharply for values beyond the best case decision of 1,800,000 units. The incremental benefit of every unit of capacity appears to have decreased sharply beyond this point. In contrast the curve for the expected value of expanded NPV does not show the same steep downturn. Every extra unit of capacity beyond the local demand of the plant region increases the ability of the firm to exploit operational flexibility. This effect is reflected in the much slower downturn in NPV for the Monte Carlo simulation model as the firm is able to exploit its larger capacity more effectively.

The dichotomous effect of introducing uncertainty on passive and expanded valuations as compared to the deterministic valuations means that ROV values for the Monte Carlo simulation model are vastly greater than the flexibility values for the deterministic model. The increase is not proportional to the increase in the expected NPV values itself, instead the ROV values are also responsible for a larger proportion of the expanded valuation. This is due to the fact that the Monte Carlo simulation model is better able to capture the benefits of operational flexibility to the firm. Since the flexibility decision is a real option, the firm will choose not to exercise this option when it is not profitable thus limiting downside potential. On the other hand the firm will exercise the flexibility of distribution options when it is beneficial thus increasing the upside potential.

	Deterministic		**Monte Carlo Simulation**	
Capacity	**Flexibility Value**	**Flexibility Value as percentage of Expanded NPV**	**Expected ROV**	**ROV as percentage of Expanded NPV**
No Investment	$0.00	0.0%	$86,138.21	1.6%
1,400,000	$11,020.98	0.2%	$107,330.99	1.9%
1,600,000	$21,249.63	0.4%	$140,971.55	2.5%
1,700,000	$27,802.35	0.5%	$156,301.43	2.7%
1,800,000	$29,772.50	0.5%	$170,710.01	3.0%
1,900,000	$35,034.64	0.6%	$187,939.61	3.3%

Table 21: Comparison of Deterministic Flexibility Value and ROV for Project 1

The ability of firm managers to flexibly decide on distribution decisions is more valuable than what the deterministic model suggested. This means that the firm can justify a larger investment into building the flexible decision making systems and managerial flexibility that will be necessary to exploit the benefits of operational flexibility.

5.4.3. Effect on variation of results

As we discussed in sub-section 2.1.1, one of the principle aims of global firms is to minimize their risk exposure and reduce the effect that environmental uncertainty will have on the firm's profitability. Operational flexibility is supposed to help firms manage risk in a number of different ways. The biggest benefit of operational flexibility is to help firms exploit environmental uncertainty asymmetrically, benefitting more from positive outcomes while managing to reduce the downside effects of negative outcomes. We will discuss this effect in greater detail in the next section. Operational flexibility also reduces the variability in the outcomes for the firm. The variability in outcomes is an important measure of risk for most firms.

In Table 22 we list the expected passive and expanded NPV values for Project 1 from the Monte Carlo Simulation model as well as the standard deviation of these values. We use the coefficient of variation, the ratio between the standard deviation and mean value, as a measure of the variability in results. For every capacity level considered, the coefficient of variation is lower for the expanded NPV than the passive NPV.

	Passive			Expanded		
	Expected value	**Standard Deviation**	**Coefficient of variation**	**Expected Value**	**Standard Deviation**	**Coefficient of variation**
No Investment	$5,344,166	$3,121,519	58%	$5,430,304	$2,948,898	54%
1400000	$5,429,752	$4,551,802	84%	$5,537,083	$4,403,235	80%
1600000	$5,513,713	$4,751,632	86%	$5,654,684	$4,607,421	81%
1700000	$5,534,955	$4,796,653	87%	$5,691,257	$4,674,583	82%
1800000	$5,538,288	$4,828,252	87%	$5,708,998	$4,711,527	83%
1900000	$5,510,965	$4,822,271	88%	$5,698,905	$4,748,989	83%
2000000	$5,479,647	$4,807,355	88%	$5,689,090	$4,743,713	83%

Table 22: Comparison of the variation in passive and expanded NPV for Project 1

5.5. Simulating the effect of increasing volatility

Uncertainty in project parameters have a major impact on the project's value. One of the benefits of the Monte Carlo simulation approach is that it makes it easier to observe the effect of increasing uncertainty on the valuation. We model increased volatility in the market by doubling the coefficient of variation of all parameters from 10% to 20%. This means that there will be twice as much variation in cost, price and demand for each region in each period. The exact values for the changed standard deviations are given in Appendix D.

	Passive			Expanded			
Extra Capacity	Expected NPV	Standard Deviation	Coefficient of Variation	Expected NPV	Standard Deviation	Coefficient of Variation	Expected ROV
No Investment	$4,867,502	$6,923,516	142%	$5,420,057	$5,991,615	111%	$555,978
1,600,000	$4,977,019	$10,136,323	204%	$5,688,213	$9,180,266	161%	$725,860
1,700,000	$5,019,766	$10,115,084	202%	$5,742,694	$9,224,177	161%	$743,014
1,800,000	$4,980,896	$10,374,731	208%	$5,773,866	$9,485,385	164%	$800,516
1,900,000	$4,938,411	$10,502,230	213%	$5,772,927	$9,625,234	167%	$846,037

Table 23: The effect of increased volatility on Passive and Expanded Expected NPV for project 1

	ROV as percentage of Expanded Value		
Extra Capacity	Deterministic	Monte Carlo Simulation at 10% volatility	Monte Carlo Simulation at 20% volatility
No Investment	0.00%	1.60%	10%
1,600,000	0.40%	2.50%	13%
1,700,000	0.50%	2.70%	13%
1,800,000	0.50%	3.00%	14%
1,900,000	0.60%	3.30%	15%

Table 24: Comparison of ROV as percentage of Expanded Value

Table 23 shows the effect of this on the expected NPV for both passive and expanded valuations as well as the coefficient of variation and the expected flexibility value for project 1. Table 24 compares the effect of increasing volatility on the real option value as a percentage of the expanded value. We can observe that the difference between the expanded and passive valuations has increased even further which results in a much larger flexibility value. The importance of operational flexibility in minimizing risk is also greater as the differences in the coefficient of variation for passive and expanded valuations show a much bigger difference.

Figure 12 demonstrates this visually. The most important result of increasing volatility is the contrasting effect on passive and expanded NPVs. The passive NPV at higher volatility is significantly lower for all capacity levels than the passive NPV at lower volatility for the corresponding levels of capacity. The effect on expanded NPV is the opposite. While the passive NPV has fallen significantly below its value at lower volatility for all capacity levels, the effect on expanded NPV is the opposite. Operational flexibility will allow the firm to exploit increased uncertainty positively and increase the NPV beyond those at lower volatility. This positive exploitation of volatility is one of the central benefits of operational flexibility in a global value chain.

