Managing Risks of Supply-Chain Disruptions: Dual Sourcing as a Real Option

by

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Abstract

This thesis examines how firms should prepare against disruption in their supply-chain and focuses on how they can use real options to value dual sourcing strategies.

As an introduction, it defines a general framework to help managers to think about supply chain disruptions and determine adapted strategies. The logic of the paper is based on this framework.

First it establishes a general review of the possible solutions to manage risk disruptions. A literature research points out that firms can use two complementary types of actions to respond to uncertainty: securing the supply-chain and developing resilience. Both can be performed in many different ways and it seems that there is no single best solution. The problem for managers is to choose a good strategy, and quantifying the benefits of the various solutions can be very helpful.

The thesis focuses on the particular approach of dual sourcing and shows that the real options concept is an adapted tool to evaluate such a strategy. It develops an analytic model to analyze and value the benefits of relying on dual sourcing. This model takes into account various parameters such as the frequency of disruption and the loss of market share. Using MATLAB, it defines the particular circumstances that justify a second supplier. Sensitivity analyses permit to determine the impact of each parameter. The model also demonstrates the value of the option of delaying decision and shows that a time-varying dynamic strategy works the best.

The thesis finishes with a few recommendations to help managers build a more resilient supply-chain and use real options to quantify their choices.

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Chapter 1 Introduction.

Modern supply chains are very complex, and recent lean practices have resulted in these networks becoming more vulnerable. For instance, there is often little buffer inventory and any disruption can have a rapid impact on the supply process. These disruptions can have many different sources: natural disasters, strikes, terrorism attacks, etc…

Since 9/11, managers are more aware of the vulnerability of their supply-chain but most of them are still confused on the way to manage risk disruptions. Why this is? Firstly, simply because there is no easy answer in crafting strategies under uncertainties. Second, because managers are reluctant to implicate recent manufacturing practices; years of optimization theory have lead to the supply-chain as it is currently and including the notion of risks is a difficult challenge. Lastly, as we will see, because managers do understand the costs that are related to risk management but have a hard time quantifying the benefits.

This thesis focuses on one particular solution to protect against supply risks: multiple sourcing. The objective is to justify this strategy using the real option framework. The first chapters step back and point out how the subject of this thesis "dual-sourcing as a real option" integrates in the more general issue "how to manage supply-chain risk disruptions". Chapter 1 defines a global framework for thinking about uncertainties and more particularly about disruptions, and chapter 2 looks at how dual sourcing fits in the more global list of solutions for managing risks.

1.1 How to Manage Uncertainty: General Framework

In the past couple of years the business environment has become more and more complex and unpredictable. Companies are struggling to get ahead in this uncertainty. The problem is that, in the new economy, managers cannot rely any more on outdated "tried-and-true" approaches; they need to adopt new mindsets and strategies. In recent literature, managers can find a lot of material to help them think and act in environments that are rapidly changing, and highly uncertain. Many different fields tackle this problem and particularly decision science, organization theory, strategy, entrepreneurship research and cognitive psychology.

This chapter relies mainly on two of books of this literature: "The Entrepreneurial Mindset, Strategies for Continuously Creating Opportunity in an Age of Uncertainty" (McGrath and

MacMillan, 2000), and “20/20 Foresight, Crafting Strategy in an Uncertain World” (Courtney, 2001). Both suggest “roadmaps” to help managers to embrace uncertainty and define adapted strategies. McGrath and MacMillan’s book is more oriented toward entrepreneurship and focuses on “positive uncertainties” (meaning opportunities). Figure 1.1 presents an adaptation of these two processes.

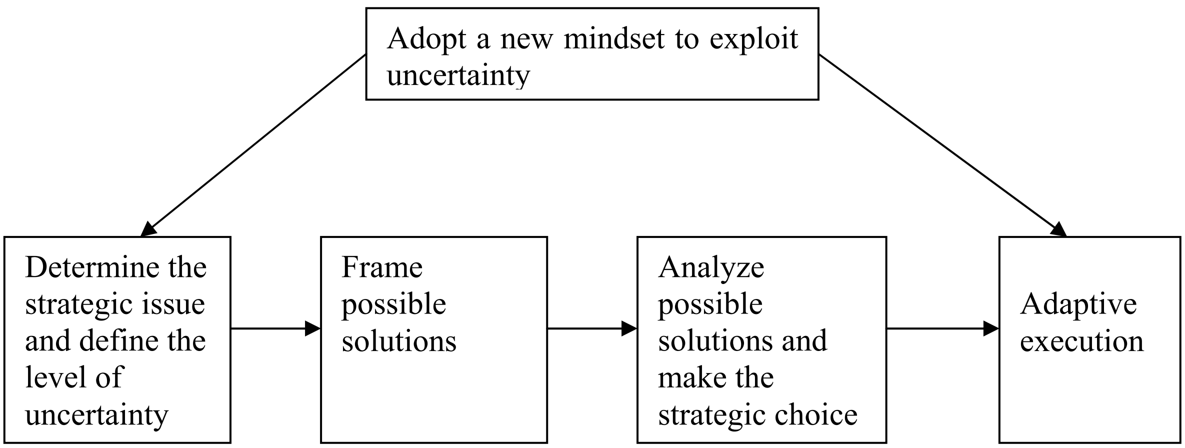


Figure 1.1: Strategy under Uncertainty - General Process

1. Adopt a new mindset to exploit uncertainty: Managers should stop avoiding uncertainty, but face it and even capitalize on it. They should stop seeing uncertainty as an enemy but on the contrary exploit and benefit from it. For example, McGrath and MacMillan argue that managers should act like entrepreneurs, and constantly look for new opportunities.

2. Determine strategic issues and define the level of uncertainty: For each strategic issue, managers must consider what is the level of uncertainty that is associated with the question at stake. This step will be crucial for the continuation of the process. Courtney defines 4 levels of uncertainty:

    - Level 1: the lowest level of uncertainty is so low that the traditional methods that forecasts can be used successfully.

    - Level 4: the highest level is that analysis cannot 'bound the range of possibilities', let alone reliably forecast.

- Levels 2 and 3--between these two extremes, the levels of uncertainty most likely to face managers. In Level 3 situations, managers can 'bound the range of possible outcomes'. In Level 2, managers can 'identify a set of distinct possible outcomes'. Firms must determine the level of uncertainty they are facing and choose accordingly their strategic posture.

3. Frame possible solutions: Once the level of uncertainty is determined, managers can start to define possible solutions. Knowing the level of uncertainty helps to frame the most adapted strategies.

   Courtney (2001) outlines the alternatives “Shape or Adapt” (e.g. seek to shape a market or adapt to an existing market), “Now or Later”, “Focus or Diversify”. McGrath and MacMillan (2000) focus on new opportunities and list the following categories: “Redesign products or services”, “Redifferentiate products or services”, “Resegment the market”, “Completely reconfigure the market”, “Develop breakthrough competences, or areas of competitive strength, that create new competitive advantages”.

4. Analyze possible solutions and make strategic choices: Once armed with a list of solutions, managers need to choose the best actions to include in the portfolio of strategies. To decide, managers must use adapted tools and frameworks. They cannot satisfy of traditional instruments such as SWOT analysis (that helps to identify firm’s Strengths, Weaknesses, Opportunities and Threats)**,** Porter’s Five Forces or Discounted Cash Flows. In uncertain environment, they are at best marginally helpful and at worst downright dangerous.

   Courtney suggests a toolkit that is more complete and depends on the level of uncertainty. In case of uncertainty the analysis tools that can be used comprise decision trees, scenario-planning exercises, game theory, real options, system dynamics models, or management flight simulators.

5. Adaptive execution: Once the strategy selected, the next challenge is to implement it. Under uncertainty it is necessary to monitor and adapt the strategy over time. Typical strategic planning may be too static and managers should consider new techniques. Courtney (2001) suggests three different approaches that depend on the level of uncertainty: contingent road maps, option portfolio management and strategic evolution

principles. McGrath and MacMillan (2000) define the “discovery-driven planning”, which allows to “adapt the course of action as the real opportunities becomes clear”.

1.2 How to manage supply-chain disruptions: Chosen Approach

Our uncertainty here is supply-chain disruptions. By adapting the general framework to this particular issue, we obtain:

1 Disruption risks exist and managers must not ignore them. It is necessary to introduce a culture of risk awareness within the organization in order to face this problem.

2. The strategic issue is to determine which actions to undertake in order to manage disruption risks. This is an important question, since disruptions may damage strongly the supply process and firms may loose business. Protecting the supply-chain against such events may even become a strategic advantage toward the competitors. For instance, in case several firms suffer from the same disruption, companies that are prepared will recover faster from hardship and may take market shares from their competitors.

According to Courtney’s framework, firms face here a level 2 of uncertainty - managers can 'identify a set of distinct possible outcomes': normal and disruption situations.

3. Managers must undertake a general review of all the possible solutions to manage risk disruptions. The purpose of chapter 2 is precisely to give a list of these measures. It is based on a literature review and suggests very general approaches. Practically, firms need to specify these solutions and adapt them to their own environment. Chapter 3 focuses on dual sourcing that is a possible strategy to protect against supply risks.

4. Once managers have identified possible solutions, they must analyze each of them precisely in order to choose the best actions and define a global strategy to manage risk disruptions. They need to rely on tools and models that are adapted to the uncertainty they are facing. In particular, it may be helpful to quantify the value of the different solutions, as managers like to think in term of costs vs. benefits. This thesis shows that real options are perfectly adapted to value flexible strategies under uncertainties. Chapter 4 introduces the concept of real options. Chapters 5 and 6 present how to use this approach by applying it to the example of dual sourcing.

5. In terms of implementation, Forrester Research (Radjou, 2002) suggests relying on adaptive planning rather on long-term plans. The idea is to generate solutions that are more adapted to the actual supply chain conditions, make decisions based on real-time data, and have executives spend time experimenting, learning and revisiting assumptions.

If dual sourcing is part of the final strategy, managers need to monitor the usefulness of such a solution over time. Their environment may change and firms need to adapt their sourcing strategies over time.

Chapter 2 How to Manage Supply-Chain Risks of Disruption?

This chapter consists in a literature review to determine what the advice of experts are in term of actions to take to prepare for the unexpected. The research shows that firms should begin with assessing the different risks. And to respond to these threats, companies can undertake two types of actions. First firms can take prevention actions in order to increase the security in their supply-chain. However, the total prevention of disruptions is impossible and firms also need to take remediation actions to mitigate the consequences once a disruption has occurred.

2.1 Literature Review

The subjects that appear in this chapter refer to different literature domains and notions. A rich literature deals with the general issue of supply-chain risk management but focuses above all on market volatility and demand uncertainty. Articles in this domain suggest that the key to survive in such context is through "agility" that is defined as the "ability of an organization to thrive in a continuously changing, unpredictable business environment" (Agility Forum, 1994). For example, "semi-postponement, that is postponement to retailer order, not end-consumer order" can be used " to cope with the variance resulting from seasonality; finalization or manufacturing is therefore done based upon retail orders". (Van Hoek, 2001).

Since 9-11 more and more articles try to include the notion of disruption and rare event- related risks as a lot of firms have seen their supply-chain weakened by such a drama. Ford for example had to shut down 5 of its plants, as it couldn't get enough parts from its suppliers in Canada – due to the reinforced security at the borders in the few days that followed 9-11. More aware of the importance of such uncertainties, Cranfield Management School (2002) has undertaken a vast research project on the global "supply-chain vulnerability" that is defined as 'an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain'; thus they include all types of risks whether it is disruption, demand uncertainty or even what they call "internal risk" (risk that "arises from interaction between constituent organizations across the supply chain").

Some articles focus precisely on disruptions and discuss the measures that companies should take to have safer supply-chains or study the different ways that could help firms to mitigate the consequences of disruption. They recall an already existing, but more and more relevant field of research on resilience that provides us with valuable insights. Coutu defines this notion of resilience as "the ability to bend and bounce back from hardship" (Coutu, 2002). Children who have schizophrenic parents and do not suffer psychological illness possess this quality of resilience. Another good illustration is the way UPS delivered packages to customers living in their cars just one day after Hurricane Andrew devastated Florida in 1992. Interest in resilience started about 40 years ago and focuses on people or organization broadly speaking without directly covering the supply-chain.

2.2 Assess Risk

Risks that can lead to supply-chain disruptions are as different as natural catastrophes, strikes, political instability, fires or terrorism. Vulnerability of supply chains to these risks has increased because of modern practices such as lean management and just-in-time inventory. As William Michels puts it "Many of the key risks factors have developed from a pressure to enhance productivity, eliminate waste, remove supply chain duplication, and drive for cost improvement" (Stauffer, 2003). But this list is not comprehensive and we can find many other reasons. For example market has put a lot of pressure on firms to differentiate their products. This has led companies to rely on several third parties and has consequently increased the risks. Vulnerability has also increased because of the growing complexity of supply networks. Indeed the probability that something happens at a particular node or connection is higher than for a small and simple network. Supply chains that comprise hundreds or even thousands of companies present numerous risks. Cranfield (2002) characterizes as "risks within the supply chain" all the factors that make the supply chain more vulnerable to external risks such as terrorism or strike.

The organizations are "crisis-prepared (or proactive)" encounter fewer disasters and recover better from hardship; in particular they "force themselves to confront crisis they have never experienced – or can't even imagine." (Mitroff and Alpasan, 2003). In order to think the unthinkable, these authors suggest a set of tools. Firms can try to put in an "internal assassin" shoes and figure out what are the weak points of the organization. Or they can do benchmarking and study other industries' weaknesses in order to identify new threats. They can also invite external parties to judge and test their crisis-preparedness plans.

However, managers must be careful not too pay too much attention on exceptional events and neglect smaller risks that have however a high frequency and can hurt as much. Small disruptions can be very severe if they are too numerous and lead to stock-out and lost customers.

MIT research group on "Supply Chain Response to Global Terrorism" (2003) have shown that firms usually focus on the type of disruption and not its source in order to know how to prepare against risks. What is important is the type of "failure modes, i.e the limited ways in which the disruption affects the supply-chain". A disruption in supply for example can be caused by a strike, an earthquake or a terrorism action and in each case will have the same impact. The team distinguishes 6 different types of failure modes (see Table 2.1) that are: "Disruption in supply, Disruption in Transportation, Disruption at facilities, Freight breaches, Disruption in communications, and Disruption in Demand."

Table 2.1: Supply-Chain Failure Modes

Failure Mode	Description
Disruption in supply	Delay or unavailability of materials from suppliers, leading to a shortage of inputs that could paralyze the activity of the company.
Disruption in Transportation	Delay or unavailability of the transportation infrastructure, leading to the impossibility to move goods, either inbound and outbound.
Disruption at Facilities	Delay or unavailability of plants, warehouses and office buildings, hampering the ability to continue operations.
Freight breaches	Violation of the integrity of cargoes and products, leading to the loss or adulteration of goods (can be due either to theft or tampering with criminal purpose, e.g. smuggling weapons inside containers).
Disruption in communications	Delay or unavailability of the information and communication infrastructure, either within or outside the company, leading to the inability to coordinate operations and execute transactions.
Disruption in demand	Delay or disruption downstream can lead to the loss of demand, temporarily or permanently, thus affecting all the companies upstream.

Source: MIT research group on "Supply Chain Response to Global Terrorism", Sheffi, Rice, Fleck and Caniato (2003)

"Don't ignore a risk just because you can't quantify it"

.

2.3 Secure the Supply-Chain

There are 3 types of initiatives that are undertaken to secure the supply-chain: "physical security, information security, and freight security."

Lee and Wolfe (2003) argue that it is possible to improve the security without destroying the actual supply-chain effectiveness. Their argument relies on the "quality management" movement that applies to products and claims that it is possible to reduce defects (or increase quality) without increasing costs. Thus, firms must "promote measures that also increase supply-chain flexibility". Applying the principles of this theory to supply-chain security, the authors argue that firms need to focus on prevention rather than inspection and have an advanced process control. It is not reasonable for example to increase too much the inspection rate as this may increase security but also dangerously lowers efficiency.

1) Prevention at the source. As the quality movement puts it: "an investment in prevention pays off handsomely because it drastically reduces the cost of inspection and the number of product failures." Firms need to adopt processes "that prevent tempering a container before, during, and after the loading process." This requires checking thoroughly the personnel who handle the products and enter the facilities. Firms should also watch carefully over the flow of materials, and the handling processes.

   C-TPAT is a program developed by U.S Customs that targets this area. It promotes collaboration between companies and US customs services. The objective is for companies (manufactures, carriers...) to become know and trusted entities to the government; thus they will cross faster the border and add value to their customers.

2) Inspection and process control. US Customs use different techniques to select the shipments that will be checked. First the Automated Targeting System checks historical data about shipments, and inspects only those that present some anomalies. The 24-hour new rule requires that detailed and complete information arrive 24hours before the container is loaded. Another level of screening is non-intrusive inspection and consists in devices that can scan for certain anomalies such as an abnormal density of the container.

   To increase effectiveness the Container Security Initiative (CSI) tries to move inspections in originating ports. This would increase not only security but also "business efficiency": shipments would be safer during transportation and this would reduce the possibility of transportation interruption due to inspection for a particular container. This initiative may be difficult to implement and requires making trade-offs.

Implementation may take time and will require important efforts from many different stakeholders. In brief: most measures and in particular shifting from inspection to prevention will require cultural change, above all with regards to the customs agencies. It will be also necessary to increase the visibility in the relations with the trading partners. It can be formalized in a contract and include "transaction compliance measurement, milestone and obligation monitoring, rebate and charge-back management." (Lee and Wolfe 2003). IT applications will be crucial, in particular in terms of inspection: for example, efforts are required to increase the reliability and the speed of non-intrusive detection systems. At last, public-private partnerships are necessary to coordinate the different actions, share expertise and define a regulation that is adapted both to the business reality and the security requirements.

As security cannot suppress totally risks, firms also need to be able to recover from disruption.

2.4 Build-in Resilience

As already mentioned in the first section of this chapter, resilience is "the ability to bounce back from hardship" (Coutu, 2002). A good illustration comes from Morgan Stanley that realized, after the 1993 World Trade Center bombing, that there was a risk in having offices in such symbolic towers. As a result, it decided to take some serious evacuation measures and to set up some recovery sites where employees could work in case of a new terrorism attack. This allowed the company to save numerous lives on September 11, 2001.

Resilience is a "critical capability". As someone said "More than education, more than experience, more than training, a person's level of resilience will determine who succeeds and who fails" (Coutu, 2002). This also applies to organizations. The MIT research group pointed out two main actions to reach a resilient supply-chain.

1) Firms need to build a resilient organization. As explained by Coutu (2002), these organizations need to have 3 main characteristics.

- First resilient companies are down-to-earth and have a sober view on reality; this means that they accept and face the true reality of their situation and therefore can train in order to survive hardship.

  Interviews that were conducted in 2003 by the research group on “Supply-Chain Response to Global Terrorism” at MIT have shown that best-prepared companies develop contingency plans that identify the different failure modes and define the measure to undertake to respond to them; they detail the different processes and determine the responsibilities. As plans are not sufficient, the most committed firms train their staff and perform simulations and drills.

  Many people insist on the fact that supply-chain risk management should be integrated in the strategic plans as well as cost improvement or innovation. Risks need to be a real concern within the organization and the different departments should cooperate more in order to figure out where the vulnerabilities are and if decisions are wised in that respect.

- Second resilient organizations have a strong set of values. In hardship, such a system helps to give a meaning to the overwhelming present and to make for a “better constructed future”. A shared vision in a company helps to frame an event, and employees all work in the same way for the survival of their organization.

- Third resilient firms are ingenious and can improvise a solution without any obvious toolkit. This quality enables organizations to keep functioning even after an unexpected and hard event. Within the organization, very often, we can also find a strict set of rules that imposes discipline and allows organization to focus on the situation when hardship occurs and thus be creative even under pressure.