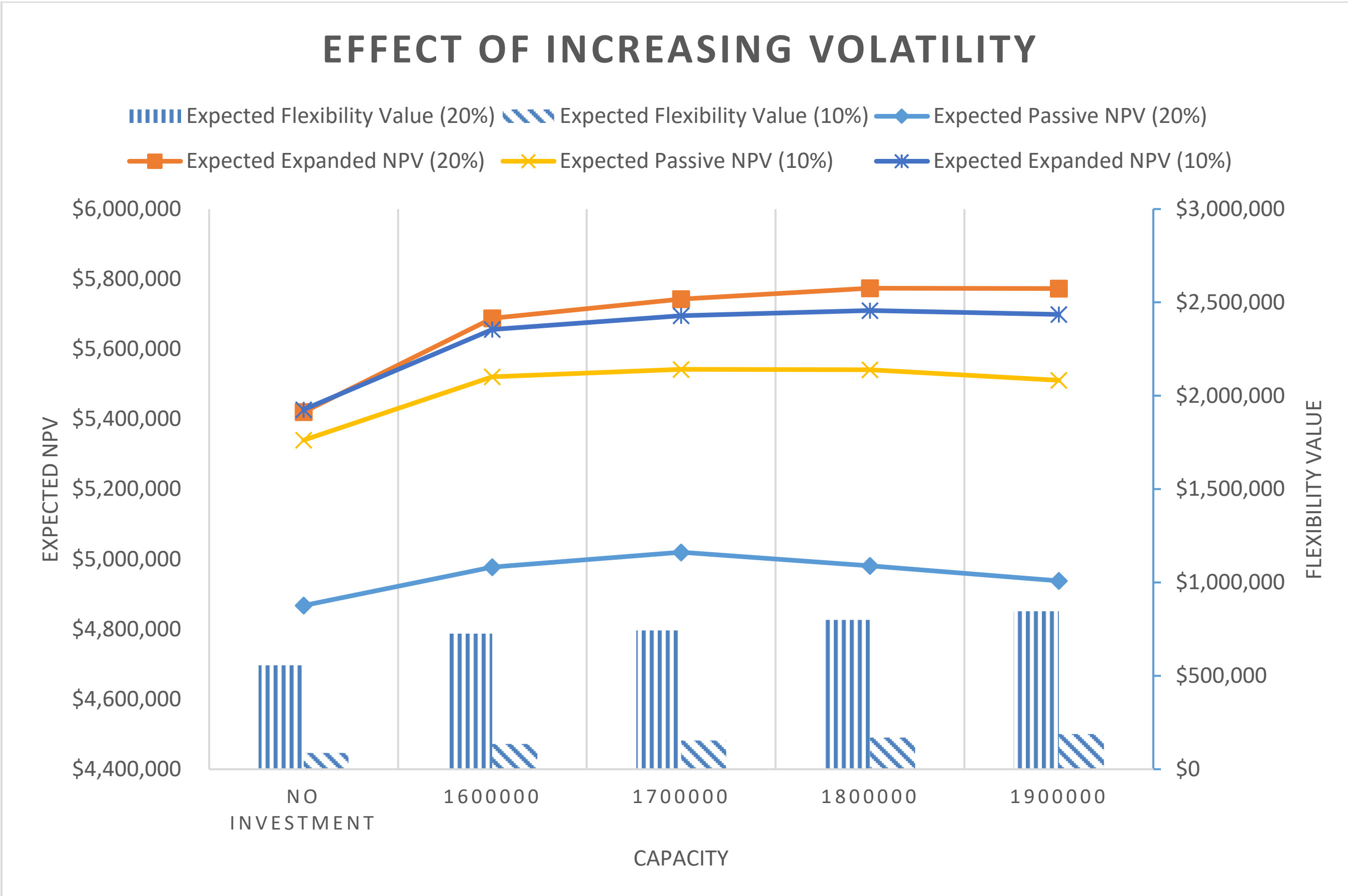


Figure 10: Comparing expected values of Passive NPV, Expanded NPV and Flexibility Values for different volatilities

Expanded NPV valuations shows higher returns than the deterministic valuations for the same capacity levels as we invest in larger capacity. Moreover, increasing volatility in market parameters is shown to be beneficial to flexibile projects. Expanded NPV valuations show that in the presence of greater volatility a project with operational flexibility could capitalize on larger upsides while hedging better against the downside as compared to passive valuations.

5.6. Conclusions from the model

The Monte Carlo simulation based model presented above provides a simplified methodology to value a capacity expansion project in a global value chain using a real options framework that explicitly incorporates the effect of operational flexibility. The model adds to the standard NPV valuation rather than building a completely new methodology. In this sense it acts as a decision support tool for the decision makers in global value chains.

In comparison to common real options methodologies, the model is easy to implement and uses concepts that are already being used for investment valuations. It is also easier to follow the model's working compared to dynamic programming models and understand where the assumptions might differ from an actual scenario. Similar to other methodologies, the accuracy of the model is a function of how accurately the model parameters mimic reality. As such it is recommended that market data on demand, prices and costs be used as much as possible when modeling the behaviour of these parameters. Our model also makes it easier to observe the effect that a change in parameters can have on final valuations. The results of the model also present a few important conclusion with regards to the importance of including the value of operational flexibility in project valuation.

Firstly we observe that a deterministic evaluation of project parameters can present an incorrect picture to decision makers. The deterministic analysis showed that the firm had very little to gain from operational flexibility and the extra time and effort required to design a flexibile decision making system was not justified. Secondly we observe that when uncertainty is incorporated into passive projects there can be a significant loss in expected profits. A project that is designed without flexibility and does not take into account active decision making on the part of managers can appear far less appealing at the planning stage diminishing its chances of being commissioned. On the other hand, if projects are considered to be flexibile and the effect of active management is taken into consideration we observe the opposite effect.

Expanded NPV valuations showed higher returns than the deterministic valuations for the same capacity levels as we invested in larger capacity. Moreover, increasing volatility in market parameters was shown to be beneficial to flexibile projects.

Expanded NPV valuations showed that in the presence of greater volatility a project with operational flexibility could capitalize on larger upsides while hedging better against the downside as compared to passive valuations.

Finally we can also make an important conclusion regarding the treatment of operational flexibility in a deterministic setting. The deterministic model fails to adequately capture all of the value the firm gains from operational flexibility. The value of operational flexibility is dependent on uncertainty and it increases with increasing uncertainty. A deterministic model will always undervalue a project because of its inability to include management's ability to exploit uncertainty to create value.

6. Effect of Changes in Duty

One of the associated negative effects of global value chains is the increase in the sources of risk facing the firm. In section 2.1.1 we discussed extensively the relationship between the expanding lengths of global value chains and the risk faced by firms operating these global value chains as well as the different forms of risks present. Real options based valuations are most effective at subsuming the effect of continuous sources of risk such as changes in supply, demand, prices or exchange rates that can be tracked over a period of time. The accuracy of valuation depends on the accuracy of the data provided as inputs. Thus using historic market prices, demand patterns and wage rates improve the accuracy of valuation while more subjective sources of uncertainty such as the probability of changes in macroeconomic policies and disruption events are best used as a means of scenario planning.

Apart from price, demand and costs, economic policy factors constitute another level of risk for firms operating global value chains. In the model provided, we have considered the tax rates in individual regions as well as the import duties as sources of macroeconomic uncertainty. An increase in the import duty for a region can significantly alter the profitability of supplying that region from a foreign plant. Conversely, a decrease in the import duty makes the region more attractive as a destination for imported products. This is especially pertinent in the context of the current global economic situations. With many countries considering greater protectionism of local industries (Globerman, 2018), it is increasingly important for global firms to accurately value the effect that a change in global tariff regimes can have on their global profitability.

In the standard NPV model, increased uncertainty is modeled using an increased discount factor that penalizes such investments. Theoretically an operationally flexible global value chain should be able to maximize on the upside gains from reduced duties while reducing the potential downside risks faced from increased duties.

In the model provided we adapt our model to include a probabilistic change in duties as part of the model. We assume that over the planning horizon the import duty can change only once for a single region however the timing and extent of the change is random. This can be modeled using a binomial distribution with a given probability of occurrence for the duty increase based on the subjective estimate of the firm. The amount by which the import duty will increase is known in advance.