“Resilience is a reflex, a way of facing and understanding the world, that is deeply etched into a person’s mind and soul.” (Coutu, 2002)

2) Firms must design a resilient network. Recent articles suggest different approaches in that respect. First it is necessary that firms enhance visibility in the supply-chain to be able to take the appropriate response. More significantly, adding redundancies can be a part of coping with

disruptions. And firms can also design a more flexible supply chain (with no duplication of resources) that will permit to adapt the supply-chain according to the changes.

Many recent articles provide with lists of recommendations. Sheffi (2001) for example explains how adding some redundancies in the supply-chain can help to deal with "the aftermath of terrorist attacks. Martha and Subbakrishna in their article "Targeting a Just-in-Case Supply Chain for the Inevitable Next Disaster" also propose a series of measures and do so by looking at past disasters. Suggested recommendations are summarized in the following of this section.

- Firms must enhance visibility in the supply-chain to be able to take the appropriate response

    - "Comprehensive Tracking and Monitoring". An effective response strategy requires detecting quickly the location and the nature of the disruption. In that respect, firms need monitoring systems, and then an effective measure would be to prioritize the disruptions and define the first actions to take.

    - 'Total Supply Network Visibility". Having information on the rest of the supply-chain can help firms to take appropriate response. For instance, if firms have a clear view on the nature and location of the stocks and flows of goods, as well as on the capacities of its suppliers and transportation providers it can easily re-route goods and re-deploy resources

- Firms can add redundancies (this will be also referred to as "flexibility with duplication of assets" in the continuation). As MIT research group on "Supply Chain Response to Global Terrorism" (2003) puts it, this duplication of resources will "ensure the availability of a backup solution in case of disruption, or at least spread the risk".

    - First firms can diversify supply sources. Such a strategy permitted Chiquita Brands to face successfully Hurricane Mitch in 98 by increasing the productivity at its untouched locations of banana production. By contrast Dole which had only one supplier struggled to find an alternative supplier of banana and suffered form a one-year disruption. Alternate sourcing is not sufficient; visibility on the supplier is also needed. The firm needs to assess the "capabilities and vulnerabilities" of its suppliers.

    - Firms can plan alternate transportation strategies. This comprises alternate delivery routes to bounce back from new regulations at certain checkpoints and alternate delivery modes when conventional transportation channel is weakened. After 9/11 there were huge delays at ports and airports and along the borders of Canada and Mexico's. As a result Ford couldn't get some important components from its Canadian suppliers and had to close temporarily five of its plants. Chrysler on the contrary, identified the problem early enough and used trucks instead of airline transportation so that the delays were minimized.

- Stock has been the traditional way to cover against uncertainty. Sheffi (2001) suggests that companies keep a "strategic emergency stock" to cover the risks of extraordinary events. However determining the adequate level of stock is really tricky. With lean management and just-in-time practices, lead times have decreased a lot as well as inventory, and the benefits have been really important in term of costs and also in term of product quality. Coming totally back on this point doesn't seem reasonable, all the more as inventory costs have become really expensive with shorter product cycles, and an increasing cost of obsolescence. As Martha and Subbakrishna (2002) say "even minor adjustments to inventory can have a major impact on costs", and therefore companies "have to carefully assess whether inventory adjustments are appropriate or whether other supply chain levers provide more effective ways to hedge risk." It is crucial that companies don't over-react.

- Knowledge and process backup. Sheffi (2001) suggests that companies should have emergency business strategies to ensure business continuity. Also, firms should backup the knowledge of their employees in readily available documents.

• Firms can also add flexibility without any duplication of assets to be able to respond to changes in the environment. Having a flexible supply chain will allow firms to adapt the supply-chain according to the availability of resources.

  - In case of a component shortage, influencing the customer demand toward a product that doesn't require such a component can be a good strategy. In that respect, after an earthquake in Taiwan that lead to a shortage in semiconductor crisis Dell managed to influence the demand of his customers toward certain products thanks to discounts and price incentives. Apple triggered the dissatisfaction of his customers by deciding on its own to ship other computers.

  - Firms can also try to lock into forward supply contracts. Gucci implemented this successfully during the destruction of cattle owing to mad cow disease that resulted in shortage of animal hide for leather.

- "Product and Process Redesign". Standardizing the manufacturing processes permits to switch easily from one plant to another, or from one supplier to another. Having more standard components would enable firms to diversify their sourcing base and increase inventory pooling with other sites. "Postponement", or delayed product differentiation, gives the opportunity to companies to change the configuration of one product at last minute in case of short supply of a component due to a disruption.

Those 3 solutions are just an illustration of flexibility. Many other solutions exist. For example, firms can try to implement a flexible workforce and set up arrangements to add labor capacity, or they can make their manufacturing capacity more flexible by dividing up the production of one component in several sites, etc…

2.5 Limitation to Resilience

1) Complexity Vs Resilience

To build a resilient supply chain has many benefits however increasing redundancies and flexibilities in the supply-chain often leads to increase complexity, which works against resilience. Indeed as complexity of the supply-chain increases, uncertainties become more and more important and firms become more vulnerable. As a result it is necessary to find a trade-off between resilience and complexity.

2) Trade-off the risks.

For example, there are risks on relying too much on a single supplier. But a single supplier allows a better protection of the company's intellectual property.

3) Cost-efficiency Vs Resilience.

Firms cannot abandon just-in-time practices as such a system permitted to save a lot of money – estimated at more than $1 billion a year in inventory carrying costs over the past ten years. On view of the recent events, drawbacks of such practices have been highlighted and trade-offs between cost and risks must therefore be assessed. On the one hand, when a decision is made to reduce cost it is necessary to check that risks haven't been increased imprudently. And in the other hand, firms need to determine if greater flexibility is worth the extra cost.

2.6 Conclusions

- Increase the security in the supply-chain and build a resilient network represent a good defense for the next disaster. But more than that, firms can benefit from it and take market share from their competitors that have an insecure and rigid supply-chain

- As MIT research group on “Supply Chain Response to Global Terrorism” (2003) puts it there are “different paths toward the same goal”. Their interview toward several big companies has shown that there is not a single way to protect the supply-chain against risks. At least actions must be coherent with the company’s characteristics. In order to choose a relevant strategy, managers need to analyze the different solutions with adapted tools and frameworks. The objective of the following paragraphs is precisely to illustrate this; the rest of the paper shows how to use real options to study and value flexible strategies by applying the method to the particular example of dual sourcing.

Chapter 3 Multiple Sourcing Approach

Multiple sourcing is often cited as a possible solution to protect against "disruption in supply". However, since the 80's most firms have made a lot of efforts to reduce their supplier base and some of them may be a little reluctant to adopt the multiple sourcing approach. The purpose of this chapter is to explain quickly the current thinking on supplier structure.

3.1 Simple or Multiple Sourcing: Theoretical Approach

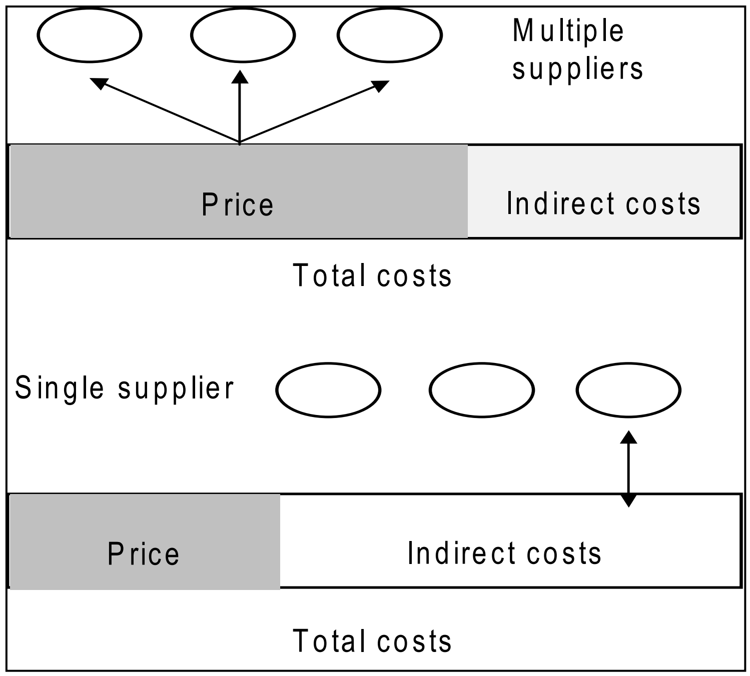
Determining the number of suppliers is one of the key issues of supplier management. Single or multiple sourcing? Each solution has its own advantages and drawbacks, as listed in the table below.

Table 3.1: Single sourcing Vs Multiple sourcing - Benefits of each approach

Single-Sourcing	Multiple-Sourcing
- Get better pricing through higher volumes - Achieve higher quality standards through continuous improvements - Lower costs that are incurred to source, process, expedite and inspect - Increase involvement and have better information - Build stronger and longer-term relationships - Obtain more influence with the supplier - Reduce lead times - Reduce inventory - Streamline the procedure	- Protect the buyer during times of shortages, strikes or other emergencies - Provide a back-up source - Maintain Competition - Keep a market feeling - Avoid complacency on the part of a single supplier - Meet local requirements for international manufacturing locations - Meet customer's volume requirements - When the technology path is uncertain

Source: Adapted from "Purchasing and Supply Management: Supplier Management", Piaw, T.C., (2002), National University of Singapore.

The most adapted approach (single Vs. multiple sourcing) depends on many parameters such as the market structure, the type of products or the cost structure. One factor that is often used is based on sourcing costs. When there are high indirect costs, single sourcing is recommended as high involvement with a single supplier permits to reduce these expenditures. On the contrary, when there are low indirect sourcing costs, multiple sourcing and competitive bidding is more adapted to reduce prices. Figure 3.1 illustrates this segmentation.



Source: "Supplier Relations", Wynstra, F., (2001), Technische Universiteit Eindhoven

Figure 3.1: Single or Multiple Sourcing – Price vs. indirect

More generally, the supplier structure must be aligned with the general principles of the purchasing strategy that has been chosen. To illustrate this point, let's consider Kraljic's portfolio that defines 4 types of commodities, which lead to differentiated purchasing strategies. The segmentation is presented on Figure 3.2.

SUPPLY RISK	HIGH	**Critical/Bottleneck** •Unique specification •Substitution is difficult •Usage fluctuates and unpredictable	**Strategic** •Availability is essential •Supplier Technology is important •Substitution difficult
	LOW	**Non-Critical/Spot** •Commodity type item •Competitive supply market •Substitution available	**Leverage** •Unit cost management is important •Competitive supply market
		LOW	HIGH
		FINANCIAL IMPORTANCE	

Source: "Purchasing and Supply Management: Supplier Management", Piaw, (2002), National University of Singapore.

Figure 3.2: Purchasing Matrix

Each of these commodities requires a different purchasing strategy towards suppliers. The structure of the supplier base and more particularly, the number of suppliers, must permit to manage successfully the supplier relationships as defined through this framework. For example, for strategic items, the company must maximize cost reductions, minimize risk and create competitive advantage. As a result it must seek long-term "Supplier Partnering" agreements and consider joint ventures with selected suppliers and customers to gain mutual advantage. In that case, the fewer suppliers, the easiest and the better.

3.2 Lean Manufacturing and Single Sourcing

In the 80's firms started to adopt new manufacturing strategies and technologies such as just-in-time manufacturing, lean manufacturing or Kanban. Those approaches allowed them to reduce drastically costs and compete better in different markets.

In particular, many companies have streamlined their supplier base following the example of the Japanese manufacturing firms. Some firms adopted single sourcing. Others turned to "tiering" – rearranging the supplier network so that manufacturer deals with limited number of 'main suppliers'. The main objective of this supplier reduction has been to build stronger and longer-term relationships with the suppliers, and to reduce the fixed costs that are incurred by multiple vendor relationships. Examples of such practices are numerous. Xerox reduced its supplier base from 5000 to 400 from 81 to 85 and reduced its lead times from 52 weeks to 18 weeks, as well as its product costs by almost 10% a year. Merck cut 30,000 of its 40,000 suppliers from 1992 to 1997. AlliedSignal reduced its supplier base from 10,000 in 92 to fewer than 2,000 in 97. The estimated savings in 93 are $28 million. Etc, etc…

While cost-effective, single sourcing happens to be very risky as many cases can prove it:

- Ericsson learned painful lessons in the danger of consolidating supply to a single sourcing when its only chips supplier Philips suffered a fire in its plant of Alburque in march 2000. Philips's site became unable to produce the computer chips that its customers, Nokia and Ericson, needed to produce mobile phone handsets. Nokia responded very fast to the lack of supply; the firm realized very early that there was a problem in the flow of chips, and pressured Philips to reroute capacity. On the contrary, Ericsson detected the problem more slowly and when it turned to Philips, it was too late as Nokia had already claimed all the production. The damages were very important for Ericsson as Philips was its only supplier: it reported that the fire contributed to a 2000 loss of $1.8B, and lost almost 4% of market share to Nokia.

- In 1999, several OEMs that were customers of Avon Rubber and Injected Plastics had to help Avon rebuild its firm in England after it took fire. It was the only choice for the customers that soled-sourced from Avon, as none alternate supplier could produce the gaskets with the specifications they needed.

- Land Rover almost had to fire hundreds of his workers due to a dispute with his single chassis vendor, UPF-Thomson. In 2001, UPF had become insolvent and forced to claim bankruptcy protection. It stopped supplying Land Rover with chassis and its lawyer KPMG asked Land Rover to make a multi-million pound "goodwill" payment. An extended shortage was very dangerous for Land Rover and could lead to 1,400 lay-offs in assembly plants. Finally the dispute was settled in court; Land Rover was entailed to pay between 10 and 20 million pounds and UPF had to change its lawyer KPMG.

3.3 Multiple Sourcing as a way to fight against disruptions in supply

Since 9/11managers are more aware than ever of the risks that can represent single sourcing and this approach may have to be revisited. Many experts in supply-chain management and purchasing advise firms to consider more flexible sourcing strategies. Lee and Wolfe (2003) suggest a list of possibilities:

- "Develop multiple supply sources for the same component or input material that will cost effectively enhance flexibility". Adding suppliers often comes with important costs, and firms must look for sourcing strategies that "combine flexibility with cost-efficiency". The new procurement strategy of Hewlett-Packard is a good illustration. First, it relies on a supplier for a fixed quantity and thus enhances efficiency. Then, it calls on a second supplier for flexible quantities, with a lower and higher volume limits, and consequently higher prices. At last, in case demand comes over the quantities contracted with those 2 suppliers, HP buys on the spot market. Martinez-de-Albeniz (2003) studied this approach and proposed a framework to help managers find the optimal portfolio. His work is presented in the appendix A.

- "Create a local supply source". Firms can use local suppliers to supplement their main foreign base in case the demand increases faster than expected, or in case of disruption. HP uses this approach for their DeskJet printers. Their main supplier is in Singapore to benefit from the lower costs of this country, and at the same time it has a local source of supply in Vancouver to respond faster to North American market. This paper studies more in detail this specific solution.

- "Create multiple supply sources with the appropriate manufacturing capacities to build the component when needed. Instead of having multiple suppliers for the same component, a company would merely reserve manufacturing capacity in several suppliers' facilities." And the company would call on one of these vendors in case of problem with the current supplier. Obviously, this require an investment but will provide with the required flexibility,

- "Use a supplier with more than one manufacturing site".

Some people continue to think that single sourcing is very valuable as it is cost-efficient and it permits to reach higher supplier quality and increased internal efficiency. In order to protect against disruption, the solution would be to go deeper in the relation with the supplier, monitor its financial and operational health and even work with him to reduce its vulnerabilities.

3.4 Conclusion

Single sourcing has allowed to reduce a lot sourcing costs and to improve firms' relationships with their suppliers. Those benefits are important, but this approach is also risky. Firms must therefore consider the possibility of relying on several suppliers to cover against disruptions in supply.

In order to make a choice between those two approaches, it may be useful to quantify their values. In that respect, real options are very useful. This tool allows to evaluate the decisions that are made in an uncertain environment, and to take into account flexibility.

Chapter 4 Real Options Presentation

Real Options analysis permits the evaluation of capital investment strategies that are made under uncertainties and integrate flexible decision-making processes. The purpose of this chapter is to explain briefly the concept of real options, show the different methods of valuation and indicate how firms should manage their options.

4.1 Definition

4.1.1 Definition by similarity with financial options

Real options have a definition close to that generally retained for the financial options. Just like them, they can be distinguished according to their nature: there are options to buy (call) and options to sell (put).

Call options give to their holder the right to undertake an investment, at a cost that is fixed in advance (the exercise price), at or before a given date (the maturity). For example keeping unexploited leases can be assimilated to a call option. Oil companies do not sell or exploit these leases as they want to keep the right to develop them later on; they may, for example, decide to use this right if ever new drilling and production technologies allow to increase recoverable reserve. This is a call option since the exploitation makes it possible to get the income of the underlying. Its exercise price is the investment cost to initiate the production, and the maturity is simply the date until which firms have the authorization to exploit.

Put options allow one to give up an investment or to resell it at a price that has been set in advance, at or before a given date. Abandoning a project for its salvage value is a typical example of a put option. For example if the market performs poorly, a company may have a valuable option to abandon its plant permanently in exchange for its salvage value (i.e, the resale value on its equipment and other assets on the second-hand market). In this case, the price of exercise is identified with the value that the plant represents for the company, and this value must be compared with the resale price on the market.

However the similarity between financial and real options is limited and some differences exist.

For example, there is no market for real options. Also, if financial option characteristics are easily known, it is much more difficult to get this kind of information for real options. In fact the main difference comes from the nature of the underlying asset.

4.1.2 The different types of option

There are various types of real options such as options to defer investment, options to expand, options to abandon or options to switch. Table 4.1 introduces the most common types.

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Table 4.1: Most Common Types of Real Options

Option	Description	Type of Flexibility	Guide to Literature
Deferral	Similar to an American Call option. Exists when management can defer the decision about the investment for a certain period of time. They are important in natural resource extraction industries, real estate development, farming and others.	Upside Potential	McDonald and Siegel (1986); Paddock, Siegel and Smith (1988); Tourinho (1979); Titman (1985); Ingersoll and Ross (1992); Dixit (1992)
Timing or Staging	Relates to the possibility of staging investments as a series of outlays to create both growth and abandonment options. Each stage can be viewed as an option on the value of subsequent stages (compound option). They are important in R&D intensive industries, capital-intensive projects and start-up ventures.	Upside Potential and Downside Protection	Brennan and Schwartz (1985); Majd and Pindyck (1987); Carr (1988); Trigeorgis (1993)
Altering Operating State	If market conditions are better than expected, a company may decide to increase its output level by investing in scaling-up the production plant either temporarily or permanently. Equally, if market conditions are adverse the firm might decide to temporarily shutdown production. Both cases are similar to call options. Important in natural resources industries where prices of output may vary constantly, commercial real estate, and in other cyclical industries such as fashion apparel and consumer goods	Upside Potential and Downside Protection	Brennan and Schwartz (1985); McDonald and Siegel (1985); Trigeorgis and Mason (1987); Pindyck (1988)
Growth	A growth option is similar to a European or American call. They exist when early investments in R&D, undeveloped land or reserves of a natural resource, information, create the opportunity of generating further revenues (I.e., developing a product and selling it in the market, exploiting the acquired reserves, and others). Growth opportunities are compound options, whose value depends on a pre-existing option.	Upside Potential	Myers (1977); Brealey and Myers (1991); Kester (1984, 1993); Trigeorgis (1988); Pindyck (1988); Chung and Charoenwong (1991)
Abandon ment	Similar to an American Put. If market conditions deteriorate, management can abandon current operations permanently and recoup the salvage value of the asset. It is important in capital-intensive industries with second-hand markets for their assets, such as the airline industry, railroads and financial services.	Downside Protection	Myers and Majd (1990), Sachdeva and Vanderberg (1993)
Switching	A combination of calls and puts that allow its owner to switch between two or more modes of operation, inputs or outputs. These options can create both product flexibility and process flexibility. They are important in facilities that are highly dependent on an input whose price varies constantly (E.g., oil, or any other commodity), and consumer electronics, toys, and autos industries where product specifications are subject to volatile demand.	Upside Potential and Downside Protection	Magrabe (1978); Kensinger (1987); Kulatilaka and Trigeorgis (1993)

Source: "Managerial Flexibility and Strategy in Resource Allocation", Trigeorgis, L., (1997)

4.1.3 Option Value

Just like a financial option, a real option is an asymmetrical asset because it gives its purchaser the right, but not the obligation, to exercise it. The option holder has the possibility to take advantage of opportunities without having to cope with unfavorable situations. For example, the holder of a lease can choose to exploit if the demand for this ore is high, or on the contrary to give up exploiting if other layers of better quality, at a reduced cost of exploitation, were discovered meanwhile. This is what gives value to the option, as also illustrated on Figure 4.1.