We model two different cases of changes in import duties in the following sections. The working of the model is further explained in Appendix C.

a. Increased Upside

In the first case (referred to as Case A) we assume that there is a chance that the import duty for Region A can increase by 10% (from the current 5% to 15%) over the next 5 periods. The probability of this increase is 10% in the first period and increases by 5% for each of the subsequent periods. We also assume that the import duty for Region B can decrease by 10% (from the current 15% to 5%) over the next 6 periods. The probability of this decrease is the same in each of the 6 periods. This probability is given as 10%.

This scenario should theoretically create an increased upside for larger investments in Region A. The increase in the duty rate for Region A means that it will be less beneficial to fulfill demand in region A from foreign plants while the decrease in duty rates for Region B means that it will be beneficial to supply more products to Region B from foreign plants. As the plant in Region A has the cheapest cost of production, the greatest positive effect should be observed here.

We will compare the passive valuations with expanded valuations to see how explicitly considering the operational flexibility affects the net profits compared to a fixed strategy. Two different passive valuations are provided. The first passive valuation is the same as the passive case for project 3 in the above sections, where each region only fulfills local demand. This is referred to as passive A. The second passive valuation is provided by fixing a policy beforehand for all the excess capacity in Region A to serve the demand of the Region B only. The expanded valuation provides for an operationally flexible value chain where the expanded capacity in Region A can be used in any region based on profitability. The results are provided in Tables 24, 25, 26 and 27. Figure 14 plots the changes in the expected NPV for the three different valuations.

Passive A			
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,339,403	$3,157,212	59%
1,600,000	$5,512,888	$4,737,424	86%
1,700,000	$5,541,933	$4,750,717	86%
1,800,000	$5,552,140	$4,732,555	85%
1,900,000	$5,523,556	$4,745,652	86%
2,000,000	$5,473,658	$4,896,509	89%
2,100,000	$5,432,101	$4,818,621	89%

Table 25: Effect of Duty Jump (Case A) on Project 1 Passive(a) NPV

Passive B			
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,339,403	$3,157,212	59%
1,600,000	$5,525,854	$4,796,378	87%
1,700,000	$5,557,902	$4,830,177	87%
1,800,000	$5,569,002	$4,826,182	87%
1,900,000	$5,542,171	$4,864,295	88%
2,000,000	$5,492,449	$5,049,108	92%
2,100,000	$5,452,418	$4,994,460	92%

Table 26: Effect of Duty Jump (Case A) on Project 1 Passive(b) NPV

Expanded					
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**	**Expected Flexibility Value A**	**Expected Flexibility Value B**
No Investment	$5,394,628.27	$2,955,250.67	55%	$87,654.16	$87,654.16
1,600,000	$5,673,171.24	$4,579,290.75	81%	$187,496.37	$174,790.24
1,700,000	$5,724,641.08	$4,615,504.39	81%	$209,258.38	$193,667.21
1,800,000	$5,754,877.67	$4,630,542.60	80%	$236,031.95	$219,736.49
1,900,000	$5,759,348.46	$4,676,442.34	81%	$281,343.65	$263,727.29
2,000,000	$5,783,957.83	$4,844,543.80	84%	$337,608.20	$319,575.55
2,100,000	$5,770,430.21	$4,794,642.86	83%	$376,351.71	$357,241.18

Table 27: Effect of Duty Jump (Case A) on Project 1 Expanded NPV

Expanded NPV						
	Standard Model			**Duty Jump Model**		
Extra Capacity	**Expected Value**	**Standard deviation**	**Coefficient of variation**	**Expected Value**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,427,132	$2,982,446	55%	$5,394,628	$2,955,250.67	55%
1,600,000	$5,656,165	$4,577,481	81%	$5,673,171	$4,579,290	81%
1,700,000	$5,695,761	$4,639,882	81%	$5,724,641	$4,615,504	81%
1,800,000	$5,710,216	$4,705,347	82%	$5,754,877	$4,630,542	80%
1,900,000	$5,699,412	$4,772,557	84%	$5,759,348	$4,676,442	81%
2,000,000	$5,686,000	$4,807,097	85%	$5,783,957	$4,844,543	84%
2,100,000	$5,660,024	$4,858,536	86%	$5,770,430	$4,794,642	83%

Table 28: Comparison of Expanded NPV for standard Model and Duty Jump Model (Case A)

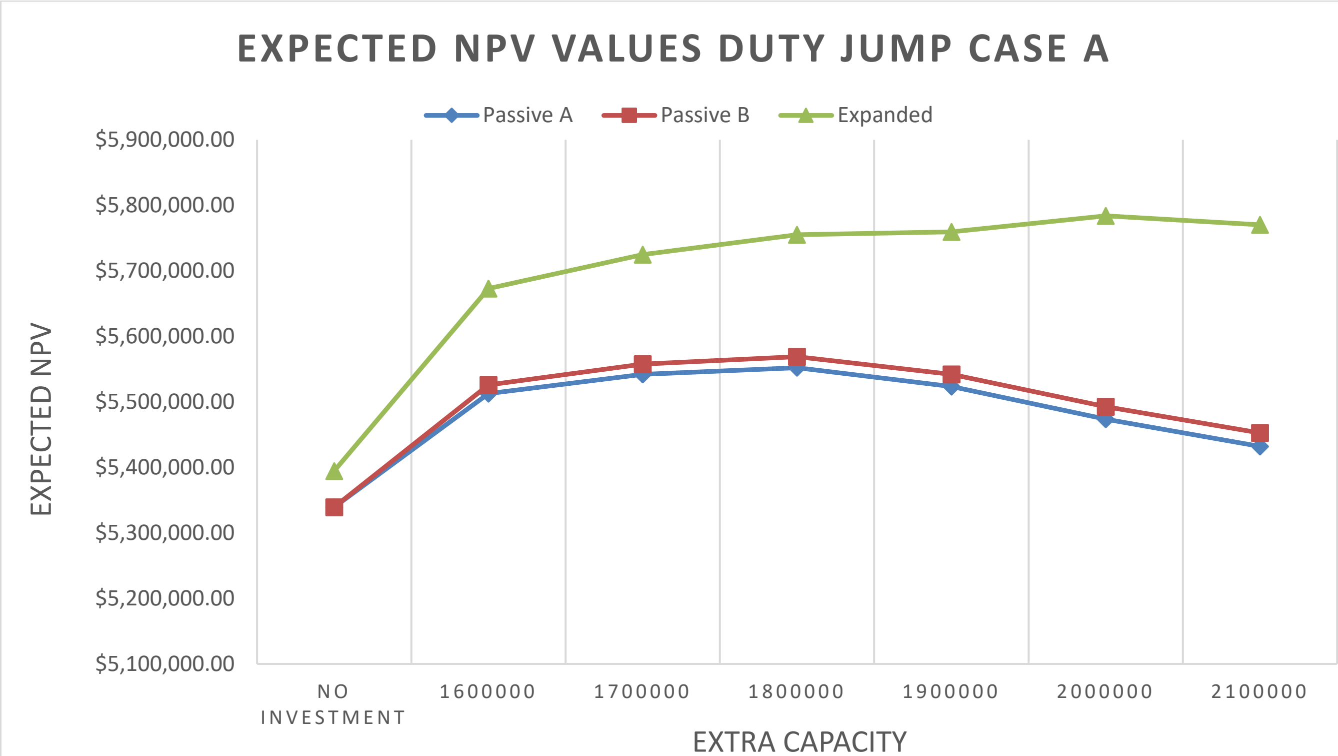


Figure 11: Comparison of Expanded and Passive NPV values for Duty Jump (Case A)

We can observe that while there is a benefit to using the extra capacity in Region A to supply Region B, the effect from fixing this policy in place is small and does not change the overall most profitable project. However the expanded NPV calculations provide significantly higher profits than either of the two passive calculations (Table 25, 26 and 27). Moreover, as initially expected, the firm is able to create a significantly larger upside from the beneficial changes in the duty rates. The increased upside benefit is so large that the most profitable capacity for the project has shifted from 1,800,000 units to 2,000,000 units (Table 28). The extra 200,000 units are beneficial because of the real option they provide the firm to benefit from the increased upside from favorable changes in the economic policy of the countries in the global value chain.

b. Increased Downside

In the second case we assume that there is a chance that the import duty for Region B can increase by 10% (from the current 15% to 25%) over the next 5 periods. The probability of this increase is 20% in each of the six periods. We also assume that the import duty for Region C can increase by 10% (from the current 10% to 20%) over the next 6 periods. The probability of this increase is also 20% in each period.