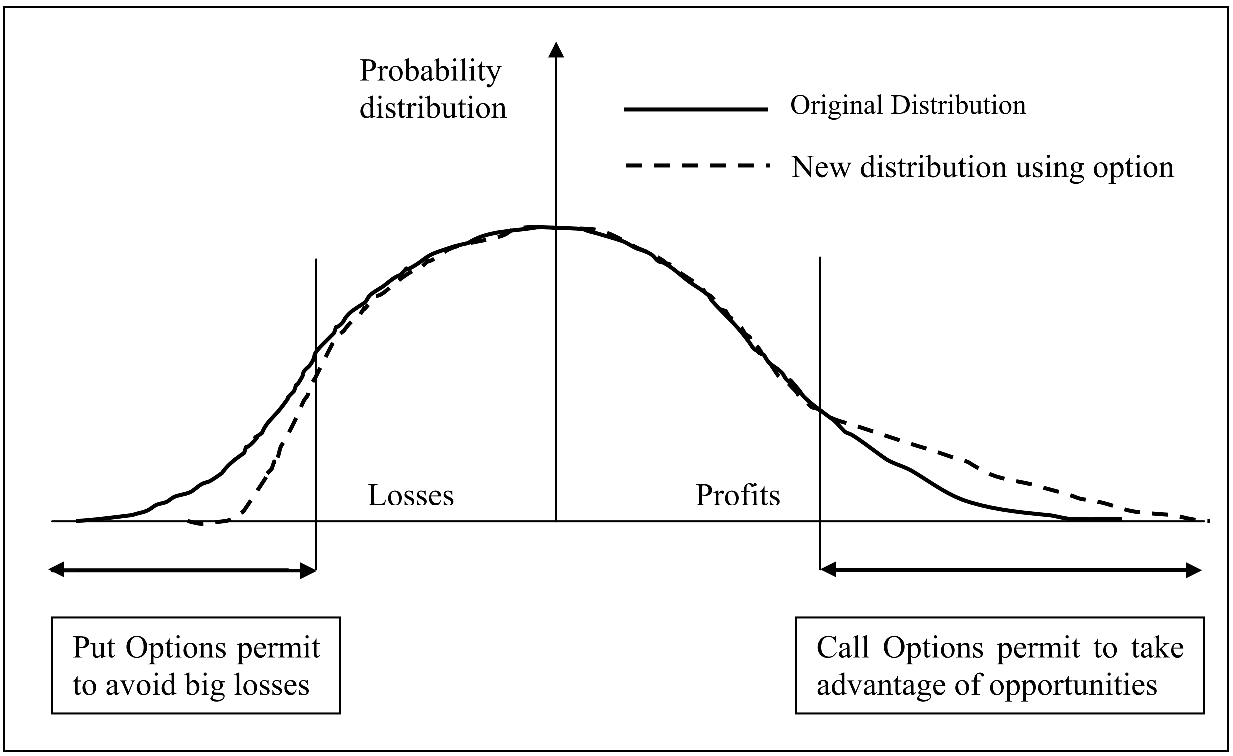


Figure 4.1: Origin of Real Option Value

Real Options match the active way managers operate business and add value as they introduce flexibility that is highly valuable in case of uncertainty. In system design for example, real option thinking is crucial. Engineers are very sensitive to risk minimization, and introduce flexibility in the design of the system so that it continues to work in many different situations.

Real Options are therefore worthwhile as they allow to take advantage of opportunities and to mitigate downsides. But they can also improve company's strategies in other ways. For example, thinking in term of real options emphasizes the logic of opportunism; managers are led to consider all the possible opportunities can come with an investment. Finally, it "promotes strategic leverage" as it forces managers to "exploit situations where incremental investment can keep their company in the game". (Leslie and Michaels, 1997).

4.2 Real Option Valuation

Traditional valuation techniques fail to capture adequately the value of the real options. This chapter first explains the flaws of traditional NPV, and then presents some different techniques of real options valuation.

4.2.1 Traditional NPV

In order to evaluate a project, firms usually use the Net Present Value analysis. Brealey and Myers define NPV as a project's net contribution to wealth – present value minus investment. "When we calculate a project's NPV we are asking whether the project is worth more than it costs. We are estimating its value by calculating what its cash flows would be worth if a claim on them were offered separately to investors and traded in the capital market". This method values future expected cash revenues and investments at a common date, and the NPV is given by the following formula:

$$\text{NPV} = \text{Present Value (Revenues)} - \text{Present Value (Investments)} \tag{1}$$

In order to estimate the present value, cash flows are discounted at a discount rate r.

$$NPV = \sum_{t=1}^{n} \frac{FCF_t}{(1+r)^t} - I_0 \tag{2}$$

with: - n: project lifetime

- FCF_t : Free-Cash-Flows of year t

- r : discount rate

- I_0 : initial investment

The problem from traditional NPV calculation is that it doesn't take into account uncertainty. Let's consider a project whose initial investment is 30 and whose benefits the first year are 50 with probability 0.5 and 100 with probability 0.5. We assume that the "risk-free" discount rate is 10%. We could be tempted to use the NPV formula and evaluate the project in this way:

$$NPV = 0.5 * (-30 + \frac{50}{1.1}) + 0.5 * (-30 + \frac{100}{1.1}) \quad (3)$$

$$NPV = (-30) + \frac{0.5 * 50 + 0.5 * 100}{1.1} \quad (4)$$

$$NPV = (-30) + \frac{75}{1.1} = 38.2 \quad (5)$$

$$NPV = (-30) + \frac{E(\Pr ofits)}{1.1} \quad (6)$$

This calculation presents 2 main flaws:

- First, the formula gives the same value as the one from a project that would require 30 of initial investment and 50 of profits during the following year. This result is wrong and is known as the flaw of average.

  $$E(NPV(X)) \neq NPV(E(X))$$

  The problem can be seen in term of discount rate. The issue is that this calculation relies on the same discount rate for the two projects, that is the risk-free discount rate. A solution would be to use a new discount rate for the project with uncertainty and that would be adjusted according risk: the risk-adjusted discount rate.

- The second problem is subtler. The use of expected pricing techniques doesn't suit the evaluation of a one-time experiment. Probabilities are obtained by repeating the same experiment a very large number of times. Therefore the expected profits would be 75 if we were to repeat the project several times. However, we are dealing here with a one-time experiment; next year the profits will be either 50 or 100 (and the probability to win 75 is zero).

Traditional NPV works only for certain future and assumes that the project will meet a given set of cash flows. As it doesn't take into account uncertainty, all the more so it doesn't integrate flexibility! Traditional NPV is therefore a static valuation method that doesn't include the value of flexibility and undervalues investment made under uncertainty.

In order to value real options, new techniques are required. Most of them rely on financial option pricing.

4.2.2 Option Pricing Theory

The basic idea enabling the pricing of options is to create a portfolio composed of N shares of the underlying asset and B bonds that will replicate the payout of the option. Since the option and the replicating portfolio have the same payoffs, they must sell at the same price to prevent arbitrage profits.

Let's assume that the price of the underlying stock S is currently \$100 and will move either up to \$140 (ie with a multiplicative factor u=1.4) with probability q or down to \$80 (with a multiplicative factor d=0.8) with probability (1-q). Assuming an exercise price of 110, the payouts of the call option contingent on S will be \$30 in the up state and \$0 in the low state. (Table 4.2)

Table 4.2: Binomial Representation of a Call Option and its Underlying

Underlying Stock	Call Option
S=100 → (q) $S^+ = 140$; (1-q) $S^- = 80$	C → (q) $C^+ = \text{Max}(S^+ - 110, 0) = 30$; (1-q) $C^- = \text{Max}(S^- - 110, 0) = 0$

The replicating portfolio is composed of N shares of the underlying risky stock and B dollars of the risk-free bond whose present value is 1\$ per pond. At the end the replicating portfolio has the following payouts:

$$\text{Replicating portfolio in the up state}: N * (\$140) + B(1 + r_f) = \$30 \tag{7}$$

$$\text{Replicating portfolio in the down state}: N * (\$80) + B(1 + r_f) = \$0 \tag{8}$$

If we assume that the B units of default-free bonds pay 8% interest rate, we find:

$$B = -37.04$$
$$N = 0.5$$

and therefore the value of the option is given by:

$$\begin{aligned} \text{Option Value} &= \text{Present Value of the Replicating Portfolio} \\ &= N * (\$100) + B * (\$1) \\ &= \$12.96 \end{aligned} \tag{9}$$

Another approach is to start with a hedge portfolio that is composed of one share of the underlying risky asset and a short position in "m" shares of the call option that is being priced. The ration m is chosen so that the portfolio is risk free over time. Calculations show that:

$$C = \frac{p * C^{+} + (1-p) * C^{-}}{1 + r_f} \tag{10}$$

with $p = \dfrac{(1 + r_f) - d}{u - d}$

In other words, the present value of the call is equal to the expected payouts multiplied by probabilities that adjust them for their risk. Those probabilities are called risk-neutral probabilities.

4.2.3 Real Option valuation techniques

Pindyck suggests two methods to evaluate investments under uncertainty and deal with Real Options.

a) <u>Contingent claim analysis.</u>

Contingent claim analysis relies on financial option pricing. Investment projects with real options are defined by a series of cash flows and represent an asset that a value. If this asset is traded, therefore its price is easily known. If the asset is not traded, the current market is sufficiently rich to permit to replicate it with a portfolio of traded assets. Then the value of the investment project is equal to the total value of the replicating portfolio to prevent arbitrage profits.

Let's analyze further the case where the asset is not traded. Suppose that the profit flow of the project depends on a variable x that follows a geometric Brownian movement:

$$dx = a(x,t)dt + b(x,t)dz = \alpha x dt + \sigma x dz \tag{11}$$

where α is the drift parameter, σ the variance parameter, dz the increment of a Wiener Process.

To value the project we just need to be able to find some other asset that is traded and "tracks or spans" perfectly the uncertainty in x. Let's denote X the price of this "spanning asset". The stochastic process of X must verify:

$$dX = A(x,t)Xdt + B(x,t)Xdz \tag{12}$$

where dz is the same increment of Wiener Process as the one in the stochastic fluctuations of x.

If we assume that the replicating asset pays a dividend at rate $D(x,t)$, its generates the total return:

$$[D(x,t) + A(x,t)]dt + B(x,t)dz$$

where $D(x,t) + A(x,t) = \mu_X(x,t)$ is the required expected return.

Now, let's note F(x,t) the value of the project . The project yields a random capital gain that we calculate using Ito's formula:

$$dF = [F_t(x,t) + \alpha x F_x(x,t) + \frac{1}{2}\sigma^2 x^2 F_{xx}(x,t)]dt + \sigma x F_x(x,t)dz \tag{13}$$

The project also pays a dividend to the owner that is the profit flow $\pi(x,t)$, and therefore the total return per dollar invested is:

$$\frac{\pi(x,t) + F_t(x,t) + \alpha x F_x(x,t) + \frac{1}{2}\sigma^2 x^2 F_{xx}(x,t)}{F(x,t)}dt + \frac{\sigma x F_x(x,t)}{F(x,t)}dz$$

Let's consider a portfolio comprising the project and n units of a short position in X. This costs [$F(x,t) - nX$] dollars and the total return is:

$$[\pi(x,t) + F_t(x,t) + \alpha x F_x(x,t) + \frac{1}{2}\sigma^2 x^2 F_{xx}(x,t) - nX(D(x,t) + A(x,t)]dt + [bF_x(x,t) - nBX]dz$$

To have a riskless portfolio, we must choose n so that $n = \frac{bF_x}{BX}$.

And the expected return of the portfolio must equal the riskless return r, so that:

$$\frac{1}{2}b^2(x,t)F_{xx}(x,t) + \{a(x,t) - [\frac{b(x,t)}{B(x,t)}][\mu_X(x,t) - r]\}F_x(x,t) - rF(x,t) + F_t(x,t) + \pi(x,t) = 0$$

Using limit conditions, this equation can be used to obtain the value of the project.

b) **Dynamic programming**

Contingent claim analysis requires the existence of a traded asset that tracks exactly the uncertainty of our real asset. This is not always possible, and another method is therefore required. In that respect, dynamic programming is quite relevant. This method relies on traditional NPV calculation and, as we can imagine from what we saw previously, it deals with the discount rate in a manner that is less rigorous than with contingent claim analysis. However it presents some advantages and is in fact closely related to contingent claim analysis – those 2 methods lead to the same results in many cases.

The basis of Dynamic programming is to split the whole process of decision in two parts: first, the immediate decision and the remaining decisions.

Let's begin with a discrete time approach. Let's assume that the current state is x_t. We will denote $F_t(x_t)$ the value of the cash flows that will occur in the future if the firm acts optimally from the current state x_t. At each period, the firm has to take a decision that is comprised in the set U_t. This will lead to an immediate profit $\pi_t(x_t, u_t)$. At t, the firms choose the action that will maximize the sum of its immediate payoff and the discounted expected value of the optimal remaining decision process. The result will be the value $F_t(x_t)$.

$$F_t(x_t) = \max_{u_t}\{\pi_t(x_t, u_t) + \frac{1}{1+\rho}E_t[F_{t+1}(x_{t+1})]\} \quad (14)$$

This equation is called the Bellman equation.

If the planning horizon is finite we can solve this problem, by determining the limit conditions and work backward to determine at the end F(x_0), the value of the project.

Let's continue with a continuous approach and consider, as in the contingent claim analysis, that the state variable follows a geometric Brownian movement:

$$dx = a(x,t)dt + b(x,t)dz = \alpha x dt + \sigma x dz\ . \quad (15)$$

Calculations show that in continuous time the Bellman equation becomes:

$$\rho F(x,t) = \max_u\{\pi(x,u,t) + \frac{1}{dt}E[dF]\} \quad (16)$$

$$\rho F(x,t) = \max_u\{\pi(x,u,t) + F_t(x,t) + a(x,u,t)F_x(x,t) + \frac{1}{2}b^2(x,u,t)F_{xx}(x,t)\} \quad (17)$$

To continue, we need to precise the situation. Let's consider the optimal stopping problem. At each period the firm has the choice to stop and get the termination payoff $\Omega(x,t)$. We note $x^*(t)$ the critical values that divide the space in two region, the continuation region above the curve and the termination region elsewhere. The bellman equation becomes:

$$F_t(x_t) = \max_{u_t}\{\Omega_t(x,t), \pi(x,t) + \frac{1}{1+\rho}E[F(x+dx, t+dt)]\} \quad (18)$$

And in the continuous regions, we get the partial differential equation:

$$\frac{1}{2}b^2(x,t)F_{xx}(x,t) + a(x,t)F_x(x,t) - \rho F(x,t) + F_t(x,t) + \pi(x,t) = 0 \quad (19)$$

The boundary limits being:

$$F(x^*(t),t) = \Omega(x^*(t),t) \text{ for all t}\ . \quad (20)$$

The differential equation is quite similar to the one derived from contingent claim analysis. The difference comes from the discount rate that is now considered as exogenous, and the coefficient of F_x. As mentioned earlier, this approach offers a less rigorous treatment of the discount rate. However they are closely relate and each one has its own advantage and drawbacks. According to the situation we may choose one or another.

4.2.4 Numerical Methods

In complex situations it is not always possible to find an analytic solution or even to write a partial differential equation. In these cases it is necessary to rely in numerical solutions that have been considerably enhanced with computing hardwares and softwares.

We can generally divide the numerical methods in two categories:

- First the numerical methods that approximate the partial differential equations such as numerical integration or the finite-difference methods (Brennan 1979, Madj and Pindyck 1987)

- Second the methods that approximate the underlying process. This includes binomial methods developed by Cox, Ross and Rubinstein (1979), and Monte Carlo simulation.

4.2.5 Conclusions

- As we can see the valuation of real options can be quite complex. For absolute precision, managers may need to call on experts with financial knowledge. Nevertheless some frameworks exist that are much easier to implement, and can give a first idea that is relatively good and above all considerably better than a plain DCF analysis.

- Also it is important to point out that determining the exact value of a real option is not always critical. Instead understanding the insights behind real options is far more important, as real options constitute not only a superior valuation tool but also a strategic one! In that respect, Tom Copeland claims that “managers don’t need to be deeply conversant with the calculation techniques of real-option valuation”.

4.3 How to Manage Real Options?

Once you have "acquired" a real option you need to manage it actively and keep monitoring its changing characteristics over time in order to make the best use of it. In this paragraph, two approaches are presented that will explain how to deal optimally with options you have introduced in your projects.

4.3.1 Proactive flexibility, a way to increase option value once acquired

Leslie and Michaels (1997) argue that it is possible to increase the value of real options once they are acquired. They refer to this concept as "proactive flexibility".

"Proactive flexibilities" exist by contrast to "reactive flexibilities", "flexibilities an option holder exploits to respond to environmental conditions and maximize his or her payoff". This refers to the traditional notion of option flexibility and is common to financial as well as real options. For example an option holder can decide *whether* to undertake a project and *when* to start it in order to optimize his payoff.

"Proactive flexibilities" are proper to Real Options (not Financial Options) and, according to Leslie and Michaels, constitute their "real power". This is "the flexibility to take in ways that will enhance the value of an option once acquired".

To explain this statement we need to quantify the value of real options. More simple options can be valued thanks to the Black and Scholes formula, which is used to value financial options:

$$V = Se^{-\delta t} * N(d_1) - Xe^{-rt} * N(d_2)$$

where: $d_1 = [\ln(\frac{S}{X}) + (r - \delta + \frac{\sigma^2}{2}) * t]/(\sigma\sqrt{t})$

$$d_2 = d_1 - \sigma\sqrt{t}$$

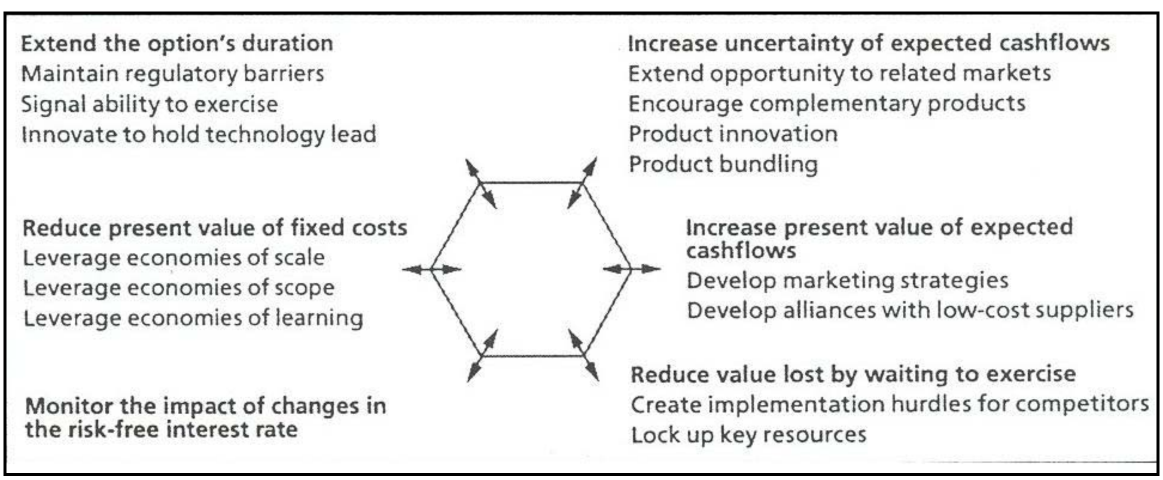
S is the stock price, X the exercise price, δ the dividends, r the risk-free rate, σ the uncertainty, t the time to expiry and N(d) the cumulative normal distribution function.

This formula shows that the value of real options depends on 6 levers that are:

- The stock price (S) which is the value of the underlying asset, calculated as the present value of the cash flows of the project without flexibility.

- The exercise price (X) which is the present value of all the fixed costs expected over the lifetime of the investment opportunity
- Uncertainty (σ) which is the volatility of the underlying asset.
- Time to expiry (t) is the time to expiration of the option
- Dividends (δ), which represent the value, that goes away from the option along time.
- Risk-free interest rate (r), which is the interest of a riskless security that has the same maturity as the duration as the option.

As a result, option holders can influence the value of their real options by pulling one or more of these 6 levers. Proactive Flexibility designates this opportunity to "increase the value of an option once acquired." This is proper to real options as financial options are exchanged in a deep and transparent market and holders have no control on the 6 correspondent parameters. Figure 4.2 describes the different actions that management can take to manage proactively flexibility.



Source: Leslie and Michaels, "The real Power of Real Options", The McKinsey Quarterly (1997)

Figure 4.2: Managing Real Option Proactively

The most counterintuitive lever is the one that consists in increasing the uncertainty of expected cash flows. Managers tend to view all forms of risk as bad, but higher uncertainty increases the value of flexibility and therefore the option value. For example, let's assume that a person has acquired a spare tire for his car, which will allow him to make a replacement in case of flat. This option has a value for the driver if he uses his car in the city of Boston. If ever he considers taking his car during his holydays in Mexico where roads are less kept, the risks of flat are higher and his spare tire becomes even more valuable.

If Black and Scholes valuation formula is only valid for a limited set of real options (many assumptions are embedded in this model; the option may be exercised only at maturity, there is only one source of uncertainty, the underlying pays no dividends etc….), the qualitative results on Proactive Flexibility remain true for all kind of real options.

4.3.2 Option Portfolio Management

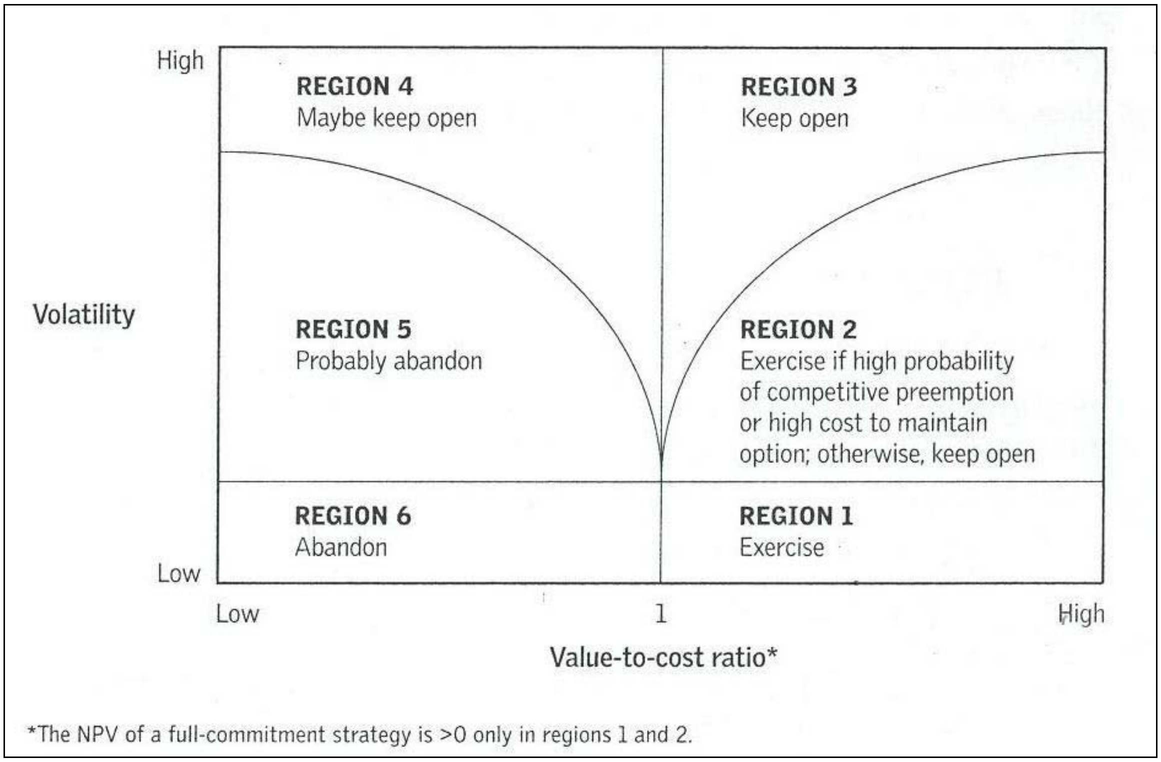
This paragraph provides with a framework to help firms manage dynamically their options, and decide when to exercise or on the contrary defer or abandon the option. This is the result of the work from Luehrman (1998).

He defines an option space that is determined by 2 different metrics:

- Volatility which is equal to "the per-period standard deviation in asset returns (uncertainty) multiplied by the square root of the option's time to expiration (duration)."
- "Value-to-cost ratio" which is equal to "the present value of the asset (stock price or present value of cash flows) divided by the present value of the expenditure required to exercise the option (the exercise price of the option at the option's expiration date, discounted back to present value using the appropriate risk-free rate)."

Real option value increases with volatility and value-to-cost ratio. As the ratio tends to decrease over time (the present value of the exercise price increases), this framework represents the trade-off between the costs of exercising that go up over time and volatility (if volatility is high, deferring allow managers to learn about business conditions or competitors' actions, and they can optimize as circumstances change).

As shown in Figure 4.3 this option space is divided in 6 regions; it allows firms to characterize and update their option management strategy.



Source: Courtney, "20/20 Foresight, Crafting Strategy in an Uncertain World", Harvard Business School Press, Boston, Massachusetts, (2001)

Figure 4.3: Six-Region Option Portfolio Management Framework

- Region 1 represents projects whose value-to-cost ratio is greater than one, and where there is no volatility (either the time has run out or there is no uncertainty as for cash flows). The NPV of an immediate full commitment is positive and firms should exercise the option.

- In region 2, the value-to cost-ration is greater than one, the NPV of an immediate full commitment is also positive, but the volatility is higher. Firms should consider exercising right away the option only if it is too costly to keep the option alive and if there are too many risks of "competitive preemption". This will constitute a big bet, as volatility is high.

- In region 3 the NPV, the value-to cost-ration is greater than one, the NPV of an immediate full commitment is negative, and the volatility is high. Firms should wait to exercise the option due to the important uncertainty, and they may be very likely benefit from a future upside.

- In Region 4, the value-to-cost ratio is lower than one, the uncertainty is high and the NPV of an immediate full commitment is negative. It is not wise to exercise the option right away but the firm keeps the option open as the very high volatility can potentially give access to high upsides.

- In region 5, the situation is the same as in region 4, except for volatility that is lower. In that case it is less likely that the option will be in the money later and firm may consider abandoning this option.

- In Region 6, as in region 4 and 5 the NPV of an immediate full commitment is negative and the value-to-cost ratio is lower than one. As the volatility is very low the option will quite certainly stay out of the money and managers should abandon such options.

As Courtney (2001) puts it in his book "20/20 foresight", this method is relatively new and it is difficult to give much evidence of its efficiency. However some big firms happen to use this method successfully. It is a useful quantitative and qualitative tool to help firms decide on their strategy and update their option portfolio.

For a good implementation, it is necessary to track the different measures that are volatility and cost-to-ratio as well as the NPV of the different option. Accordingly firms can revise their strategy.

Chapter 5 Modeling Dual-Sourcing as a Real Option

This chapter shows how to use and value real options by applying the concept to dual sourcing.

5.1 The model

The problem is inspired from Sheffi (2001). A firm sells a product whose per unit output price Pr, and whose demand D changes along time. The firm has two suppliers, supplier 1 in a foreign country and supplier 2 that is a local supplier and sells the product at a more important price. The company estimates that there is a probability p that the foreign supplier will be disrupted and will not be able to deliver for an extended period. To cover this risk the firm can decide to and gives him a portion x of the production if it guarantees to supply all of the company's requirements should the need rise. Taking two suppliers requires an initial investment I, to which we will refer as the initial investment cost. Once the firm has taken two suppliers, the choice is not definitive; it can cancel the new arrangement and give back all its production to the main foreign supplier. Also, the firm can decide to abandon totally the main supplier and to rely only on the local supplier.

All these decisions are made under uncertainty and evolve along time. In particular, by making a contract with the local supplier, the firm takes an option to have a back up in case of disruption. Real Options constitute a relevant tool to value this flexible process.

5.2 Model Formulation

5.2.1 State variables and associated dynamic

The production horizon is given by $[0,T]$ where T depicts the product's lifetime termination. We divide time up into discrete periods of lengths Δt.

Let $D(t), t \in [0,T]$ define the demand quantity over the production horizon $[0,T]$ where T depicts the product's lifetime termination.

The demand D(t) is assumed to follow a Geometric Brownian Movement with Drift.

$$dD = \alpha dt + \sigma dz \tag{21}$$

where dz is the increment of a Wiener Process, α the drift parameter, and σ the variance parameter.

Translated in discrete terms, in each period the variable D either moves up or down by an amount

$$\Delta D = \sqrt{\sigma^2 * \Delta t + (\alpha - \frac{\sigma^2}{2})^2 * (\Delta t)^2} \tag{22}$$

The probability that it moves up is

$$p_{up} = \frac{1}{2} * (1 + (\alpha - \frac{\sigma^2}{2}) * \frac{\Delta t}{\Delta D}) \tag{23}$$

The disruption dates $(q_1, q_2, ..., q_n, ...)$ follow a Poisson process, with mean arrival rate λ, meaning that during a time interval of length Δt, the probability that a disruption will occur is given by $\lambda \Delta t$, and the probability that a disruption will not occur is given by $1 - \lambda \Delta t$.

Let's note N the normal state, when the main supplier is able to produce normally and Di the disruption state when the main supplier is unable to do business due to a recent disruption. Let assume that the disruption state lasts for a period P once a disruption has occurred.

If the firm is in the normal state, the probability to pass to the disruption state is

$$p_{n \to d} = \lambda dt \tag{24}$$

If the firm is in the disruption state, the probability to pass to the normal state depends on the time of the last disruption q.

If $(t - q) < P$,

$$p_{d \to n} = 0 \tag{25}$$

$$p_{(d \to d)\text{ and last disruption at q}} = (1 - \lambda * dt) \tag{26}$$

$$p_{(d \to d)\text{ and last disruption at t}} = \lambda * dt \tag{27}$$

Else, if $(t-q) \geq P$

$$p_{d \to n} = 1 - \lambda dt \tag{28}$$

$$p_{(d \to d)\text{ and Last disruption at t}} = \lambda dt \tag{29}$$

Let's consider that at t the state of the world is represented by the couple (D(t), N) if the state of the main supplier is normal, or by the triplet (D(t), Di, Time of the last disruption q) if the main supplier is in the disruption state. The different future states and probabilities that are associated are represented in the figure below.

Initial State at t Normal	Possible states at t+ Δt	Probabilities
(D(t),N)	(D+ ΔD, N)	$p_{up} * p_{n \to d}$
	(D+ ΔD, Di, t)	$p_{up} * (1 - p_{n \to d})$
	(D- ΔD, N)	$(1 - p_{up}) * p_{n \to d}$
	(D- ΔD, Di, t)	$(1 - p_{up}) * (1 - p_{n \to d})$

Initial State at t Disruption	Possible states at t+ Δt	Probabilities
(D(t),Di,q)	(D+ ΔD, N)	$p_{up} * p_{d \to n}$
	(D+ ΔD, Di, q)	$p_{up} * p_{(d \to d)\text{ and Last disruption at q}}$
	(D+ ΔD, Di, t)	$p_{up} * p_{(d \to d)\text{ and Last disruption at t}}$
	(D- ΔD, N)	$(1 - p_{up}) * p_{(d \to n)}$
	(D- ΔD, Di, q)	$(1 - p_{up}) * p_{(d \to d)\text{ and Last disruption at q}}$
	(D- ΔD, Di, t)	$(1 - p_{up}) * p_{(d \to d)\text{ and Last disruption at t}}$

We will describe the firm's current status by a state variable X. At any date or period t, the current value of this variable X_t is known, but future variables $X_{t+1}, X_{T+2} \dots$ are random variables.

5.2.2 Control variables

At t, the firm can decide to change its sourcing strategy and decide to use dual sourcing if ever it has only one supplier, or on the contrary to abandon one of its supplier if it currently uses two. The firm can also decide to abandon its main supplier to rely only on the local supplier, or vice-versa. At last, the firm can simply decide to maintain its current sourcing policy. We represent these different choices by the control variables that can be equal to K_{MS} (keep main supplier), K_{LS} (keep local supplier), K_{DS} (keep dual sourcing), T_{DS} (change sourcing strategy to dual sourcing), T_{LS} (change sourcing strategy to take local supplier only), T_{MS} (change sourcing strategy to take main supplier only). The set of control variables is denoted U.

5.2.3 Profit Function

The firm sells devices on the US market and buys its main components from a foreign manufacturer. This supplier delivers the components at a price of $\mathrm{w_M}$ dollars per piece and the devices are sold at P dollars a piece. Fixed costs including marketing and channel setup have been estimated at c dollars per device. Thus, using only the main supplier, in the normal state the company can make profits of:

$$\pi_{\text{Main Supplier}} = \mathrm{P} - \mathrm{w_M} - \mathrm{c} \quad \text{dollars per device} \tag{30}$$

The local supplier delivers the same components at a higher price $w_{L1} \geq w_M$, and on products using these components the firm makes a profit of

$$\pi^1_{\text{LocalSupplier}} = \mathrm{P} - \mathrm{w_{L1}} - \mathrm{c} \quad \text{dollars per device} \tag{31}$$

and $$\pi^1_{\text{LocalSupplier}} < \pi_{\text{Main Supplier}} \tag{32}$$

Under a dual supply arrangement the local supplier may be given a portion x of the business if it guarantees to supply all of the company's requirements should the need arise.

For the proportion x (where $x < 100\%$), the local supplier sells the components at a price $w_{L2} \geq w_{L1}$ in order to take into account the scale effect. On these components the firm makes a profit of

$$\pi^{2}_{\text{LocalSupplier}} = \text{P} - \text{w}_{\text{L2}} - \text{c} \quad \text{dollars per device} \tag{33}$$

There is a cost premium to ask the second supplier to increase its production from x to 100% in case of disruption of the main supplier. As it is very expensive for the supplier to ramp up quickly its production, it will provide immediately the remaining components at a price $w_{L3} \geq w_{L2} \geq w_{L1}$. The selling of the remaining components is guaranteed only for a limited time – until the end of disruption - which can also justify a higher price. The profits made on these components are:

$$\pi^{3}_{\text{LocalSupplier}} = \text{P} - \text{w}_{\text{L3}} - \text{c} \quad \text{dollars per device} \tag{34}$$

Another alternative to model the cost premium is to add a delay in the supplying of the remaining components as it may require time for the local supplier to increase its production for the firm.

The total profits of the firm depend on two elements that are the state of the main supplier (normal or disruption) and the type of sourcing contract that the firm has taken (single or dual sourcing). Table 5.1 prevents those profits in the case of three different prices from the local supplier (w_{L3}, w_{L2}, w_{L1}) and no delay.

Table 5.1: Firm Profits

	Single Sourcing Main Supplier	Dual Sourcing	Single Sourcing Local Supplier
Normal State	$\pi_{\text{Main Supplier}}$	$(1-\text{x}) * \pi_{\text{Main Supplier}} + \text{x} * \pi^{2}_{\text{LocalSupplier}}$	$\pi^{1}_{\text{LocalSupplier}}$
Disruption State	0	$(1-\text{x}) * \pi^{3}_{\text{LocalSupplier}} + \text{x} * \pi^{2}_{\text{LocalSupplier}}$	$\pi^{1}_{\text{LocalSupplier}}$

Seeing the costs assumptions, profits are linear with the demand.

Changing supplier or adding a supplier requires an investment. Indeed, the firm needs to allocate resources to define a new supplying contract and set up a new purchasing process. The different investment costs are denoted $\mathrm{I}_{\mathrm{MainSupplier->DualSourcing}}$, $\mathrm{I}_{\mathrm{LocalSupplier->DualSourcing}}$, $\mathrm{I}_{\mathrm{MainSupplier->LocalSupplier}}$ and $\mathrm{I}_{\mathrm{LocalSupplier->MainSupplier}}$.

5.2.4 Other assumptions

In the model we can easily add some assumptions to make it more real.

For example, as just defined the model doesn't take into account the loss of market share that can happen when the firm is not supplied anymore. We can therefore improve the model by assuming that the supplier looses x% of his market share each year of disruption if ever he relies on single sourcing.

5.3 Valuation Model

The goal of the firm is to maximize its profits. In order to choose the best sourcing strategy, the firm needs to evaluate the different solutions. This valuation is to be done in an uncertain environment, and must integrate a flexible decision process along time. This can be done using Real Options.

We will use Dynamic Programming and Bellman equations, as Contingent Claim Analysis is not adapted in our case. Disruptions occur according to a Poisson Process and as a result it is impossible to find an asset that duplicates the stochastic dynamics of the firm's profits.

The state and the control at time t affect the firm's immediate profit flow, which we denote by $\pi_t(X_t, U_t)$.

The aim is to choose the optimal vector of control variables $\{U_t\}$ as a function of time such that the total value of the payoffs at the initial time is maximized.

The basic idea of dynamic programming is to split the decision sequence into two parts, the immediate period and the whole continuation beyond that.

Suppose that the current date is t and the state is X_t. Let us denote by $F_t(X_t)$ the value of all the future payoffs when the firm follows the optimal decision process from this state.

When the firm chooses the control variables U_t, it gets the profit flow $\pi_t(X_t, U_t)$ at t. At the next period (t+1), the state will be X_{t+1}. The firm will get $F_{t+1}(X_{T+1})$ if it follows the optimal decision process from this point onwards. As a t, the future is uncertain, it expects to get on average $E_t[F_{t+1}(X_{T+1})]$. Therefore if the firm chooses U_t at t and makes all decisions optimally afterwards it will get: $\pi_t(X_t, U_t) + \frac{E_t[F_{t+1}(X_{T+1})]}{1+\rho}$, where ρ is the discount rate.

The firm will choose U_t to maximize this, and the result will be the value $F_t(X_t)$. Thus

$$F_t(X_t) = \max_{U_t}\left\{\pi_t(X_t, U_t) + \frac{E_t[F_{t+1}(X_{T+1})]}{1+\rho}\right\} \qquad (35)$$

The above is the Bellman equation.

The optimal sourcing strategy $\{U_t\}$ is determined by the different Bellman equations, and its value is given by:

$$F_0(X_0) = \max_{U_{0t}}\left\{\pi_0(X_0, U_0) + \frac{E_0[F_1(X_1)]}{1+\rho}\right\} \qquad (36)$$

To solve this problem, we work backward all the way to initial conditions. We start at the end of the horizon T. At this point there are no future states, and no expected value of F. We can therefore determine the optimal decision u_T given the state X_T. We can also determine $F_T(X_T)$ and $E_{T-1}[F_T(X_T)]$. Next, we can go one step backward to (T-1) and determine u_{T-1} using the equation 35 for t=(T-1) as we know every term. The procedure is repeated by taking another step backward to T-2, and continuing to iterate until the very beginning at t=0.