This case should create a greater downside of having larger capacities in project 1 (i.e. invest in plant A). Both the markets that the plant in Region A can supply are likely to face an increase in their import duties hence making them less profitable as destinations for imported products. We will again compare the three valuations as in the previous case, two for fixed passive projects and an expanded NPV valuation where the value chain of the firm is considered to be operationally flexible. The results for the model are shown in tables 28, 29, 30 and 31. Figure plots the changes in the expected NPV values for each of the three different valuations for the different capacity levels.

Passive A			
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,338,207.68	$3,161,382.89	59%
1,600,000	$5,520,671.39	$4,694,559.75	85%
1,700,000	$5,542,743.46	$4,748,853.54	86%
1,800,000	$5,544,354.09	$4,785,996.00	86%
1,900,000	$5,519,587.40	$4,792,626.06	87%
2,000,000	$5,483,163.62	$4,797,351.22	87%
2,100,000	$5,424,858.15	$4,877,907.30	90%

Table 29: Effect of Duty Jump (Case B) on Project 1 Passive(a) NPV

Passive B			
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,338,207.68	$3,161,382.89	59%
1,600,000	$5,490,241.13	$4,758,717.47	87%
1,700,000	$5,510,208.93	$4,854,458.75	88%
1,800,000	$5,502,228.63	$4,916,460.93	89%
1,900,000	$5,461,945.91	$4,962,665.22	91%
2,000,000	$5,410,455.81	$5,036,743.31	93%
2,100,000	$5,345,981.71	$5,081,774.97	95%

Table 30: Effect of Duty Jump (Case B) on Project 1 Passive(b) NPV

Expanded					
Extra Capacity	**Expected**	**Standard Deviation**	**Coefficient of Variation**	**Expected Flexibility Value A**	**Expected Flexibility Value B**
No Investment	$5,427,049.73	$2,983,992.60	55%	$88,842.06	$88,842.06
1600000	$5,639,577.24	$4,555,557.16	81%	$118,905.86	$144,197.35
1700000	$5,676,770.13	$4,602,564.63	81%	$134,026.67	$167,578.94
1800000	$5,685,935.33	$4,656,761.28	82%	$141,581.25	$183,084.51
1900000	$5,671,331.16	$4,683,768.78	83%	$151,743.76	$204,794.98
2000000	$5,647,769.48	$4,707,903.16	83%	$164,605.87	$231,042.18
2100000	$5,607,186.97	$4,798,753.09	86%	$182,328.82	$261,763.99

Table 31: Effect of Duty Jump (Case B) on Project 1 Expanded NPV

Expanded NPV						
	Standard Model			Duty Jump Model		
Extra Capacity	**Expected Value**	**Standard deviation**	**Coefficient of variation**	**Expected Value**	**Standard Deviation**	**Coefficient of Variation**
No Investment	$5,427,132	$2,982,446	55%	$5,427,049	$2,983,992	55%
1,600,000	$5,656,165	$4,577,481	81%	$5,639,577	$4,555,557	81%
1,700,000	$5,695,761	$4,639,882	81%	$5,676,770	$4,602,564	81%
1,800,000	$5,710,216	$4,705,347	82%	$5,685,935	$4,656,761	82%
1,900,000	$5,699,412	$4,772,557	84%	$5,671,331	$4,683,768	83%
2,000,000	$5,686,000	$4,807,097	85%	$5,647,769	$4,707,903	83%
2,100,000	$5,660,024	$4,858,536	86%	$5,607,186	$4,798,753	86%

Table 32: Comparison of Expanded NPV for standard Model and Duty Jump Model (Case B)

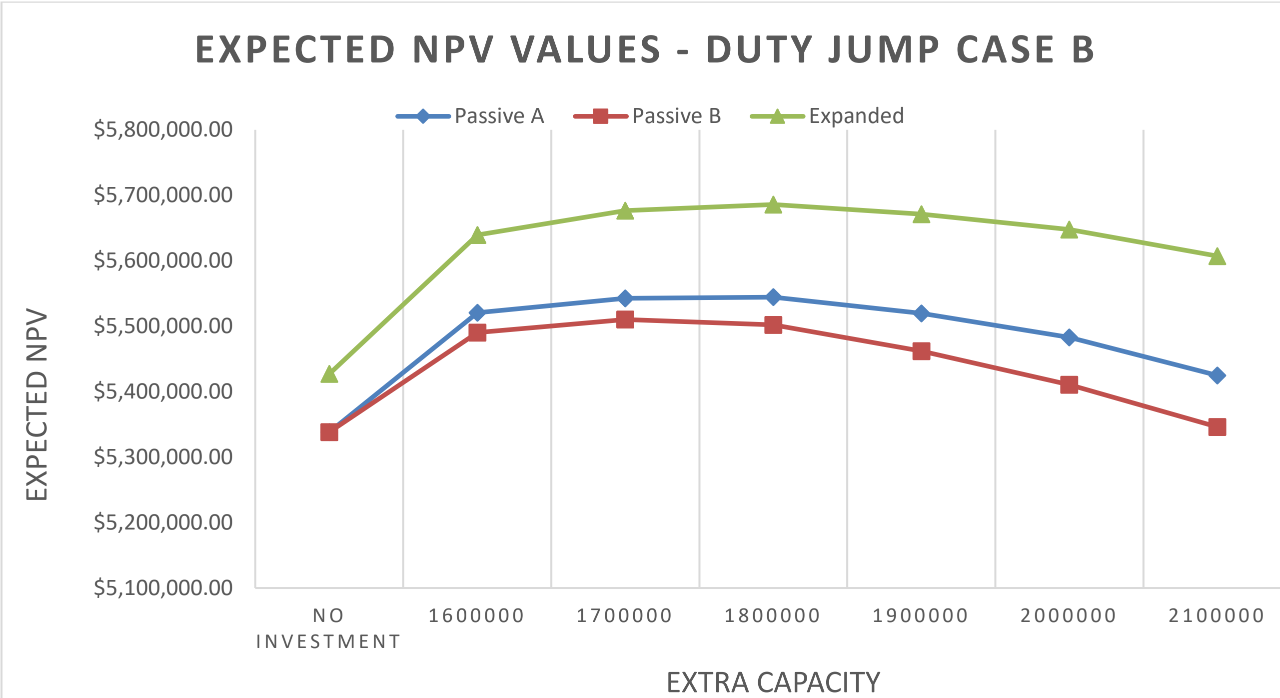


Figure 12: Comparison of Expanded and Passive NPV values for Duty Jump (Case B)

For the case with an increased downside risk we again observe that passive fixed valuations that do not account for the flexibility of the firm and provide much lower valuations for all projects compared to the expanded valuations that factor in this flexibility (Table 29, 30 and 31). The change in duties results in a decrease in valuations compared to the standard model with no duty changes, however the overall best project remains the same as for the standard model (Table 32). The expected NPV curve for passive valuations in Figure 12 shows a significantly sharper decline for higher capacity levels than the expected NPV curve for the expanded valuation. This difference is a direct result of the option value created from higher capacity levels that provide the firm with a greater level of operational flexibility.