5.4 Programming on Matlab

To solve the sequence of computations we used MATLAB. A lattice, as represented on Figure 5.1, models the demand evolution.

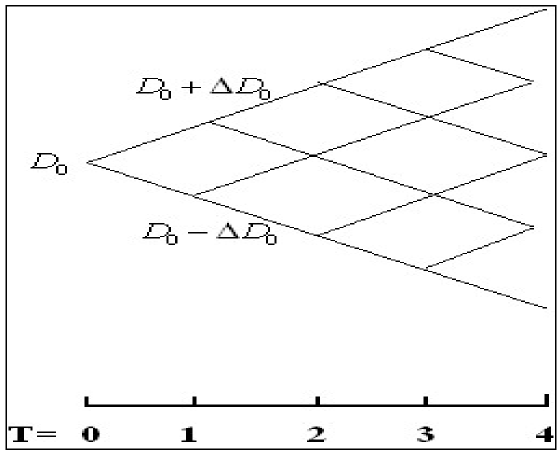


Figure 5.1: Demand Model - Lattice Tree

For each node, the firm can either be in the normal or disruption states, and the program calculates the values of the sourcing strategy in both situations. It is important to notice that the value in the disruption state depends on the past; indeed the probabilities of going in the next state depend on the moment of the last disruption. As a result, at t, for any demand node, the program does t calculations in order to take into account all the possible states of disruption, and one calculation to take into account the normal state. As there are t nodes at t, the number of calculations is $(t+1)*t$ per period. To cover the whole tree, the programs does $\sum_{i=1}^{T}(t+t^2) = \frac{T(T+1)}{2} + \frac{T(T+1)(2T+1)}{6} \underset{T\infty}{\approx} \frac{T^3}{3}$ calculations.

This high idea of size is due to the fact that the process is path dependent, and as a result running the program may take a few minutes.

The detailed MATLAB program is presented in Appendix C.

5.5 Discussion on the methodology

To tackle this problem writing and solving stochastic equations is difficult as the value at t depends on the past and more particularly on the moment of the last disruption. Such a numerical approach, as binomial lattices, makes the resolution easier.

This methodology can also be used to quantify other flexible strategies that firms could envisage in order to avoid disruptions. For example, firms could rely on this approach to determine the optimal safety stock to cover against disruption shortages.

Chapter 6 Results of the Model

This chapter presents a view of the results obtained thanks to real options analysis.

6.1 Sourcing strategy depends on the intensity of disruption risks.

The company estimates that there is a probability p that the foreign supplier will be disrupted and will not be able to deliver for an extended period. To cover this risk the firm considers the possibility to take a second supplier. Actually the firm can also choose to abandon totally the main supplier and rely only on the local supplier. Let us call the three different possible sourcing strategies, respectively: "main supplier strategy", "dual sourcing strategy" and "local supplier strategy". To decide, the firm needs to weigh the benefits and costs of each solution, as listed in the table below.

Table 6.1: Pros and Cons of different sourcing strategies

Strategy \ State	**Normal Situation**	**Disruption Situation**
Main Supplier	⊕ Cheap (Price w_M)	⊖ Shortage of components ⊖ Loss of market share
Dual Sourcing	⊖ Costs to maintain dual sourcing. ⊖ Components delivered by local supplier are more expensive (Price $w_{L2} > w_{L1}$)	⊕ 100% supply ⊖ Costs to maintain dual sourcing ⊖ Extra components are more expensive (Price $w_{L3} > w_{L2} > w_{L1}$) ⊖ Delay
Local Supplier	⊖ Expensive (Price $w_{L1} \geq w_M$)	⊕ 100% supply ⊕ Cheap (Price $w_{L1} < w_{L2} < w_{L3}$) ⊕ Continuous supply – No delay

The model we developed in the previous chapter permits one to get quantitative results, and obtain the total value (benefits-costs) of each strategy over the product lifetime. Let us consider that the firm has not launched his project yet and wants to evaluate the different sourcing strategies. We also assume that the company sticks to the same sourcing approach until the end and that all parameters stay constant over time. Lastly, we take the immediate investment costs to implement the different sourcing strategies equal to zero. The detail of the different parameter values that were used to obtain the results is given in Appendix B.

The optimal sourcing strategy depends on the intensity of the risk. Figure 6.1 shows that dual sourcing is the best solution for a limited range of disruption frequencies $[\alpha_1;\alpha_2]$.

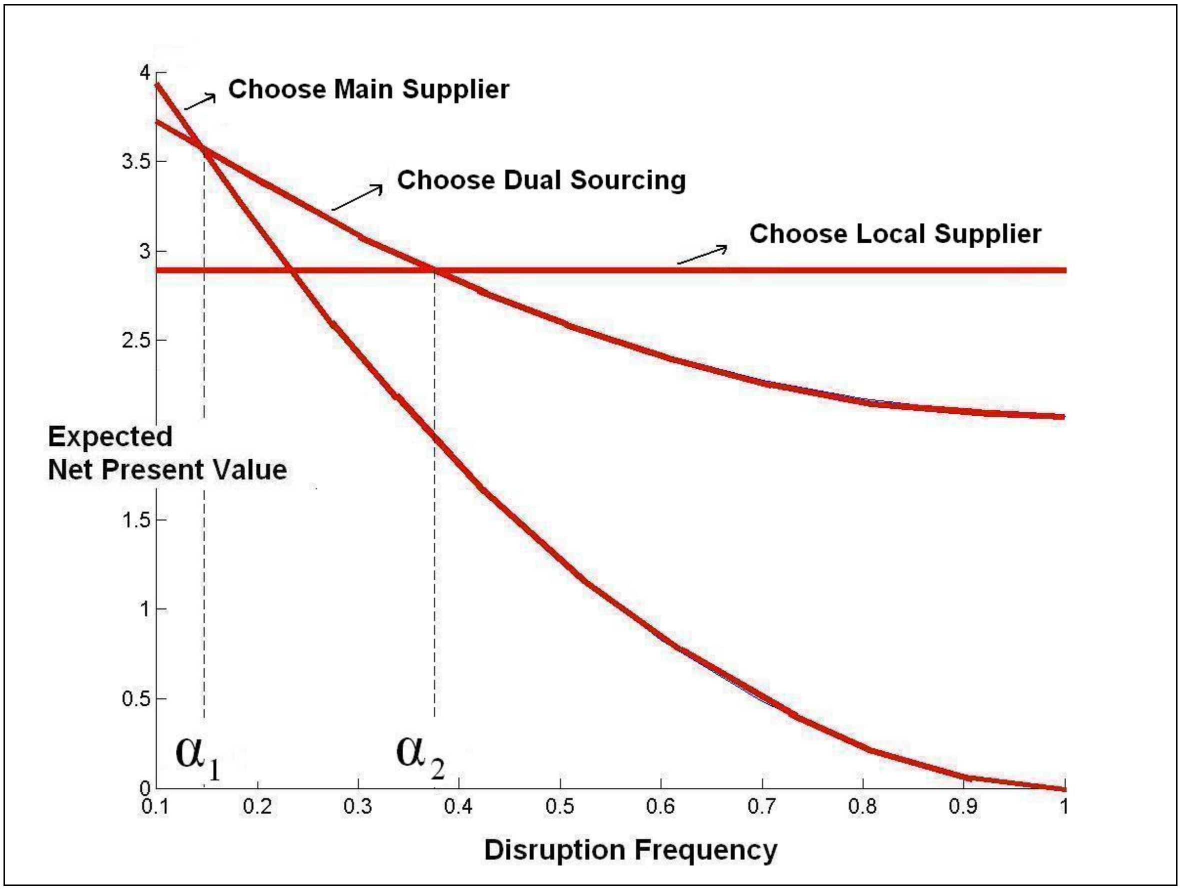


Figure 6.1: Optimal Sourcing Strategy According to Disruption Frequency

The figure presents the expected profits (or expected net present value) that the firm will make over the product lifetime according to the sourcing strategy it chooses and the disruption frequency. As we can easily understand, if the firm decides to rely only the local supplier, the profits he will make do not depend on the disruption frequency of the main supplier. On the contrary, if the company uses the main supplier its profits will decrease with the disruption frequency. We distinguish 3 different cases:

- When the disruption probability is very low, the best sourcing strategy is to rely only on the main supplier. Thus the firm will expect the most profits as the main supplier is relatively reliable (the disruption costs are not high enough to justify a second supplier), and its prices are the cheapest.

- Between α_1 and α_2, the main supplier is less reliable and the supply is likely to disrupt. Since the disruption costs are higher, the firm finds it valuable to make a supply arrangement with the local supplier in order to hedge the disruption risk.

- When the disruption probability is sufficiently high, the main supplier is very likely to default and the firm calls on relatively often on the second supplier. The problem is that the dual sourcing option is very expensive: in case of disruption the local supplier adds a premium to the extra components in order to reflect the emergency of the command, and there may even be a short delay. Moreover keeping the two vendors requires high maintenance costs. As a result, it is better to rely directly on the second supplier that will sell the products at its regular price and without delay.

6.2 Sensitivity Analysis

The values of the sourcing strategies depend on numerous parameters. To cite only a few of them: prices of local and main suppliers, duration of disruption, loss of market share in case of no supply, delay in supply by the local supplier, forecast of demand evolution etc…

Sensitivity analyses permit to measure the impact that each of these parameters has on value, and determine the most important drivers. Let us vary for example the price at which the local supplier sells its components in case of disruption (i.e. the price of the extra components denoted w_{L3} in the model). A change in price will affect the value of the "dual sourcing strategy", but not the value of the "local supplier strategy". In Figure 6.1, this price is taken equal to \$360 (the product selling at 400\$), and if the disruption probability is 0.25, dual sourcing is the best sourcing strategy. If ever the local supplier increases his price, relying on dual sourcing becomes less interesting and Figure 6.2 shows that if the price exceeds P1, this solution is no longer the most appropriate. Knowing this break-even is useful when negotiating the contract with the local supplier.

Figure 6.2 gives another type of information. It permits the measure of the impact that price has on value. Let us say that the firm considers that a change of 0.1 in value is consequent. The actual price being $360, Figure 6.2 shows that this change corresponds to a change in price from 360 to 365 dollars or from 360 to 355 dollars. As a result the firm knows that it must be very careful on the local supplier prices and that a variation in price of only 5 dollars (plus or minus) has important consequences.

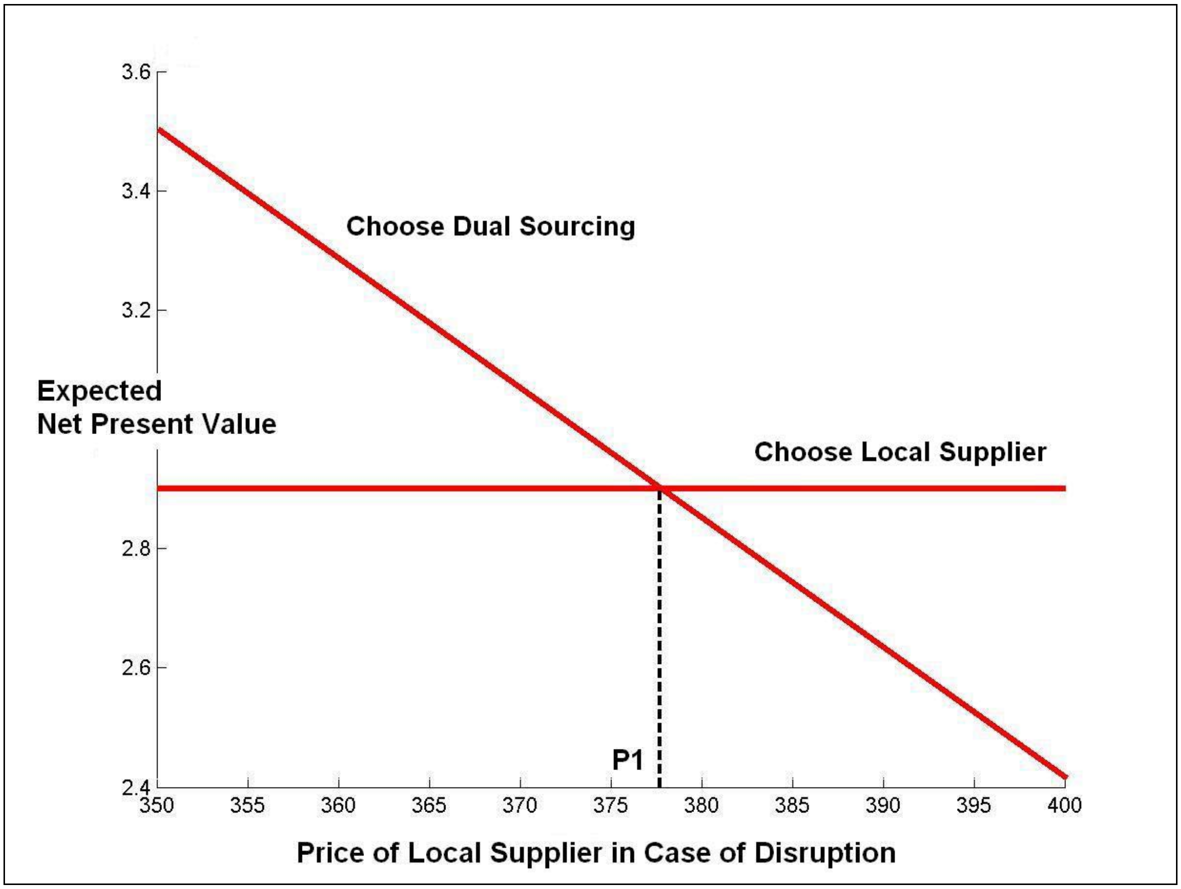


Figure 6.2: Variation in value according to the changes in price from the local supplier

Another way to think about this problem is to look at the rate of variation of the value per unit of a parameter. The higher the rate, the most impact the parameter has on value and the most attention the firm must pay to it.

Doing sensitivity analysis for all parameters allow one to organize them into a hierarchy and to identify those that have the most impact. If we deal with parameters on which the firm can have a control, such a hierarchy is useful as the company can concentrate its efforts on the most important drivers – in particular at the time of negotiation. It is also valuable to know which exogenous parameters affect a lot the value; with such information the firm knows which ones are to be valued with most accurately in order to get precise results. More generally, knowing the quantitative impact of exogenous variables permits a determination of the accuracy of the result.

In the analysis just done the firm has not launched his project yet and is "starting from zero" in term of supply. Let us consider a new case. Now, the firm currently relies on the foreign supplier and is considering changing is sourcing strategy. One parameter that is important is the investment price to realize this change (either the immediate investment price to use two suppliers, or the one to change for the local supplier). If the disruption the disruption probability is 0.25, Figure 6.1 shows that dual sourcing is the best solution; in our new situation, this means that if the investment price to use dual sourcing is zero the company should make a contract with the local supplier in addition to the foreign supplier. However, the investment is not very likely to be zero and it is important that the firm knows until which amount it can considers dual sourcing. When the investment cost increases the value of taking a second supplier decreases. Figure 6.3 shows that I1 is the limit investment; once exceeded this break-even, the costs are too expensive to justify the benefits of dual sourcing.

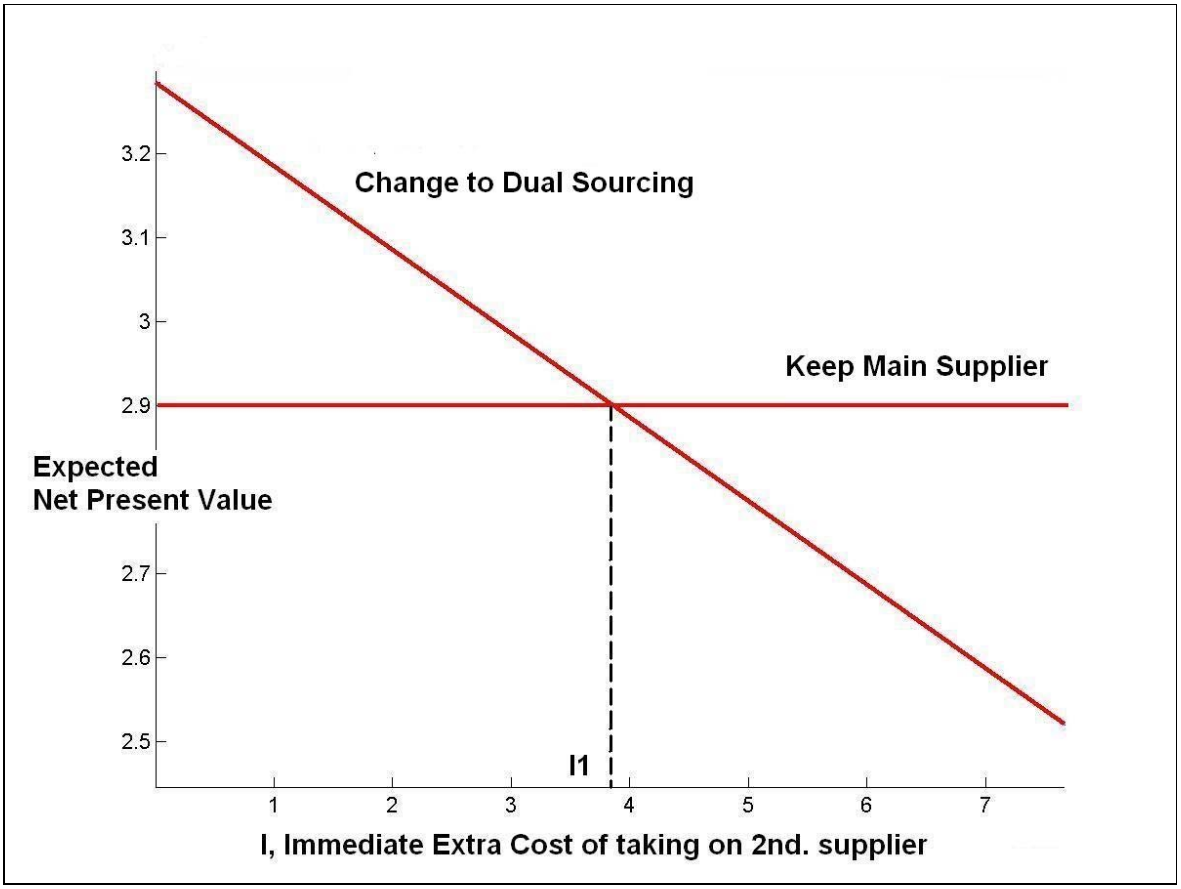


Figure 6.3: Impact of investment costs on the sourcing strategy

6.3 More Options Thinking: Delay Option

The firm faces not only disruption risks, but also demand uncertainty. The new product it has just launched may be a real hit or just a flop. The company can deal with this uncertainty and take options on it to add value to its sourcing choice.

Assume that the firm has actually only one supplier (the foreign one) and disruption risks are such that dual sourcing is the best strategy. The firm considers the possibility of making arrangements with the local supplier but this will require an immediate extra investment cost I (denoted $I_{MainSupplier->DualSourcing}$ in the model). Calling on a second supplier will be justified if the firm effectively manages to sell its products successfully. If it is not the case, the company would have been better off keeping its main supplier, since investing in dual sourcing would cost too much compared to the low benefits in case of disruption. The problem is that the firm does not know what will happen. To hedge this demand uncertainty, the firm can delay its decision to observe changes over time and make the right decision at the right time. In the real option theory, this is called a delay option. Figure 6.4 points out the value that is added by delaying the decision to take a second supplier.