When modeling the effect of one time changes in macroeconomic factors, we again observe that modeling operational flexibility as a real option provides a more accurate valuation with regards to the firm’s ability to counteract these risks.

7. Conclusion

Global value chains represent the modern paradigm in international trade. Firms have to increasingly work across national boundaries and extend their supply chains in order to compete successfully. Global operations are not just a means to increase sales anymore but present firms with a competitive advantage. However just as global value chains present firms with new opportunities they raise new challenges too. Firms need to design their strategies in a way that leverages the benefits of global value chains while protecting them from the associated risks.

In this thesis we presented the argument that the consideration of operational flexibility is crucial when evaluating projects in global value chains and real options analysis provides a better means to do this than traditional discounting methods such as NPV analysis. In the first part of the literature review it was argued that decision making in global value chains must incorporate the effect of greater environmental variability that results from global operations. This increases the risk faced by projects in global value chains but also provides firms with the ability to exploit this volatility and create a greater upside potential. Operational flexibility was identified as the key to unlocking this potential. In the second section of the literature review we introduced real options, highlighted the weakness of traditional discounted cash flow methods and presented a short review of the different applications of real options available in the literature. We also used empirical studies to show that real options thinking is crucial in unlocking the benefits of operational flexibility for global value chains. If global value chains are not designed with the capacity for flexibility and the managerial systems to deliver on the potential, then simply the presence of global operations does not create these benefits for the firm.

In the next section we discussed the valuation methodology for real options analysis and the current challenges in using real options analysis for investment valuation. Despite the considerable academic literature we showed that real options have not seen the level of corporate adoption that was initially expected. This is due to questions regarding methodology and the best way to implement real options. The discussion leads to the conclusion that there is a need for simpler means to demonstrate the benefits of real options thinking to managers in global firms. The limited current literature on modeling operational flexibility in global value chains was also discussed. While dynamic programming models are most commonly used for modeling operational flexibility in global value chains, these models are complex, require assumptions that are difficult to follow and are vastly more difficult to implement than standard discounted cash flow methods. We concluded that the use of a framework that incorporates real options thinking and NPV methodology can provide most of the benefits of the more rigorous modeling techniques without the added complexity.

Based on these conclusions we illustrated for a specific case how this can be implemented by formulating a simple spreadsheet based Monte Carlo simulation model for a firm operating across three regions and looking to expand current capacity. The model relies on simulating the decision process for a firm that possesses operational flexibility to counteract uncertainty and valuing this expanded valuation using the NPV method. This was achieved using a hierarchy-based decision logic regarding the distribution decisions based on the profit function for different links in the network. The model makes certain assumptions that are transparent while the model's decision process is easy to follow. As a point of comparison we also formulated a deterministic model that takes into account mean values for the parameters to provide insight into how considering flexibility without uncertainty fails to provide an accurate picture of the future.

The deterministic model showed no potential benefit from operational flexibility at any capacity level for 2 of the projects while showing only a small benefit in the third. In contrast, the simulation model showed a vastly expanded value of operational flexibility compared to the deterministic valuations. Furthermore, the inclusion of uncertainty significantly diminished the profits for a passive valuation. The inclusion of flexibility in the decision process allowed the firm to both curtail its downside risk while maximizing on the upside potential. We demonstrated this effect using a measure of variations in output values and comparing it between passive and expanded valuations. We also demonstrated that increasing volatility made larger investments, with larger real option values, more desirable. This is counter to the traditional approach of considering more volatility as being detrimental to global operations. As an extension to the initial model, we simulated two scenarios with changes in the duty rates for different regions in the value chain. It was observed that the expanded valuations that include the value of operational flexibility favor larger investments in cases where a favorable change in import duties is expected. The firm's ability to benefit from this favorable change in the macroeconomic environment cannot be captured without the expanded valuation. When the change in import duties is expected to not be favorable to the firms, the expanded valuation still provides a higher value suggesting that larger capacities, with larger associated real options, are better able to protect the global value chain from the downside risk of a negative macroeconomic situation. The results from the model support the argument that explicitly considering operational flexibility as part of investment decisions in global value chains can have significant impacts on the overall valuation and decision making. In addition the modeling of projects with operational flexibility in mind should also have a positive impact in building the managerial flexibility needed to deliver on this potential. Deterministic valuations or passive valuations that incorporate uncertainty are bound to undervalue investments due to their inability to value operational flexibility in global value chains.

The model presented includes a number of simplifications and is not meant to be prescriptive. Our argument through this research is to forward the approach we use to create the model rather than the specific model itself. Our approach relies on understanding the decisions that a global firm is faced with, understand the options created through its investments and to explicitly include the decision options available in the valuation process. The model can also be expanded to include more complexity in the form of a greater number of regions or added sources of uncertainty. A larger supply chain network with a greater number of regions will create complexity in the decision making process and require new decision rules or alternative approaches such as stochastic programming. The current model is limited in its ability to expand and cover a larger network. The model is also vertically limited covering only production and sales. Inclusion of supply side variability can present a broader picture and help improve the valuation. Lastly, a comparison of results between simplified models such as the one presented in this thesis and the more complex methodologies can provide a good comparison for the best way forward for research in the field. Simplified models such as the one presented can also be used as a first step towards creating corporate buy-in towards using more complex methodologies such as stochastic programming to provide more mathematically rigorous valuations and create less restricted models.

There is still significant areas of research in the field. A generalization of real options methodology can have a positive impact on the field as a whole. Simpler models with clearer assumptions will lead to wider adoption of real options in corporate contexts. Modeling the decision process for different managerial decisions rather than modeling all problems into the strict option models can potentially provide the way forward. The advances in simulation technologies and processing power of personal computers also make it easier to incorporate Monte Carlo simulation into the option valuation process. The earlier real options methodologies that relied on stochastic differential equations are an impediment towards a wider adoption of real options analysis by corporate managers.

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Appendix A: Mean values and Standard Deviations of Model Parameters for Monte Carlo Simulation

	Mean	**Standard Deviation**
Annual Growth for Demand in Region A	20%	2.00%
Annual Growth for Demand in Region B	5%	0.50%
Annual Growth for Demand in Region C	15%	1.50%
Annual Growth for Production Cost in Region A	4%	0.40%
Annual Growth for Production Cost in Region B	2%	0.20%
Annual Growth for Production Cost in Region C	3%	0.30%
Annual Growth for Raw Material Cost	0%	5.00%
Annual Growth for Price in Region A	3%	0.30%
Annual Growth for Price in Region B	1%	0.10%
Annual Growth for Price in Region C	2.5%	0.25%

Appendix B: Monte Carlo Simulation Model

Model Parameters:

This section shows the input values for all model parameters. The values for the first period are input by the user along with the growth rate. The values for each subsequent period are calculated based on formulas. The model is setup to work across multiple spread sheets. The first sheet (Basic Parameters) is used only to calculate the values of these parameters for each period in the planning horizon. The value used in the models are referenced from this sheet of basic parameters. This allows a comparison between different projects for the same realization of random parameters.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	Demand							Growth						
3		1	2	3	4	5	6	2	3	4	5	6		
4	Region A	850,000	1,005,015	1,218,119	1,475,891	1,742,069	2,158,223	18.24%	21.20%	21.16%	18.04%	23.89%		
5	Region B	2,000,000	2,095,052	2,223,485	2,312,884	2,437,761	2,556,971	4.75%	6.13%	4.02%	5.40%	4.89%		
6	Region C	1,125,000	1,283,302	1,474,733	1,699,005	1,952,798	2,298,019	14.07%	14.92%	15.21%	14.94%	17.68%		
7		3975000												
8														
9	Capacity	Existing	Addition	Fixed Cost	Variable Cost/unit									
10	Region A	-		$ 2,500,000.00	$1.00									
11	Region B	2,100,000		$ -	$3.00									
12	Region C	1,200,000		$ -	$1.50									
13		3300000												
14	Costs													
15	Region Component							Growth						
16		1	2	3	4	5	6	2	3	4	5	6		
17	Region A	$ 3.00	$ 3.11	$ 3.23	$ 3.36	$ 3.49	$ 3.64	3.63%	3.89%	4.01%	4.01%	4.19%		
18	Region B	$ 4.50	$ 4.59	$ 4.69	$ 4.78	$ 4.88	$ 4.99	1.96%	2.17%	2.00%	2.16%	2.07%		
19	Region C	$ 3.50	$ 3.63	$ 3.74	$ 3.85	$ 3.96	$ 4.08	3.62%	3.16%	2.90%	2.89%	3.01%		
20	Resource Component													
21		$ 5.50	$ 5.58	$ 5.93	$ 6.09	$ 5.57	$ 5.56	1.38%	6.39%	2.74%	-8.66%	-0.16%		
22														
23	Production Costs							Distribution Costs						
24		1	2	3	4	5	6							
25	Region A	$ 8.50	$ 8.68	$ 9.16	$ 9.45	$ 9.06	$ 9.20	Same region	$1					
26	Region B	$ 10.00	$ 10.16	$ 10.62	$ 10.88	$ 10.45	$ 10.54	All other regions	$1.50					
27	Region C	$ 9.00	$ 9.20	$ 9.67	$ 9.94	$ 9.53	$ 9.64							
28														
29	Price							Growth					Duties	Tax Rate
30		1	2	3	4	5	6	2	3	4	5	6		
31	Region A	$ 10.00	$ 10.31	$ 10.67	$ 10.98	$ 11.27	$ 11.60	3.081%	3.536%	2.884%	2.659%	2.878%	5%	20%
32	Region B	$ 11.50	$ 11.62	$ 11.74	$ 11.87	$ 11.96	$ 12.08	1.042%	1.048%	1.078%	0.793%	1.017%	15%	35%
33	Region C	$ 10.25	$ 10.48	$ 10.72	$ 11.03	$ 11.29	$ 11.55	2.201%	2.312%	2.957%	2.292%	2.319%	10%	30%

Figure 13: Basic Parameters Spreadsheet on MS Excel

Cells B4 to G4, B5 to G5 and B6 to G6 contain the demand in each period for regions UD, D and DG respectively. Celss B17 to G17, B18 to G18 and B19 to G19 contain the values for the regional component of the costs for each period while cells B21 to G21 contain the resource component. The total production costs are calculated as a sum of these two components in cells B25 to G25, B26 to G26 and B27 to G27 for each region.

Cells B31 to G31, B32 to G32 and B33 to G33 contain the prices for each region in each of the periods.

The additional capacity for each project is input in cell C10 to C12 based on the project being simulated.The distribution cost for supplying the same region as the plant is given in cell I26 and for supplying a different is given in cell I27.

These values are then referenced on the sheets that simulate the actual distribution schedule for the firm. All formulas in the sheets that model the distribution schedule reference the values from the secondary tables that themselves reference the values calculated in the primary Basic Parameters sheet.

	A	B	C	D	E	F	G	H	I
1									
2				Demands					
3		1	2	3	4	5	6		
4	Region A	850,000	1,005,015	1,218,119	1,475,891	1,742,069	2,158,223		
5	Region B	2,000,000	2,095,052	2,223,485	2,312,884	2,437,761	2,556,971		
6	Region C	1,125,000	1,283,302	1,474,733	1,699,005	1,952,798	2,298,019		
7									
8	Capacity		Addition	Fixed Cost	Variable Cost	Total			
9	Region A	-	1800000	$ 2,500,000.00	$ 1,800,000.00	$ 4,300,000.00			
10	Region B	2,100,000	0		$ -	$ -			
11	Region C	1,200,000	0		$ -	$ -			
12			1800000			$ 4,300,000.00			
13	Costs								
14				Production Costs				Distribution Costs	
15		1	2	3	4	5	6		
16	Region A	$ 8.50	$ 8.68	$ 9.16	$ 9.45	$ 9.06	$ 9.20	Same region	$1
17	Region B	$ 10.00	$ 10.16	$ 10.62	$ 10.88	$ 10.45	$ 10.54	All other regions	$1.5
18	Region C	$ 9.00	$ 9.20	$ 9.67	$ 9.94	$ 9.53	$ 9.64		
19									
20				Price				Duties	Tax Rate
21		1	2	3	4	5	6		
22	Region A	$ 10.00	$ 10.31	$ 10.67	$ 10.98	$ 11.27	$ 11.60	5%	20%
23	Region B	$ 11.50	$ 11.62	$ 11.74	$ 11.87	$ 11.96	$ 12.08	15%	35%
24	Region C	$ 10.25	$ 10.48	$ 10.72	$ 11.03	$ 11.29	$ 11.55	10%	30%
25									

Figure 14: Project 1 ROV Spreadsheet parameters

	A	B	C	D	E
1					
2				Demands	
3		1	2	3	4
4	Region A	='Basic Parameters'!B4	='Basic Parameters'!C4	='Basic Parameters'!D4	='Basic Parameters'!E4
5	Region B	='Basic Parameters'!B5	='Basic Parameters'!C5	='Basic Parameters'!D5	='Basic Parameters'!E5
6	Region C	='Basic Parameters'!B6	='Basic Parameters'!C6	='Basic Parameters'!D6	='Basic Parameters'!E6
7					
8	Capacity		Addition	Fixed Cost	Variable Cost
9	Region A	='Basic Parameters'!B10	1800000	=IF(C9>0,'Basic Parameters'!D10,0)	='Basic Parameters'!E10*C9
10	Region B	='Basic Parameters'!B11	0		='Basic Parameters'!E11*C10
11	Region C	='Basic Parameters'!B12	0		='Basic Parameters'!E12*C11
12			=SUM(C9:C11)		
13	Costs				
14				Production Costs	
15		1	2	3	4
16	Region A	='Basic Parameters'!B25	='Basic Parameters'!C25	='Basic Parameters'!D25	='Basic Parameters'!E25
17	Region B	='Basic Parameters'!B26	='Basic Parameters'!C26	='Basic Parameters'!D26	='Basic Parameters'!E26
18	Region C	='Basic Parameters'!B27	='Basic Parameters'!C27	='Basic Parameters'!D27	='Basic Parameters'!E27
19					
20				Price	
21		1	2	3	4
22	Region A	='Basic Parameters'!B31	='Basic Parameters'!C31	='Basic Parameters'!D31	='Basic Parameters'!E31
23	Region B	='Basic Parameters'!B32	='Basic Parameters'!C32	='Basic Parameters'!D32	='Basic Parameters'!E32
24	Region C	='Basic Parameters'!B33	='Basic Parameters'!C33	='Basic Parameters'!D33	='Basic Parameters'!E33
25					

Figure 15: Project 1 ROV Spreadsheet parameters with formulas

Simulating uncertainty:

For each parameter the value in the next cell is calculated by multiplying the previous period's value by a growth factor.