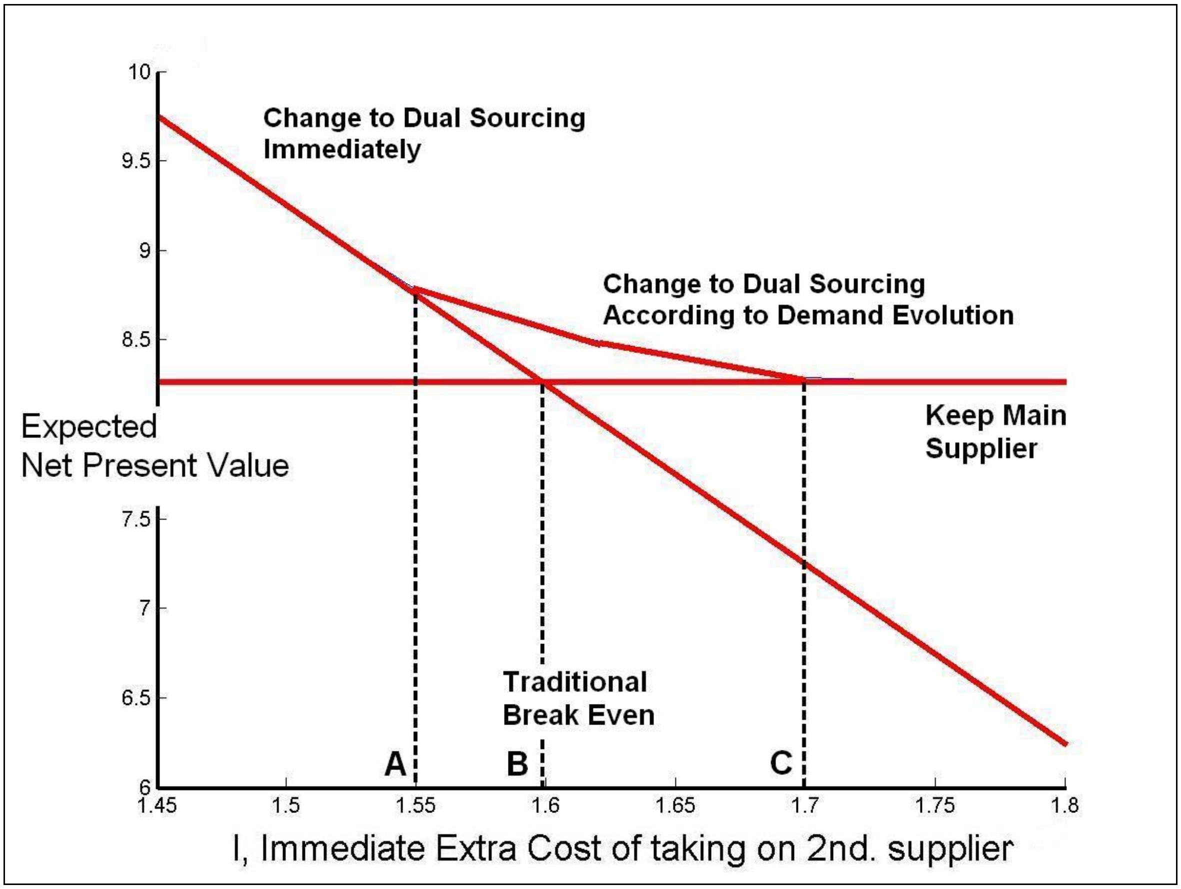


Figure 6.4: Added value thanks to delay option

If $A < I < C$, the firm should delay its decision to take a second supplier and make new supply arrangements if the demand increases enough. On the contrary, if demand decreases, investing in a new supply contract with a 2^{nd} supplier would cost too much comparing to the benefits of having this extra supplier, and it is better to stick to the main supplier. Figure 6.5 illustrates this concept.

Also the break-even, that represents the maximum investment that is allowed to take a second supplier, differs with the delay option. As seen on figure 12, if the firm decides to change its strategy to dual sourcing immediately (i.e. “Without delay option”) the break-even is B, whereas if the company decides according to demand evolution (i.e. “With the delay option”), the break-even becomes C that is higher: delaying the decision allows a more important investment.

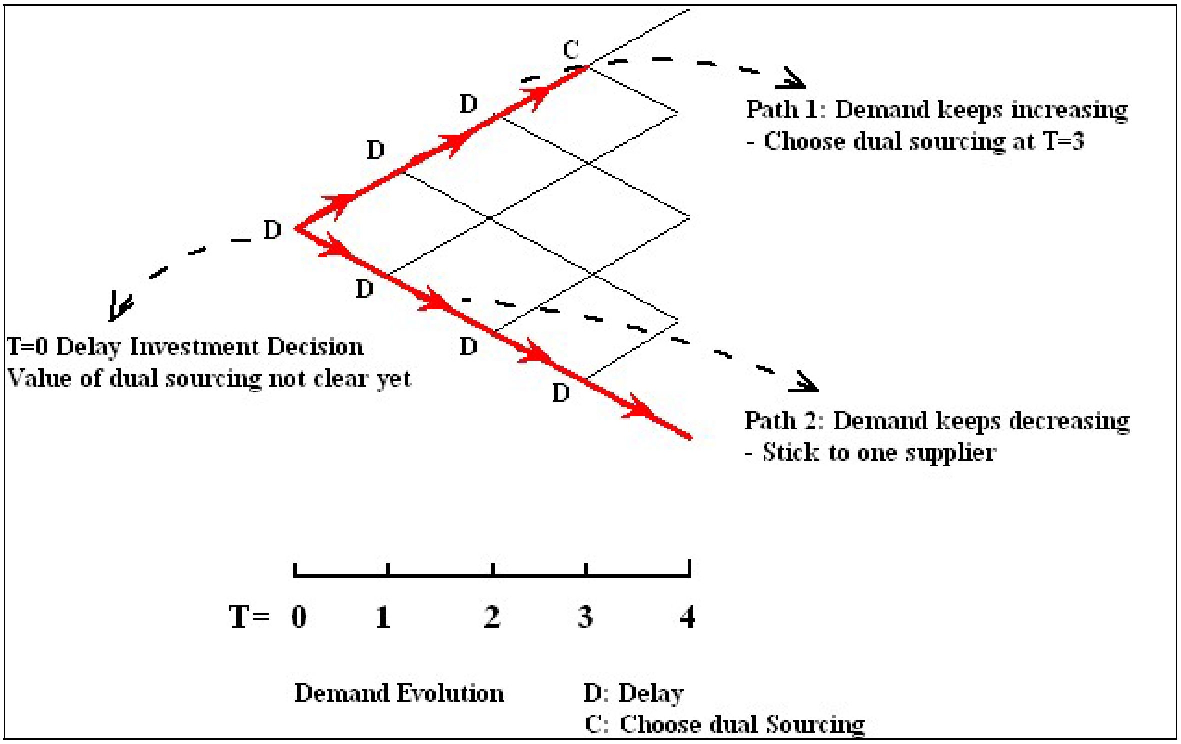


Figure 6.5: Delay Option - the decision to change to dual sourcing depends on demand evolution

6.4 Management over time

The company needs to adapt its sourcing strategy over time. The value of dynamic management has been proven in the last section; the delay option permits to adapt to demand evolution and increase the value of the dual sourcing process. Moreover, many other parameters may evolve such as the prices of local supplier or the probability of disruption. According to the changes, the firm needs to review the adequacy of its current strategy and eventually change it. In that respect, it is very important that the firm monitor the evolution of the different drivers. Sensitivity analyses are essential as they permit to determine which parameters are to be followed with most attention.

6.5 Conclusions

- Real options allow managers to quantify the benefits of dual sourcing, and help them to determine if such a strategy is adapted to their situations. The calculations can be useful for many different things. For example, managers will be able to point out the parameters that are the most important to monitor in order to manage dynamically their option over time. The information will also facilitate negotiations, as managers will know the limit they can accept and which parameters are to be controlled.

- More than a calculation tool, real options can help managers to think about agility within the supply-chain. Having such a concept in their heads will force them to think constantly about flexibility and how they can add value to their projects.

- It is important to consider flexibility not only as a protection from catastrophes but also as a way to gain benefits. The firm that will be the best prepared against disruption will do better than its competitors.

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Chapter 7 Recommendations

Managers are aware that their supply-chain is vulnerable and are concerned about disruptions. However, most of them share the same disorientation on how to deal with them. The previous chapters have tried to help managers delimit better this issue. The main objective has been to show that real options could help managers value flexible strategies, which is important to justify investment in risk management. From this work, we can deduce a few recommendations for managing disruption risks within a firm. This chapter presents these conclusions. It first gives some advice to build a supply-chain that is more resilient (that is to say, that can "bend and bounce back from hardship"). It then focuses on real options implementation. The chapter finishes with tracks for future research.

7.1 General recommendations to build a more resilient supply-chain

7.1.1 Build a Risk Awareness Culture

Managers must be aware of the vulnerabilities that may exist in their supply-chains. Recent supply-chain networks have become more and more vulnerable due to new manufacturing practices (such as lean manufacturing or just-in-time), and to increased external risks (such as terrorism actions or political instabilities in foreign countries). It is necessary that all employees in the firm share this risk awareness and understand his role in the risk management process: one effective way to achieve this is to build a culture of risk within the organization in the same way as quality has been embedded into the cultural fabric.

Risk consideration should lead to organizational changes and influence the supply-chain design. Although risk management is not the first priority of a firm, it is important that such a concern be in the forefront of supply-chain management. Such considerations can even constitute strategic advantages as shown in the case Nokia vs. Ericsson. Nokia recovered much better than Ericsson from the fire that destroyed the plant of their common chips supplier Phillips. This is partly due to the fact that the process that existed within Nokia to give account of a problem and solve it was much more efficient than the one in Ericsson. And the result was that Nokia took almost 4% of market share from its competitor.

7.1.2 Find a trade-off between recent practices such as Lean Manufacturing or JIT and Risk Management

As mentioned previously, one of the main reasons that have made supply chain networks more vulnerable is the raise of recent manufacturing practices such as Lean Manufacturing or Just-in-Time (JIT). Among other things, those approaches have tried to eliminate all the wastes in the supply-chain, and focused a lot on cost reduction. These have led many firms to centralize their assets, reduce their supplier base or decrease dramatically their stocks. Those concepts have led to important improvements in the supply-chain. For example, Martha and Vratimos (2002) estimated that inventory costs in the auto industry have been reduced by more than $1B a year thanks to JIT techniques. It would be absurd to totally abandon those practices, however the benefits must be weighed and balanced against the future risks of disruptions. Adjustments need to be made. This means that firms should in particular consider the following alternatives: single vs. multiple sourcing, zero stock vs. safety stock, centralization vs. dispersion.

7.1.3 Revisit single sourcing strategies

Single sourcing has many advantages; it is cost-effective and permits the improvement of the quality of the relationships with the supplier. But it introduces an important level of risk since the supplier can go out of business, be acquired by another company, or provide lower quality services. An extended shortage for key components could be dangerous for the firm that may have to close some plants and loose business.

A firm can envisage two different ways to tackle this problem.

- It can deepen the relations with its supplier. The manufacturer relies on single sourcing but strengthens disruption clauses in the contract and monitors the health of the concerning company. It is important that the manufacturer keep full and continuous review of financial results and operational stability of its partner, which allows it to monitor the probability of disruption. The firm must only continue business with strong suppliers, and for example favor those with more than one manufacturing site.

- Second, the company can consider more flexible strategies and contract with back-up suppliers.

This can be done in various ways. First, the firm can establish different contracts (long-term contracts, option contract and supply contract) with various suppliers. The firm can also create a local supply source or create multiple supply sources with the appropriate manufacturing capacities to build the components when needed.

7.1.4 Introduce flexibility to enhance resilience

Flexibility is defined as the ability to respond to changes in the environment. Having a flexible supply chain will allow firms to adapt the supply-chain according to the availability of resources, and quickly take corrective actions to minimize the impact of unexpected disruptions.

In that respect firms can add redundancies and build operating links to facilitate a rapid changeover when needed. Firms can also consider other strategies without any duplication of resources as mentioned in section 2.4. For example, the firm can redesign its products or manufacturing processes to be more standard; it will help the firm to switch more easily from one plant to another or from one supplier to another.

7.1.5 Quantifying the rewards of risk management can help to justify risk management investments

JIT practices have been easily justified as they led to important savings. Supply-chain risk management also leads to important benefits as it permits the avoidance of big losses, but the quantification is not as obvious as for JIT. The problem is that managers know the costs they will have to pay all the time (for extra-capacity for example) but they have a less clear view on the rewards. As a result they tend to focus only on costs and are tempted not to undertake any measure of risk management.

To illustrate this point, consider once again the problem posed in Sheffi (2001) that we used as a starting point for our study in section 5.1. It is presented again in the box below. Sheffi approximates easily the costs that arise from taking two suppliers. Let us retrace quickly its argument. If the firm uses only the main supplier its expected profit are:

$$
\begin{aligned}
E(P_{MainSupplier}) &= 0.99 * E(P_{MainSupplier,NormalSituation}) + 0.01 * E(P_{MainSupplier,DisruptionSituation}) \\
&= 0.99 * (\$400 - \$100 - \$200) + 0.01 * (-\$200)
\end{aligned}
$$

$$= 0.99 * (\$100) + 0.01 * (\text{-}\$200)$$
$$= \$97 \text{ per device}$$

In case the supplier makes a dual-sourcing arrangement, the profits are:

$$E(P_{LocalSupplier}) = 0.99 * E(P_{DualSourcing,NormalSituation}) + 0.01 * E(P_{DualSourcing,DisruptionSituation})$$
$$= 0.99 * \text{E}(\$400 - (0.8 * \$100 + 0.2 * \$150) - \$200) + 0.01 * (\$400 - \$150 - \$200)$$
$$= 0.99 * (\$90) + 0.01 * (\$50)$$
$$= \$89.6 \text{ per device}$$

As a result dual sourcing costs the company \$7.4 in expected profits. This figure gives a relatively a simple approximation of the price that the firm must pay to ensure against disruption. And "the value of the insurance is that if a disruption does occur, the company will experience a profit of \$50 instead of a loss of \$200 per device". This reward is less convincing than the previous figure, and above all quite difficult to compare with the costs.

Sheffi's case.

"A high technology company sells medical devices made by a contract manufacturer in Malaysia. The Malaysian supplier delivers the devices at \$100 a piece and the devices are sold by the US company at \$400 each. Fixed costs, including marketing and setup, have been estimated at \$200 per device. The company estimated that there is a 1% probability that the Malaysian supplier will not be able to deliver for an extended period. A local supplier can deliver the same devices for \$150 each. Under a dual supply arrangement the local supplier may be given a portion, say 20% of the business if it guarantees to supply all of the company's requirements should the need arise."

Quantifying the rewards of risk management may help to justify risk management investments, as they permit to think in terms of cost vs. benefits – thinking that is very familiar to managers. Moreover having numbers is important; as it is often said in companies "What is measured is managed" (Zsidin 2001). He suggests an approach to measure supply risks that he approximates as the probability of disruption multiplied by the impact on EBIT on a quarterly basis. This gives an idea of the rewards of risk management. However, Zsidin's measure of benefits as well as Sheffi's calculations of costs are simple and ignores a lot of parameters such as the time value of money, or the future repercussions of a disruption. Moreover, those two calculations are not necessarily homogeneous and it is difficult to compare them.

Real options provide a good framework to value the benefits of flexibility, and compare them with the investment costs.

7.1.6 Use real options framework to value the benefits of flexible strategies

NPV is the usual tool companies use to value projects and justify investments. The problem is that this method assumes that the project will meet a given set of cash flows and therefore works only for certain future.

In a flexible strategy, managers take many options to adapt and revise their decisions to unexpected events such as disruptions. The real option framework allows to value this flexibility, and to make up for NPV lacks.

Real Options are similar to financial options except that the underlying is a real asset instead of a financial asset. They embody the formal concept of flexibility. This concept has been studied from several years and many methods of valuation have been developed.

Let us consider once again Sheffi's example. Through dual sourcing, the manufacturer has taken the option to call on the local supplier if ever there is a problem with the main supplier. This is called a put option, as it permits to minimize the negative and avoid big losses (as with insurance). Chapters 5 and 6 have shown that "dynamic programming", which is a possible method to value real options, could be used to evaluate the benefits of dual sourcing. All the results that were obtained in chapter 6 are precisely based on a Sheffi's problem, but with different parameters and extra adjustments. Now, let us consider the parameters mentioned in the initial case, and make the other assumptions necessary for value calculations as in Table 7.1.

Table 7.1: Assumption on Parameter Values

Parameters	Values
Product Lifetime	15 years
Disruption Duration	2 years
Initial Demand	e^{10}
Demand Drift	0.1
Demand Variance	0.1
Discount Rate	0.05

Running the MATLAB program we obtain the following results:

$$Value(MainSupplierStrategy) = \$3.93e^{7}$$

$$Value(DualSourcingStrategy) = \$3.99e^{7}$$

Under the previous assumptions the calculations show that the “dual sourcing strategy” is worth 1.5% more that the “main supplier strategy”. This quantification constitutes an important criterion that can help managers to decide which sourcing strategy to implement. They can balance this gain with other factors such as the quality of supplier relationship for example (that may be better under a sole sourcing contract).

Obviously, it is very important to conduct sensitivity analysis, as this was done in chapter 6, in order to assess the strength of those calculations according to parameter changes.

7.2 Recommendations on Real Options Implementation

7.2.1 Consider Real Options as a way of thinking

More than a calculation tool, real options analysis is a way of thinking. It provides a simple way of modeling flexibility. There are many types of options: the delay option that relates to the possibility of waiting before investing, the growth option that gives the opportunity to generate further revenues after making an early investment, the switching option that allows its owner to switch between one or more modes of operation, the abandonment option etc…Keeping in mind these concepts allows managers to introduce flexibility in their strategies, and to exploit uncertainties.

Taking a second supplier to back-up in case of disruption constitutes a real option. It is possible to introduce other real options in this project to add flexibility and increase the total value. For example, Chapter 6 shows that delaying the decision to invest in dual sourcing increases value as it permits to observe changes over time and make the right decision at the right time. It is an option on the decision to invest, and is called a compound option as this is a real option on another option. It exploits demand uncertainty.

7.2.2 Rely on experts to deal with real option calculations

Valuation of real options can be hard, depending in particular on how complex uncertain variables and decision process are. And precisely, disruption events are relatively difficult to deal with. It may be useful to rely on experts who will master the different valuation methods that have been developed since the beginning of research on real options.

Advances in both computing power and understanding of option pricing over the last 20 years make it easier now to analyze business strategy as a chain of real options.

7.2.3 Put a lot of efforts on valuating inputs: this requires much time and will condition the quality of the analysis.

A lot of inputs are necessary to build in the model, and determining each of them generally requires much work. In our simple dual sourcing model there are more than ten parameters and very few are obvious. For example, evaluating the costs of local suppliers demands an important work of research to find alternate suppliers and ask them for their prices in normal situation and in case of disruption. The choice of an adequate discount rate is also difficult and there is no universally accepted method to help firms. In particular, the discount rate is generally considered as constant over time whereas it should be constantly adjusted to reflect the changes in the project level of risk. The disruption probability is also difficult to estimate as it includes many different risks that are not always well known.

7.2.4 Exploit at maximum real option calculations

Once the method of valuation found and calculations made, it is important to exploit at maximum this work. Conducting sensitivity analysis for example will permit the determination of the parameters that have the most impact. This will be most useful in time of negotiations, as the firm will be able to concentrate only on the most important parameters, and for monitoring, as here again the firm can reserve its efforts for the significant drivers.

7.3 Recommendations for Future Research

This paragraph provides with a few recommendations on possible further research.

7.3.1 Analyze the supplier side

The results rely on the strong assumption that the local supplier accepts to make a contract with the manufacturer. But, is it really interesting for the supplier to make a contract with the company in order to get x% of its commands in normal situation, and ensure that he will ramp up its production to supply all the components in case of emergency?

With the contract, the manufacturer protects itself against risks and is able to continue producing even in case of disruption. This contract is in reality an insurance for the firm. The cost of this insurance is the premium paid for using the local supplier who gets x% of the components in normal situation. The firm just needs to ensure that the benefits are worth the costs.

Under the contract, the local supplier is the one who carries out the disruption uncertainty: in normal situations, he only deals with x% of the manufacturer's commands, and in case of disruption he has to be able to supply 100% of the components. Being able to increase fast the production has a cost, and one may wonder why the supplier would agree to offer such a contract. Practically, the local supplier will have the manufacturer pay for this extra cost (though higher prices in our case), but this is possible only if the cost stays reasonable. One solution is to maintain additional capacity and this is all the more possible as disruptions are likely. Or the supplier can shift production from other customers with less demanding time constraints, and bear penalties that he will pass through to the manufacturer. This might be considered only if disruptions are rare. The supplier can also make contracts with other suppliers in emergency, or maintain lots of raw material, etc… The solution that is taken by the supplier depends a lot on the specifics of the case.

In the same way we did for the manufacturer it is necessary to weigh the costs and benefits of the different approaches that are available for the supplier. Two questions are important: at which price the local supplier should supply the components in the normal situation, and which risks can he accept? The whole problem is to find a contract that works for both parties.

7.3.2 Test the methodology on real data

The demonstration that was made in this paper relies on Sheffi's model. It would be very interesting to implement the methodology on a true situation using real data. This would permit to capture better the preoccupations of the firm and answer several important questions: what is the amount of work necessary to implement such a method? What resources are to be put on the project? What are the principal difficulties that can be encountered? What is the impact of such quantification? How such a project would be accepted within the organization? Etc… With such information, we could define a more precise implementation plan and help firms to understand better the use and impact of such a method.

The implementation does not need to be done on dual sourcing but can be applied to other flexible strategies. For example, it could be interesting to investigate the problem of safety stock. With lean manufacturing, levels of stocks have been reduced dramatically, but this can be very risky. Are safety stocks a good strategy to hedge disruption risks? If so, what is the optimal level? How do firms need to manage their stocks over time?

7.3.3 Investigate other methods to assess risk management benefits.

Real options constitute a possible method to quantify the benefits of risk management, but there are others; it may be interesting to compare the different approaches and define which is the most adapted according to the use and situation. For example more simple approaches may be more appropriate for a first analysis. In that respect, it could be worth studying further the solution proposed by Zsidin (2001) or finding other simple quantification methods.

Courtney (2001) suggests a list of techniques to study strategies under uncertainties: decision trees, scenario-planning exercises, game theory, real options, system dynamics models, or management flight simulators. Wilson (2002) gives a good illustration of the use of system dynamics. She developed “ a general simulation model to assess the impact of transportation disruptions under different scenarios”, which then helped him to define “appropriate policy responses”.

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APPENDIX A: CONTRACT PORTFOLIO AS A SOURCING APPROACH

Martinez-de-Albeniz (2003) studied the solution that consists in creating a portfolio of procurement contracts with different suppliers. He also included the possibility of disruption of a supplier and defined the optimal portfolio in this case. This paragraph presents briefly his work.

The objective of defining a "contract portfolio" is to protect against demand and price uncertainty, in a cost-effective manner. These portfolios are a "combination of many traditional contracts, such as long-term contracts, options and flexibility contracts". In a long-term contract, both parties agree on a price and a quantity to be delivered; thus the manufacturer eliminates financial uncertainties but takes huge inventory risks. A more flexible approach is the option contract where the buyer pays an advance up-front, in return of the supplier's commitment to provide up to a capacity C for a fixed price w later on. At last, in a flexibility contract, "a fixed amount of supply is determined when the contract is signed, but the amount to be delivered and paid for can differ by no more than a given percentage determined upon signing the contract.' Of course, a portfolio contract may also include commodities bought on the spot market.

Martinez-de-Albeniz provides a framework to help buyers determine the optimal portfolio.

An option is determined by a "pre-paid reservation unit cost" (paid up-front) v, an execution cost w per unit delivered, and a maximum capacity x. It is represented by the triplet (v,w,x). A long-term contract is a particular case where w = 0. The portfolio contract is determined by the sequence $\{(v_1, w_1, x_1), (v_2, w_2, x_2), ..., (v_n, w_n, x_n)\}$ with (v_1, w_1, x_1) representing the long-term contract ($v_1 > 0$ and $w_1 = 0$. The objective is to determine the optimal n-uplet $(x_1, x_2, ..., x_n)$ that represents the different capacities to book in each contract.

To solve this problem, the first step is to determine the optimal inventory policy (and the quantities the manufacturer executes from each contract and buys on the spot market) in each period, given a choice of capacities in each contract. This can be analyzed using dynamic programming, and permits to calculate the value of a portfolio contract considering that the buyer follows an optimal inventory replenishment policy. The next step is to determine how much capacities suppliers needs to reserve for the future, by maximizing the expected value of the portfolio.

The paper of Martinez-de-Albeniz presents two types of result. First it characterizes the optimal replenishment policies and then it provides structural properties of the portfolio. In case of a single period model, it even derives *closed form* expressions that can be easily solved.

Martinez-de-Albeniz, in particular, expands its study to disruption management. Improving his model, he defined a random variable A in [0,1] so that the amount that can be ordered by the manufacturer from the contract is no more than Ax (where x is the maximum capacity, defined as previously). To model disruption, A is such that it takes the value 0 with probability p, and 1 otherwise. He defines new optimality equations, and in the particular case of a single period and an exponentially distributed demand he derives n closed form equations that permit to determine easily the optimal n-uplet $(x_1, x_2, ..., x_n)$.

In particular he solves the problem posed in Sheffi (2001). A high technology company sells medical devices made by a contract manufacturer in Malaysia. The Malaysian supplier delivers the devices at \$100 a piece and the devices are sold by the US company at \$400 each. Fixed costs, including marketing and setup, have been estimated at \$200 per device. The company estimated that there is a 1% probability that the Malaysian supplier will not be able to deliver for an extended period (that was modeled as a single period in Albeniz's paper). A local supplier can deliver the same devices for \$150 each.

Using the previous notations we have:

$$v^1 = 100, w^1 = 0, A^1 = \begin{Bmatrix} 0 \text{ w.p. } \alpha \\ 1 \text{ w.p. } 1 - \alpha \end{Bmatrix}$$
$$v^2 = 150, w^2 = 0, A^2 = 1 \text{ w.p. } 1$$

Assuming that the demand is exponential with probability 1, Figure A.1 presents the optimal capacities to reserve toward each supplier, according to the disruption probability.

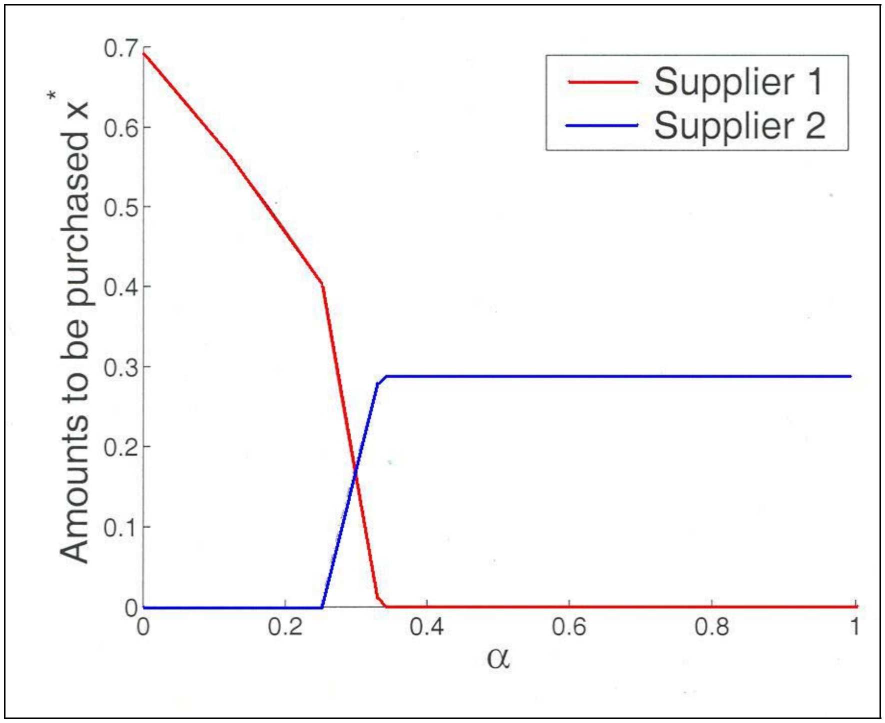

Figure A.1: Optimal portfolio quantities as a function of the disruption probability α

APPENDIX B: PARAMETER VALUES USED TO OBTAIN THE RESULTS

The table presents the parameters as they were taken to make the Figure 6.1.

Table B.1: Parameter Values

Parameters	Values
Product Lifetime	15 years
Disruption Duration	2 years
Initial Demand	e^{10}
Demand Drift	0.1
Demand Variance	0.1
Main Supplier Price (w_M)	$300
Local Supplier Price for 100% of the production (w_{L1})	$340
Local Supplier Price for x% of the production (w_{L2})	$350
Local Supplier Price in case of disruption (w_{L3})	$360
Percentage of Production given to the Local Supplier in Normal Situation	0.3
Delay	0 year
Loss of Market Share	0 %
Discount Rate	0.05

APPENDIX C: MATLAB PROGRAM

Important Notice: the program is very rough. The purpose of the thesis was not to do an efficient program, but rather to get reasonable results quickly.

1) Structure of the program

This paragraph will explain very briefly the structure of the program.

- Algorithm

It is based on the dynamic program methodology that has been explained in Chapter 5. The main idea is to work backward all the way to initial conditions. At each period there is a series of possible "states of the world" that are characterized by the uncertain variables (level of demand and state of the main supplier – normal or disruption) and by the current sourcing strategy. For each of these states the program will determine what is the best decision in term of sourcing strategy for the following period. This decision only depends on the future and that's why we can work backward until t=0. This algorithm permits the determination of the optimal sourcing decision process over time and the valuation of this strategy.

- Functions and matrices created

Let us explain shortly the "objects" and functions created in this program.

There are two uncertain state variables: the demand and the disruption events. The resulting states are represented by the triplets (m,k,j) where :

- (m.k) stands for the demand level. The function *GenBinTree* gives the correspondence between the couple (m,k) and the demand level. k actually represents the current period.

- j is the time of the last disruption.

At each node, there are 6 possible states for the firm. The firm can have a sourcing strategy that consists in having the main supplier only (referred as supplier 1), the local supplier only (referred as supplier 2) or dual sourcing (referred as supplier "3=1+2"). And the current situation can be normal or in disruption.

The program builds 6 “value matrices” (OneNormal, TwoNormal, ThreeNormal, OneDisruption, TwoDisruption, ThreeDisruption) that represent the values of the 6 possible states of the firm according to the uncertain state (m,k,j).

Actually there is a redundancy, as the disruption is represented both in the uncertain state (m,k,j) (the duration of disruption is given at the beginning and knowing the time of last disruption permits to determine the current state of the main supplier – normal or disruption) and in the firm state. It would have been better to consider only three states for the firm representing the different sourcing strategies (One, Two and Three)

We dealt separately with the particular case (m,k,0). The program builds 6 additional “value matrices” (InitialOneNormal, InitialTwoNormal, InitialThreeNormal, InitialOneDisruption, InitialTwoDisruption, InitialThreeDisruption).

The value calculation of each element of the matrixes is done thanks to the function *Value* (or *InitialValue* for the particular case (m,k,0)).

The function *main* reproduces the backward algorithm and calculates all the elements of the “value matrices” starting from the last period until t=0.

The function *loop* allows one to run the function main for different values of the parameters.

Also, the function *GenNormalProba* defines the probabilities of evolution when the situation is normal and *GenDisruptionProba* when the situation is in disruption. The function *Constants* defines the values of the different parameters.

A small tip to finish. In order to fix the decision process we just need to put the different variables $I_{MainSupplier->DualSourcing}$, $I_{LocalSupplier->DualSourcing}$, $I_{MainSupplier->LocalSupplier}$ and $I_{LocalSupplier->MainSupplier}$ at a very high level.

2) Code

```
-----------------------------------------------------------------------------------------------------------
---------------------------------------------- GENERAL LOOP -----------------------------------------------------
-----------------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------------
 Author: Sophie Pochard
 Written on March 28th 2003
-----------------------------------------------------------------------------------------------------------

% Program to build the Figure 6.1.

clear CONSTANTS;

CONSTANTS=constant;

CONSTANTS.OnetoTwo=1000000000;
CONSTANTS.OnetoThree=1000000000;
CONSTANTS.TwotoOne=1000000000;
CONSTANTS.TwotoThree=1000000000;
CONSTANTS.ThreetoOne=1000000000;
CONSTANTS.ThreetoTwo=1000000000;

for i=1:1:10
   i
   x(i)=0+0.1*i
   CONSTANTS.lambda=x(i)
   Opt=Main(CONSTANTS);
   ValeurOneSupplier(i)=Opt.InitValueOneNormal(1,1)
   ValeurTwoSuppliers(i)=Opt.InitValueTwoNormal(1,1)
   ValeurThreeSuppliers(i)=Opt.InitValueThreeNormal(1,1)
end
figure(3)
hold on
plot(x,ValeurOneSupplier)
hold on
plot(x,ValeurTwoSuppliers)
hold on
plot(x,ValeurThreeSuppliers)
xlabel('Probability of Rare Events');
ylabel('Value');
```

-- **GENERAL MAIN** ---
----

function [Principal] = Main(CONSTANTS)

----------------------------------Initialization of matrices and parameters ----------------------------------

```
TREE = GenBinTree(CONSTANTS);
Z=TREE.X;

NormalProba = GenNormalProba(CONSTANTS,TREE);
DisruptionProba=0;

%"Value matrices" creation

T=CONSTANTS.num_period+1

Principal.ValueOneNormal=zeros(T,T,T,T);
Principal.ValueOneDisruption=zeros(T,T,T,T);
Principal.ValueTwoNormal=zeros(T,T,T,T);
Principal.ValueTwoDisruption=zeros(T,T,T,T);
Principal.ValueThreeNormal=zeros(T,T,T,T);
Principal.ValueThreeDisruption=zeros(T,T,T,T);
Principal.DecisionOneNormal=zeros(T,T,T,T);
Principal.DecisionThreeNormal=zeros(T,T,T,T);

Principal.InitValueOneNormal=zeros(T,T,T,T);
Principal.InitValueTwoNormal=zeros(T,T,T,T);
Principal.InitValueThreeNormal=zeros(T,T,T,T);
Principal.InitDecisionOneNormal=zeros(T,T,T,T);
Principal.InitDecisionTwoNormal=zeros(T,T,T,T);
Principal.InitDecisionThreeNormal=zeros(T,T,T,T);

%"Value matrices" initialization

Principal.ValueOneNormal(:,:,:,:)=NaN;
Principal.ValueOneDisruption(:,:,:,:)=NaN;
Principal.ValueTwoNormal(:,:,:,:)=NaN;
Principal.ValueTwoDisruption(:,:,:,:)=NaN;
Principal.ValueThreeNormal(:,:,:,:)=NaN;
Principal.ValueThreeDisruption(:,:,:,:)=NaN;
Principal.DecisionOneNormal(:,:,:,:)=NaN;
Principal.DecisionThreeNormal(:,:,:,:)=NaN;

Principal.InitValueOneNormal(:,:)=NaN;
Principal.InitValueTwoNormal(:,:)=NaN;
Principal.InitValueThreeNormal(:,:)=NaN;
Principal.InitDecisionOneNormal(:,:)=NaN;
Principal.InitDecisionTwoNormal(:,:)=NaN;
Principal.InitDecisionThreeNormal(:,:)=NaN;

Principal.ValueOneNormal(:,T,:,:)=0;
Principal.ValueOneDisruption(:,T,:,:)=0;
```

```
Principal.ValueTwoNormal(:,T,:,:)=0;
Principal.ValueTwoDisruption(:,T,:,:)=0;
Principal.ValueThreeNormal(:,T,:,:)=0;
Principal.ValueThreeDisruption(:,T,:,:)=0;

Principal.InitValueOneNormal(:,T)=0;
Principal.InitValueTwoNormal(:,T)=0;
Principal.InitValueThreeNormal(:,T)=0;

---------------------------------------------  Value Matrices Calculations ----- ------------------------------------

for k=CONSTANTS.num_period:-1:1
   for m=1:1:k
         for g=1:1:k
            for l=1:1:g
              v=0;
              DisruptionProba=GenDisruptionProba(CONSTANTS,TREE,m,k,g);
              v=Value(CONSTANTS,TREE,NormalProba,DisruptionProba,Principal.ValueOneNorm
              al,Principal.ValueOneDisruption,Principal.ValueTwoNormal,Principal.ValueTwoDisrupti
              on,Principal.ValueThreeNormal,Principal.ValueThreeDisruption,m,k,g,l);
              Principal.ValueOneNormal(m,k,g,l)=v.OneNormal;
              Principal.ValueTwoNormal(m,k,g,l)=v.TwoNormal;
              Principal.ValueThreeNormal(m,k,g,l)=v.ThreeNormal;
              Principal.DecisionOneNormal(m,k,g,l)=v.DecOneNormal;
              Principal.DecisionTwoNormal(m,k,g,l)=v.DecTwoNormal;
              Principal.DecisionThreeNormal(m,k,g,l)=v.DecThreeNormal;
              Principal.ValueOneDisruption(m,k,g,l)=v.OneDisruption;
              Principal.ValueTwoDisruption(m,k,g,l)=v.TwoDisruption;
              Principal.ValueThreeDisruption(m,k,g,l)=v.ThreeDisruption;
            end
         end
      w=0;
      DisruptionProba=0;
       w=InitialValue(CONSTANTS,TREE,NormalProba,DisruptionProba,Principal.InitValueOneNor
       mal,Principal.InitValueTwoNormal,Principal.InitValueThreeNormal,Principal.ValueOneDisrupt
       ion,Principal.ValueTwoDisruption,Principal.ValueThreeDisruption,m,k);
      Principal.InitValueOneNormal(m,k)=w.OneNormal;
      Principal.InitValueTwoNormal(m,k)=w.TwoNormal;
      Principal.InitValueThreeNormal(m,k)=w.ThreeNormal;
      Principal.InitDecisionOneNormal(m,k)=w.DecOneNormal;
      Principal.InitDecisionTwoNormal(m,k)=w.DecTwoNormal;
      Principal.InitDecisionThreeNormal(m,k)=w.DecThreeNormal;
  end
end
```

-- **Constants Subprogram** --

```
function [CONSTANTS] = constant


% Project lifetime
CONSTANTS.Tlife_y = 15;   [years]

% Number of periods considered from t=0 to t=Project lifetime
CONSTANTS.num_period=15;

% Duration of disruption
CONSTANTS.d =2;   [in years/num_period]

% Initial Value of Demand
CONSTANTS.bintree_init=10;

% Loss of market share per year of disruption
CONSTANTS.c=0;  [in % market share/year]

% DiscountRate
CONSTANTS.r=0.05;

% Probability of rare events
CONSTANTS.lambda=0.5;

% Volatility of demand
CONSTANTS.sigma=0.1;

% Drift of the demand
CONSTANTS.alpha=0.1;

% Price and Costs
CONSTANTS.Price=400;  [in dollars]
CONSTANTS.CostMainSupplier=300;  [in dollars]
CONSTANTS.CostLocalSupplierOnly=340;  [in dollars]
CONSTANTS.CostLocalSupplierDualContractNormal=350;  [in dollars]
CONSTANTS.CostLocalSupplierDualContractDisruption=360; [in dollars]

% Percentage of production given to Local Supplier
CONSTANTS.PercentageLocalSupplier=0.1;

% Investments to change of supplier structure
CONSTANTS.OnetoTwo=0;
CONSTANTS.OnetoThree=0;
CONSTANTS.TwotoOne=0;
CONSTANTS.TwotoThree=0;
CONSTANTS.ThreetoOne=0;
CONSTANTS.ThreetoTwo=0;

% Supplemental cost of having two suppliers
CONSTANTS.FixedCostTwoSuppliers=0;
```

```
% Delay Local Production when disruption
CONSTANTS.Delay=0;  [in % of production/period]
```