For example, the demand in period 2 is given by: Demand Period 1 * (1+growth rate for region)

	A	B	C	D	E
1					
2				Demand	
3		1	2	3	4
4	Region A	850000	=B4*(1+H4)	=C4*(1+I4)	=D4*(1+J4)
5	Region B	2000000	=B5*(1+H5)	=C5*(1+I5)	=D5*(1+J5)
6	Region C	1125000	=B6*(1+H6)	=C6*(1+I6)	=D6*(1+J6)
7		=SUM(B4:B6)			

Figure 16: Demand Formula

The growth factors are a random variable picked from a normal distribution. The mean and standard deviation of the distribution are provided as inputs.

	H	I	J	
1				
2			Growth	
3	1	2	3	4
4	=PsiNormal(0.2,0.02,PsiBaseCase(0.2))	=PsiNormal(0.2,0.02,PsiBaseCase(0.2))	=PsiNormal(0.2,0.02,PsiBaseCase(0.2))	=Ps
5	=PsiNormal(0.05,0.005,PsiBaseCase(0.05))	=PsiNormal(0.05,0.005,PsiBaseCase(0.05))	=PsiNormal(0.05,0.005,PsiBaseCase(0.05))	=Ps
6	=PsiNormal(0.15,0.015,PsiBaseCase(0.15))	=PsiNormal(0.15,0.015,PsiBaseCase(0.15))	=PsiNormal(0.15,0.015,PsiBaseCase(0.15))	=Ps
7				

Figure 17: Demand Growth Rate formula

The same process is used for simulating the uncertainty in all other parameters.

Passive NPV Model:

The NPV calculations for the passive NPV model calculates the sales, production costs, distribution costs and the profits based on a pre-defined strategy. For example, the passive NPV for a new plant in Region A calculates the NPV based on the project being used only for local demand in the region. The sales, production costs and profits for Region A are calculated as follows (in rows 32, 33 and 36 of Figure 18 respectively).

Sales = MIN(Capacity, Demand)

Production Costs = Total Production Costs in Region A * Sales in Region A

Profits = IF[Unit Profit(A)*Sales(A) > 0, {1-Tax rate(A)} * {Unit Profit(A) * Sales(A)}, {Unit Profit(A) * Sale(A)}]

	A	B	C	D
28				
29	Region A	0	1	2
30	Demand		=B4	=C4
31	Capacity		=$B$9+$C$9	=$B$9+$C$9
32	Sales		=MIN(C31,C30)	=MIN(D31,D30)
33	Production Costs		=B16*C32	=C16*D32
34	Distribution Costs		=$I$16*C32	=$I$16*D32
35	Total Costs		=SUM(C33:C34)	=SUM(D33:D34)
36	Profits		=IF((C32*B22)-C35>0,(1-$I$22)*((B22*C32)-C35),(C32*B22)-C35)	=IF((D32*C22)-D35>0,(1-$I$22)*((C22*D32)-D35),(D32*C22)-D35)
37	Investment	=F9		
38	Rate	0.1		
39	NPV	=NPV(B38,C36:H36)-B37		

Figure 18: Project 1 Passive NPV Spreadsheet with formula

	A	B	C	D	E	F	G
21		1	2	3	4	5	6
22	Region A	$ 10.00	$ 10.25	$ 10.60	$ 10.92	$ 11.28	$ 11.64
23	Region B	$ 11.50	$ 11.61	$ 11.71	$ 11.81	$ 11.92	$ 12.03
24	Region C	$ 10.25	$ 10.53	$ 10.87	$ 11.14	$ 11.45	$ 11.73
25							
26							
27							
28							
29	Region A	0	1	2	3	4	5
30	Demand		850000	1023287	1227659	1490689	1851947
31	Capacity		1800000	1800000	1800000	1800000	1800000
32	Sales		850000	1023287	1227659	1490689	1800000
33	Production Costs		$ 7,225,000.00	$ 9,254,924.93	$ 11,050,977.13	$ 13,846,024.72	$ 16,965,595.80
34	Distribution Costs		$850,000	$1,023,287	$1,227,659	$1,490,689	$1,800,000
35	Total Costs		$ 8,075,000.00	$ 10,278,212.32	$ 12,278,636.00	$ 15,336,713.74	$ 18,765,595.80
36	Profits		$ 340,000.00	$ 169,096.11	$ 588,805.89	$ 750,747.55	$ 1,227,616.81
37	Investment	$ 4,300,000.00					
38	Rate	10%					
39	NPV	($1,259,308.62)					
40							
41	Region B	0	1	2	3	4	5
42	Demand		2000000	2101621	2210520	2315088	2417872
43	Capacity		2100000	2100000	2100000	2100000	2100000
44	Sales		2000000	2100000	2100000	2100000	2100000
45	Production Costs		$ 20,000,000.00	$ 22,044,619.51	$ 21,943,732.85	$ 22,466,757.16	$ 22,657,343.54
46	Distribution Costs		$2,000,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000
47	Total Costs		$ 22,000,000.00	$ 24,144,619.51	$ 24,043,732.85	$ 24,566,757.16	$ 24,757,343.54
48	Profits		$ 650,000.00	$ 152,636.30	$ 362,187.15	$ 157,664.76	$ 184,568.00
49	Investment	$ -					

Figure 19: Project 1 Passive NPV Spreadsheet without formula

For a plant in a region other than A, the model designates all the extra capacity left in the expanded plant after fulfilling local demand towards Region A. For example, for the model calculting passive NPV for a plant in Region B (Cells C31 and D31 in Figure 20).

Capacity available for Region A = IF{Capacity(B) - Demand(B) > 0, Capacity(B) - Demand(B), 0}

The distribution costs would use the price for cross-regional distribution and the total costs will include the import duty

Total costs in Region A = Distribution costs + {(1 + Duty rate)*(Production Costs)}

When calculating the profits the tax rate of the regions where the sales are being is used.

	A	B	C	D
28				
29	Region A	0	1	2
30	Demand		=B4	=C4
31	Capacity		=IF(($B$10+$C$10)-C42>0,($B$10+$C$10)-C42,0)	=IF(($B$10+$C$10)-D42>0,($B$10+$C$10)-D42,0)
32	Sales		=MIN(C31,C30)	=MIN(D31,D30)
33	Production Costs		=B17*C32	=C17*D32
34	Distribution Costs		=$I$17*C32	=$I$17*D32
35	Total Costs		=C34+((1+$H$22)*C33)	=D34+((1+$H$22)*D33)
36	Profits		=IF((C32*B22)-C35>0,(1-$I$22)*((B22*C32)-C35),(C32*B22)-C35)	=IF((D32*C22)-D35>0,(1-$I$22)*((C22*D32)-D35),(D32*C22)-D35)
37	Investment	=F9		
38	Rate	0.1		
39	NPV	=NPV(B38,C36:H36)-B37		
40				

Figure 20: Project 2 Passive NPV Spreadsheet

Expanded NPV Model:

Profit matrix

For each period a profit matrix is designed that simulates the profits on each link for that period using the parameters for that period. The tax rate, duties and distribution costs are fixed while the price and costs change for each trial of the simulation.