--------------------------------- **GENERATION OF BINOMIAL TREE** --
----

function [TREE] = GenBinTree(CONSTANTS)

```
% Period length
d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;
TREE.dt = d_t;

% Variation of revenues at each period
d_Y = sqrt(CONSTANTS.sigma^2*d_t + (CONSTANTS.alpha-CONSTANTS.sigma^2/2)^2*d_t^2);

% Probability of a step up
step_up_p = 0.5 * (1 + (CONSTANTS.alpha-CONSTANTS.sigma^2/2)*d_t/d_Y);
TREE.step_up_p = step_up_p;

% Values at the end point which is the decision point (possible values of X at decision point)
TREE.Y(1,1)= CONSTANTS.bintree_init;

for k=2:1:CONSTANTS.num_period +1
   TREE.K(k) = (k-1)*d_t;
   for m=1:1:k
      TREE.Y(m,k) = TREE.Y(1,1) + (k-1)*d_Y - 2*(m-1)*d_Y;
   end
end

for k=1:1:CONSTANTS.num_period+1
   for m=k+1:1:CONSTANTS.num_period+1
      TREE.Y(m,k) = NaN;
   end
end

TREE.X = exp(TREE.Y);
```

--------------------------------- **GENERATION OF NORMAL PROBA** --
----

function [NormalProba] = GenNormalProba(CONSTANTS,TREE)

```
% Period length
d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;
NormalProba.dt = d_t;

% Probability of going from (m,k,j)/normal to (m,k+1,j)/normal
NormalProba.P1=(1-CONSTANTS.lambda(1)*d_t)*TREE.step_up_p;

% Probability of going from (m,k,j)/normal to (m,k+1,j)/disruption
NormalProba.P2=CONSTANTS.lambda(1)*d_t*TREE.step_up_p;
```

```
% Probability of going from (m,k,j)/normal to (m+1,k+1,j)/normal
NormalProba.P3=(1-CONSTANTS.lambda(1)*d_t)*(1-TREE.step_up_p);

% Probability of going from (m,k,j)/normal to (m+1,k+1,j)/disruption
NormalProba.P4=CONSTANTS.lambda(1)*d_t*(1-TREE.step_up_p);
```

---------------------------- **GENERATION OF DISRUPTION PROBA** ---
----

function [DisruptionProba] = GenDisruptionProba(CONSTANTS,TREE,m,k,j)

```
% Period length
d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;
NormalProba.dt = d_t;

% P1: Probability of going from (m,k,j)/Disruption to (m,k+1,j)/Normal
% P2: Probability of going from (m,k,j)/Disruption to (m,k+1,j)/Disruption
% P3: Probability of going from (m,k,j)/Disruption to (m,k+1,k)/Disruption
% P4: Probability of going from (m,k,j)/Disruption to (m+1,k+1,j)/Normal
% P5: Probability of going from (m,k,j)/Disruption to (m+1,k+1,j)/Disruption
% P6: Probability of going from (m,k,j)/Disruption to (m+1,k+1,k)/Disruption


if j==0
   DisruptionProba.P1=(1-CONSTANTS.lambda*d_t)*TREE.step_up_p;
   DisruptionProba.P3=CONSTANTS.lambda*d_t*TREE.step_up_p;
   DisruptionProba.P4=(1-CONSTANTS.lambda*d_t)*(1-TREE.step_up_p);
   DisruptionProba.P6=CONSTANTS.lambda*d_t*(1-TREE.step_up_p);
   DisruptionProba.P2=0;
   DisruptionProba.P5=0;

else
   if (k-j)<CONSTANTS.d
      DisruptionProba.P2=(1-CONSTANTS.lambda*d_t)*TREE.step_up_p;
      DisruptionProba.P3=CONSTANTS.lambda*d_t*TREE.step_up_p;
      DisruptionProba.P5=(1-CONSTANTS.lambda*d_t)*(1-TREE.step_up_p);
      DisruptionProba.P6=CONSTANTS.lambda*d_t*(1-TREE.step_up_p);
      DisruptionProba.P1=0;
      DisruptionProba.P4=0;
   else
      DisruptionProba.P1=(1-CONSTANTS.lambda*d_t)*TREE.step_up_p;
      DisruptionProba.P3=CONSTANTS.lambda*d_t*TREE.step_up_p;
      DisruptionProba.P4=(1-CONSTANTS.lambda*d_t)*(1-TREE.step_up_p);
      DisruptionProba.P6=CONSTANTS.lambda*d_t*(1-TREE.step_up_p);
      DisruptionProba.P2=0;
      DisruptionProba.P5=0;
   end
end
```

-- **PROFIT FUNCTION** --

```
function Pi = profit(d,n,s,CONSTANTS)

d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;

% N: number of suppliers
% s: situation (s=0: normal situation; s=1: disruption situation)

if n==1
   if s==0
      Pi=(CONSTANTS.Price-CONSTANTS.CostMainSupplier)*d*d_t;
   elseif s==1
      Pi=0;
   end

elseif n==2
          Pi=(CONSTANTS.Price-CONSTANTS.CostLocalSupplierOnly)*d*d_t;

elseif n==3
   if s==0
      Pi=((CONSTANTS.Price-CONSTANTS.CostMainSupplier)
              *(1-CONSTANTS.PercentageLocalSupplier)
           +(CONSTANTS.Price-CONSTANTS.CostLocalSupplierDualContractNormal)
              *CONSTANTS.PercentageLocalSupplier)*d*d_t
           -CONSTANTS.FixedCostTwoSuppliers*d_t;
   elseif s==1
      Pi=((CONSTANTS.Price-CONSTANTS.CostLocalSupplierDualContractDisruption)
              *(1-CONSTANTS.PercentageLocalSupplier)
          +(CONSTANTS.Price-CONSTANTS.CostLocalSupplierDualContractNormal)
              *CONSTANTS.PercentageLocalSupplier)*d*d_t
          -CONSTANTS.FixedCostTwoSuppliers*d_t;
   end
end
```

-- **InitialValue Subprogram** --

```
function [InitValue] = InitialValue(CONSTANTS,TREE,NormalProba,DisruptionProba,InitValueOneNormal, InitValueTwoNormal,
InitValueThreeNormal,ValueOneDisruption,ValueTwoDisruption,ValueThreeDisruption,m,k)

d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;

--------------------------------------------- INITIAL VALUE  MATRIX: 1 SUPPLIER / NORMAL SITUATION -----------------------------------------------------------

g=0;
InitKeepOne = (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),1,0,CONSTANTS)
                +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),1,1,CONSTANTS)
                +(NormalProba.P1*InitValueOneNormal(m,k+1)+NormalProba.P2*ValueOneDisruption(m,k+1,k,1)
                + NormalProba.P3*InitValueOneNormal(m+1,k+1)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t);
InitTakeTwo= (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),2,0,CONSTANTS)
                +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),2,1,CONSTANTS)
                +(NormalProba.P1*InitValueTwoNormal(m,k+1)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,1)
                +NormalProba.P3*InitValueTwoNormal(m+1,k+1)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                 - CONSTANTS.OnetoTwo;
InitTakeThree=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),3,0,CONSTANTS)
                 +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),3,1,CONSTANTS)
                 +(NormalProba.P1*InitValueThreeNormal(m,k+1)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,1)
                 +NormalProba.P3*InitValueThreeNormal(m+1,k+1)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                 -CONSTANTS.OnetoThree;
InitValue.OneNormal=max([InitKeepOne InitTakeTwo InitTakeThree]);

if (InitKeepOne>InitTakeTwo & InitKeepOne>InitTakeThree)
      InitValue.DecOneNormal=1;
elseif (InitTakeTwo>InitKeepOne & InitTakeTwo>InitTakeThree)
      InitValue.DecOneNormal=2;
else
      InitValue.DecOneNormal=3;
end
```

```
----------------------------------------- INITIAL VALUE MATRIX : 2 SUPPLIERS / NORMAL SITUATION   ------------------------------------------------------------

InitTakeOne=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),1,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),1,1,CONSTANTS)
                  +(NormalProba.P1*InitValueOneNormal(m,k+1)+NormalProba.P2*ValueOneDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueOneNormal(m+1,k+1)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.TwotoOne;
InitKeepTwo=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),2,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),2,1,CONSTANTS)
                  +(NormalProba.P1*InitValueTwoNormal(m,k+1)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueTwoNormal(m+1,k+1)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t);
InitTakeThree=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),3,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),3,1,CONSTANTS)
                  +(NormalProba.P1*InitValueThreeNormal(m,k+1)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueThreeNormal(m+1,k+1)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.TwotoThree;
InitValue.TwoNormal=max([InitTakeOne InitKeepTwo InitTakeThree]);

if (InitTakeOne>InitKeepTwo & InitTakeOne>InitTakeThree)
      InitValue.DecTwoNormal=1;
elseif (InitKeepTwo>InitTakeOne & InitKeepTwo>InitTakeThree)
      InitValue.DecTwoNormal=2;
else
      InitValue.DecTwoNormal=3;
end
```

```
-----------------------------------------------------INITIAL VALUE MATRIX : 3 SUPPLIERS / NORMAL SITUATION ------------------------------------------------

InitTakeOne=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),1,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),1,1,CONSTANTS)
                  +(NormalProba.P1*InitValueOneNormal(m,k+1)+NormalProba.P2*ValueOneDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueOneNormal(m+1,k+1)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.ThreetoOne;

InitTakeTwo=  (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),2,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),2,1,CONSTANTS)
                  +(NormalProba.P1*InitValueTwoNormal(m,k+1)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueTwoNormal(m+1,k+1)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.ThreetoTwo;
InitKeepThree=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k),3,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k),3,1,CONSTANTS)
                  +(NormalProba.P1*InitValueThreeNormal(m,k+1)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,1)
                  +NormalProba.P3*InitValueThreeNormal(m+1,k+1)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,1))/(1+CONSTANTS.r*d_t);
InitValue.ThreeNormal=max([InitTakeOne InitTakeTwo InitKeepThree]);

if (InitTakeOne>InitTakeTwo & InitTakeOne>InitKeepThree)
      InitValue.DecThreeNormal=1;
elseif (InitTakeTwo>InitTakeOne & InitTakeTwo>InitKeepThree)
      InitValue.DecThreeNormal=2;
else
      InitValue.DecThreeNormal=3;
end
```

-- **Value Subprogram** --

```
function value = Value(CONSTANTS,TREE,NormalProba,DisruptionProba,ValueOneNormal,ValueOneDisruption,ValueTwoNormal,
                        ValueTwoDisruption,ValueThreeNormal,ValueThreeDisruption,m,k,g,l)

d_t= CONSTANTS.Tlife_y/CONSTANTS.num_period;
r=CONSTANTS.c*d_t;

--------------------------------------------- INITIAL VALUE  MATRIX: 1 SUPPLIER / NORMAL SITUATION ----------------------------------------------------------

if (k-g>CONSTANTS.d)
   KeepOne=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),1,0,CONSTANTS)
              +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),1,1,CONSTANTS)
              +(NormalProba.P1*ValueOneNormal(m,k+1,g,l)+NormalProba.P2*ValueOneDisruption(m,k+1,k,l+1)
              +NormalProba.P3*ValueOneNormal(m+1,k+1,g,l)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,l+1))/(1+CONSTANTS.r*d_t);
   TakeTwo=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),2,0,CONSTANTS)
              +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),2,1,CONSTANTS)
              +(NormalProba.P1*ValueTwoNormal(m,k+1,g,l)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,l)
              +NormalProba.P3*ValueTwoNormal(m+1,k+1,g,l)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t)
              -CONSTANTS.OnetoTwo;
   TakeThree=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),3,0,CONSTANTS)
              +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),3,1,CONSTANTS)*CONSTANTS.Delay
              +(NormalProba.P1*ValueThreeNormal(m,k+1,g,l)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,l)
              +NormalProba.P3*ValueThreeNormal(m+1,k+1,g,l)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t)
              -CONSTANTS.OnetoThree;
   value.OneNormal=max([KeepOne  TakeTwo TakeThree]);
else
   value.OneNormal=NaN;
   value.DecOneNormal=NaN;
end

if (KeepOne>TakeTwo & KeepOne>TakeThree)
      value.DecOneNormal=1;
elseif (TakeTwo>KeepOne & TakeTwo>TakeThree)
      value.DecOneNormal=2;
```

```
else
      value.DecOneNormal=3;
end

------------------------------------------- INITIAL VALUE  MATRIX: 2 SUPPLIERS / NORMAL SITUATION ------------------------------------------------------------

if (k-g>CONSTANTS.d)
TakeOne = (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),1,0,CONSTANTS)
               +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),1,1,CONSTANTS)
               +(NormalProba.P1*ValueOneNormal(m,k+1,g,l)+NormalProba.P2*ValueOneDisruption(m,k+1,k,l+1)
               +NormalProba.P3*ValueOneNormal(m+1,k+1,g,l)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,l+1))/(1+CONSTANTS.r*d_t)
               -CONSTANTS.TwotoOne;
KeepTwo =(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),2,0,CONSTANTS)
               +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),2,1,CONSTANTS)
               +(NormalProba.P1*ValueTwoNormal(m,k+1,g,l)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,l)
               +NormalProba.P3*ValueTwoNormal(m+1,k+1,g,l)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
TakeThree = (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),3,0,CONSTANTS)
               +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),3,1,CONSTANTS)*CONSTANTS.Delay
               +(NormalProba.P1*ValueThreeNormal(m,k+1,g,l)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,l)
               +NormalProba.P3*ValueThreeNormal(m+1,k+1,g,l)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t)
               -CONSTANTS.TwotoThree;
value.TwoNormal=max([TakeOne KeepTwo TakeThree]);

else
   value.TwoNormal=0;
   value.DecTwoNormal=0;
end

if (TakeOne>KeepTwo & TakeOne>TakeThree)
      value.DecTwoNormal=1;
elseif (KeepTwo>TakeOne & KeepTwo>TakeThree)
      value.DecTwoNormal=2;
else
      value.DecTwoNormal=3;
end
```

```
---------------------------------------------------------- VALUE  MATRIX: 3 SUPPLIERS / NORMAL SITUATION  ---------------------------------------------------------

if (k-g>CONSTANTS.d)
  TakeOne = (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),1,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),1,1,CONSTANTS)
                  +(NormalProba.P1*ValueOneNormal(m,k+1,g,l)+NormalProba.P2*ValueOneDisruption(m,k+1,k,l+1)
                  +NormalProba.P3*ValueOneNormal(m+1,k+1,g,l)+NormalProba.P4*ValueOneDisruption(m+1,k+1,k,l+1))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.ThreetoOne;
  TakeTwo = (NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),2,0,CONSTANTS)
                  +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),2,1,CONSTANTS)
                  +(NormalProba.P1*ValueTwoNormal(m,k+1,g,l)+NormalProba.P2*ValueTwoDisruption(m,k+1,k,l)
                  +NormalProba.P3*ValueTwoNormal(m+1,k+1,g,l)+NormalProba.P4*ValueTwoDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t)
                  -CONSTANTS.ThreetoTwo;
  KeepThree=(NormalProba.P1+NormalProba.P3)*profit(TREE.X(m,k)*(1-r*l),3,0,CONSTANTS)
                    +(NormalProba.P2+NormalProba.P4)*profit(TREE.X(m,k)*(1-r*l),3,1,CONSTANTS)
                    +(NormalProba.P1*ValueThreeNormal(m,k+1,g,l)+NormalProba.P2*ValueThreeDisruption(m,k+1,k,l)
                    +NormalProba.P3*ValueThreeNormal(m+1,k+1,g,l)+NormalProba.P4*ValueThreeDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
value.ThreeNormal=max([TakeOne TakeTwo KeepThree]);
else
   value.ThreeNormal=0;
   value.DecThreeNormal=0;
end

if (TakeOne>TakeTwo & TakeOne>KeepThree)
      value.DecThreeNormal=1;
elseif (TakeTwo>TakeOne & TakeTwo>KeepThree)
      value.DecThreeNormal=2;
else
      value.DecThreeNormal=3;
end
```

-- VALUE MATRIX: 1 SUPPLIER / DISRUPTION SITUATION --

```
DisruptionProba=GenDisruptionProba(CONSTANTS,TREE,m,k,g);
if (k-g)<CONSTANTS.d
   KeepOne=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),1,0,CONSTANTS)
              +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),1,1,CONSTANTS)
              +(DisruptionProba.P2*ValueOneDisruption(m,k+1,g,l)+DisruptionProba.P3*ValueOneDisruption(m,k+1,k,l+1)
              +DisruptionProba.P5*ValueOneDisruption(m+1,k+1,g,l)+DisruptionProba.P6*ValueOneDisruption(m+1,k+1,k,l+1))/(1+CONSTANTS.r*d_t);
else
   KeepOne=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),1,0,CONSTANTS)
             +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),1,1,CONSTANTS)
             +(DisruptionProba.P1*ValueOneNormal(m,k+1,g,l)+DisruptionProba.P3*ValueOneDisruption(m,k+1,k,l+1)
             +DisruptionProba.P4*ValueOneNormal(m+1,k+1,g,l)+DisruptionProba.P6*ValueOneDisruption(m+1,k+1,k,l+1))/(1+CONSTANTS.r*d_t);
end
value.OneDisruption=KeepOne;
```

-- VALUE MATRIX: 2 SUPPLIERS / DISRUPTION SITUATION --

```
DisruptionProba=GenDisruptionProba(CONSTANTS,TREE,m,k,g);
if (k-g)<CONSTANTS.d
    KeepTwo=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),2,0,CONSTANTS)
             +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),2,1,CONSTANTS)
             +(DisruptionProba.P2*ValueTwoDisruption(m,k+1,g,l)+DisruptionProba.P3*ValueTwoDisruption(m,k+1,k,l)
             +DisruptionProba.P5*ValueTwoDisruption(m+1,k+1,g,l)+DisruptionProba.P6*ValueTwoDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
else
    KeepTwo=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),2,0,CONSTANTS)
             +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),2,1,CONSTANTS)
             +(DisruptionProba.P1*ValueTwoNormal(m,k+1,g,l)+DisruptionProba.P3*ValueTwoDisruption(m,k+1,k,l)
             +DisruptionProba.P4*ValueTwoNormal(m+1,k+1,g,l)+DisruptionProba.P6*ValueTwoDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
end
value.TwoDisruption=KeepTwo;
```

--- VALUE MATRIX: 3 SUPPLIERS / DISRUPTION SITUATION ---

```
DisruptionProba=GenDisruptionProba(CONSTANTS,TREE,m,k,g);
if (k-g)<CONSTANTS.d
   KeepThree=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),3,0,CONSTANTS)
         +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),3,1,CONSTANTS)
         +(DisruptionProba.P2*ValueThreeDisruption(m,k+1,g,l)+DisruptionProba.P3*ValueThreeDisruption(m,k+1,k,l)
         +DisruptionProba.P5*ValueThreeDisruption(m+1,k+1,g,l)+DisruptionProba.P6*ValueThreeDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
else
   KeepThree=(DisruptionProba.P1+DisruptionProba.P4)*profit(TREE.X(m,k)*(1-r*l),3,0,CONSTANTS)
         +(DisruptionProba.P2+DisruptionProba.P3+DisruptionProba.P5+DisruptionProba.P6)*profit(TREE.X(m,k)*(1-r*l),3,1,CONSTANTS)
         +(DisruptionProba.P1*ValueThreeNormal(m,k+1,g,l)+DisruptionProba.P3*ValueThreeDisruption(m,k+1,k,l)
         +DisruptionProba.P4*ValueThreeNormal(m+1,k+1,g,l)+DisruptionProba.P6*ValueThreeDisruption(m+1,k+1,k,l))/(1+CONSTANTS.r*d_t);
end
value.ThreeDisruption=KeepThree;
```