For example, for the link between Region A and Region B the profit function is as follows:

Profit (A to B) = {1 - MIN(Tax rate A, Tax rate B)} * [Price(B) - {Production Cost(A) * (1 + Duty rate B) + Distribution Costs for different region}

	A	B	C	D
29				
30	Period 1			
31	Profit Matrix			
32		Region A	Region B	Region C
33	Region A	=(1-MIN(I22,I22))*(B$22-(B$16*(1+0)+$I$16))	=(1-MIN(I22,I23))*(B$23-(B$16*(1+$H$23)+$I$17))	=(1-MIN(I22,I24))*(B$24-(B$16*(1+$H$24)+$I$17))
34	Region B	=(1-MIN(I23,I22))*(B$22-(B$17*(1+$H$22)+$I$17))	=(1-MIN(I23,I23))*(B$23-(B$17*(1+0)+$I$16))	=(1-MIN(I23,I24))*(B$24-(B$17*(1+$H$24)+$I$17))
35	Region C	=(1-MIN(I24,I22))*(B$22-(B$18*(1+$H$22)+$I$17))	=(1-MIN(I24,I23))*(B$23-(B$18*(1+$H$23)+$I$17))	=(1-MIN(I24,I24))*(B$24-(B$18*(1+0)+$I$16))
36				

Figure 21: Project 1 ROV Spreadsheet profit matrix

Distribution Matrix:

Based on the profit matrix the distribution matrix is calculated. For cells that simulate deliveries from a local plant the minimum between the capacity available in the local plant and the local demand for that period is used. For example for the link between the plant in Region B and the local market the following formula is used:

Volume Shipped (B - B) = MIN{Demand(B), Capacity(B)}

For cells that simulate deliveries from a foreign expanded plant to a market in a different region the formula simulates the decision process shown in section 4.1.1. For example, for the link between Region A and Region B when evaluating a new plant in Region A (cell C39 in Figure 22).

Volume shipped (A-B) = IF[Profit (A-B)>0, IF{Profit(A-B)>Profit(A-C), MIN{Capacity(A) - Shipped(A-A), Demand(B) - Shipped(B-B)}, MIN{Capacity(A) - (Shipped(A-A) + Shipped(A-C)), Demand (B) - Shipped(B-B)}, 0]

	A	B	C	
37	Supply			
38		Region A	Region B	Region C
39	Region A	=MIN(B$4,$B$9+$C$9)	=IF(C33>0,IF(C33>D33,MIN(($B$9+$C$9)-B39,B$5-C40),MIN(($B$9+$C$9)-(B39+D39),B$5-C40)),0)	=IF(D33>0,IF
40	Region B	0	=MIN(B$5,$B$10+$C$10)	0
41	Region C	0	0	=MIN($B$11-
42		=SUM(B39:B41)	=SUM(C39:C41)	=SUM(D39:D
43		<=	<=	<=
44	Demands	=B$4	=B$5	=B$6
45	Lost Sales	=SUM(B44:D44)-SUM(B42:D		
46	Profits	=SUMPRODUCT(B33:D35,B3		

Figure 22: Project 1 ROV Spreadsheet Distribution Matrix

The profit for each distribution schedule in each region is calculated by multiplying the respective profit cells and distribution cells for each link. Total NPV is calculated by using the NPV formula for profits in each period. Expanded NPV is calculated by subtracting the NPV value calculated by the passive model from the above model for each simulation run.

Appendic C: Duty Jump Model

For the duty jump model, the sheet that calculates the basic parameters also calculates the changes in the duty rates for each period.

	A	B	C	D	E	F	G	H
34								
35	Duty Jump							
36		Probabilities						
37		1	2	3	4	5	6	Change amount
38	Region A	10%	15%	20%	25%	30%	35%	10%
39	Region C	10%	10%	10%	10%	10%	10%	-10%
40								
41		Duty Changes						
42	Periods	1	2	3	4	5	6	
43	Region A							
44	Event realization (ind)	0	0	0	0	0	0	
45	Event realization (Conditional)	0	0	0	0	0	0	
46	Region B							
47	Event realization (ind)	0	0	1	0	0	0	
48	Event realization (Conditional)	0	0	1	0	0	0	
49								
50		Duties						
51		1	2	3	4	5	6	
52	Region A	5%	5%	5%	5%	5%	5%	
53	Region B	15%	15%	15%	15%	15%	15%	
54	Region C	10%	10%	0%	0%	0%	0%	
55								

Figure 23: Duty Jump Project 1 Case A Basic Parameters Spreadsheet

In cells B38 to G38 and B39 to G39 the probabilities for a change in the duty rate is given as an input for the respective regions. Cells H38 and H39 take the value of the expected change in the duty rate (Figure 23 and Figure 24).

The actual change is simulated in two steps. First an individual event realization for the change is calculated using a Bernoulli distribution that uses the probabilities given above. In the second step the model checks if the event has been realized at any prior point in the planning period. If this is true, the model returns a value of zero (or no change in duty) even if the individual event realization for this period was true.

	A	B	C	D	E	
34						
35	Duty Jump					
36					Probabilities	
37		1	2	3	4	5
38	Region A	0.1	0.15	0.2	0.25	0.3
39	Region C	0.1	0.1	0.1	0.1	0.1
40						
41					Duty Changes	
42	Periods	1	2	3	4	5
43	Region A					
44	Event realization (ind)	=PsiBernoulli(B38)	=PsiBernoulli(C38)	=PsiBernoulli(D38)	=PsiBernoulli(E38)	=Psi
45	Event realization (Conditional)	=B44	=IF(B45=1,0,C44)	=IF(OR(B45=1,C45=1),0,D44)	=IF(OR(B45=1,C45=1,D45=1),0,E44)	=IF(
46	Region B					
47	Event realization (ind)	=PsiBernoulli(B39)	=PsiBernoulli(C39)	=PsiBernoulli(D39)	=PsiBernoulli(E39)	=Psi
48	Event realization (Conditional)	=B47	=IF(B48=1,0,C47)	=IF(OR(B48=1,C48=1),0,D47)	=IF(OR(B48=1,C48=1,D48=1),0,E47)	=IF(
49						
50					Duties	
51		1	2	3	4	5
52	Region A	=M31+(B45*$H$38)	=B52+(C45*$H$38)	=C52+(D45*$H$38)	=D52+(E45*$H$38)	=E52
53	Region B	0.15	0.15	0.15	0.15	0.15
54	Region C	=M33+(B47*$H$39)	=B54+(C47*$H$39)	=C54+(D47*$H$39)	=D54+(E47*$H$39)	=E54
55						
56						

Figure 24: Duty Jump Project 1 Case A Basic Parameters Spreadsheet with formula

Appendix D: Mean values and Standard Deviations of Model Parameters at 20% Coefficient of Volatility

	Mean	**Standard Deviation**
Annual Growth for Demand in Region A	20%	4.00%
Annual Growth for Demand in Region B	5%	1.00%
Annual Growth for Demand in Region C	15%	3.00%
Annual Growth for Production Cost in Region A	4%	0.80%
Annual Growth for Production Cost in Region B	2%	0.40%
Annual Growth for Production Cost in Region C	3%	0.60%
Annual Growth for Raw Material Cost	0%	10.00%
Annual Growth for Price in Region A	3%	0.60%
Annual Growth for Price in Region B	1%	0.20%
Annual Growth for Price in Region C	2.50%	0.50%