uOttawa

L'Université canadienne
Canada's university

t

FACULTÉ DES ÉTUDES SUPÉRIEURES ET POSTOCTORALES

uOttawa

L'Université canadienne
Canada's university

FACULTY OF GRADUATE AND POSDOCTORAL STUDIES

Sébastien Casault
AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.Sc. (Management)
GRADE / DEGREE

Telfer School of Management
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Real Option Pricing Model Applied to Industrial and Regional Benefits Policy

TITRE DE LA THÈSE / TITLE OF THESIS

Jonathan Linton
DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

Tom Bruzustiwski

Kevin Brand

Hendrick de Haan

Daniel Duguay

Gary W. Slater
Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

Real Option Pricing Model Applied to Industrial and Regional Benefits Policy

Sébastien Casault
B.Sc. University of Waterloo 2004
M.Sc. University of Ottawa 2007

THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTERS OF SCIENCE IN MANAGEMENT

uOttawa

Your file Votre référence
ISBN: 978-0-494-73841-2
Our file Notre référence
ISBN: 978-0-494-73841-2

SUMMARY

This research intends to inform policy discussion on the subject of Aerospace and Defence sector procurement strategies at Industry Canada (IC). Specifically, this research explores procurement strategies in terms of a real option pricing model that move toward a novel use of Industrial and Regional Benefits (IRB) policies in promoting sector-specific, innovation-driven growth. It is further hypothesized that IRB obligations can be better tailored to encourage value adding activities within prime contractors' supply chains (typically small and medium enterprises in this sector). This research focusses on the novel development of a decision support tool using a theory of option pricing for derivatives whose returns fluctuate according to a power law distribution. This tool is shown to provide guidance to assist in adequately rewarding prime contractors who invest in innovative activities while fulfilling their IRB obligations.

SOMMAIRE

Ce mémoire vise à supporter la prise de décision en matière de stratégies d'approvisionnement gouvernementales chez Industrie Canada et ce, en utilisant le secteur de l'aérospatiale et de la défense comme exemple. Plus précisément, ce projet développe spécifiquement une stratégie d'approvisionnement avec l'aide d'un modèle d'évaluation d'options réelles pour assister à la quantification d'une utilisation novatrice du programme des retombées industrielles et régionales à fin de promouvoir une politique sectorielle orientée vers l'innovation, la recherche et le développement. L'hypothèse principale de ce mémoire et donc que les obligations face aux retombées industrielles et régionales rattachées aux contrats d'approvisionnement militaires peuvent être mieux adaptées pour favoriser une augmentation au niveau des activités innovatrices chez les entreprises privées et au niveau de leurs chaînes de valeur (généralement constituées de petites et moyennes entreprises dans ce secteur). Ce projet de recherche propose donc un outil d'aide à la décision qui peut être utilisé pour récompenser adéquatement les récipiendaires principaux de contrats d'approvisionnement qui investissent dans des activités dites innovatrices tout en remplissant leurs obligations face aux retombées industrielles et régionales. Une théorie modifiée de la valuation des options est dérivée pour quantifier, avec plus de précision, les dérivées financières qui comptent des retours fluctuants selon une distribution Cauchy.

STATEMENT OF ORIGINALITY

Originality is the fine art of remembering what you hear but forgetting where you heard it.
(Laurence J. Peter, 1919–1988)

The work presented in this thesis is, to the best of my knowledge and belief, new and original. Unless specified and appropriately cited, the advances presented in this thesis are a result of my work during the last two years with the help of my supervisor. All analytical and numerical results presented here were obtained using my own Maple™, Matlab™, and C++ codes. This work conforms to the rules on academic integrity of the University of Ottawa.

ACKNOWLEDGEMENTS

Special acknowledgments go to my supervisors, Daniel Duguay and Dr. Jonathan Linton for their enthusiastic support and expert advice. Thank you for the countless opportunities you have made available for me during the past years. Further acknowledgements to Dr. Hendrick de Haan who helped with some eleventh hour mathematical simplifications. Finally, thank you Jocelyn for your enduring support and friendship.

Table of contents

1

Introduction

If you're not failing every now and again, it's a sign you're not doing anything very innovative.
(Woody Allen)

1.1 Thesis outline

The Government of Canada has identified the need "to better use the opportunities presented by public procurement to promote innovation and commercialization by Canadian firms." Additionally, Canada has set an ambitious target of becoming a global leader in the aerospace sector by 2025 [1].

The goal of this research project is to inform policy discussion on the subject of Aerospace and Defence sector procurement strategies at Industry Canada (IC). Specifically, this research project explores procurement strategies in terms of a real option pricing model that moves towards a novel use of Industrial and Regional Benefits (IRB) policies in promoting sector-specific, innovation-driven growth. First and foremost, this thesis was aimed at the development of a decision support tool that can be used to assist in adequately rewarding prime contractors who invest in innovative activities in their Canadian supply chains while fulfilling their IRB obligations. It is hypothesized that IRB obligations can be better tailored to encourage value adding activities within prime contractors' supply chains (typically small and medium enterprises in this sector).

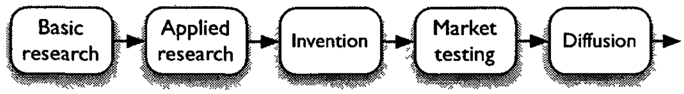

FIGURE 1.1 Linear model of innovation describing a sequential process of events. In this model, basic research leads to applied research, which leads to application and to market wealth.

This thesis begins with a brief historical perspective on innovation and the role of S&T in society. Following this, the role of government in fostering a culture of innovation is discussed. An emphasis is placed on the current IRB program and its potential role in promoting innovation. Chapter 3 focuses entirely on the use of the Real Option Pricing (ROP) model and its use in evaluating optimal levels of R&D investments in military procurement contracts. First, the standard Black-Scholes option model is derived as a general risk-minimization economic tool and later expanded to accommodate objects whose value does not vary according to a Gaussian distribution. Chapter 4 presents results on the use of the ROP using American historical procurement data.

1.2 Innovation and its importance

Innovation is not a single activity – it is a process by which knowledge is transformed (i.e., embedded) into a new commercially successful product or service [2]. Some innovations are revolutionary (e.g., the use of the semiconductor in computing) and are the impetus for entire new industries while others are incremental and give one a particular commercial advantage. Regardless of the scope of the innovation, their cumulative effect accounts for a significant portion of the observed exponential growth in macro- and micro-economic wealth [3, 4].

Many of the current policies surrounding matters of innovation are based on the paradigm which states that activities that lead to innovation lie on a spectrum separating basic research, applied research, and development. That is to say that the transformation of scientific knowledge undergoes a natural linear process up to its successful commercialization. The linear model view (shown in figure Figure 1.1) is often criticized for its simplistic view and for its misrepresentation of the actual reality of conducting research however, it continues to be a popular mental model for policy makers. The strength of this model is that it breaks innovation into a series of events

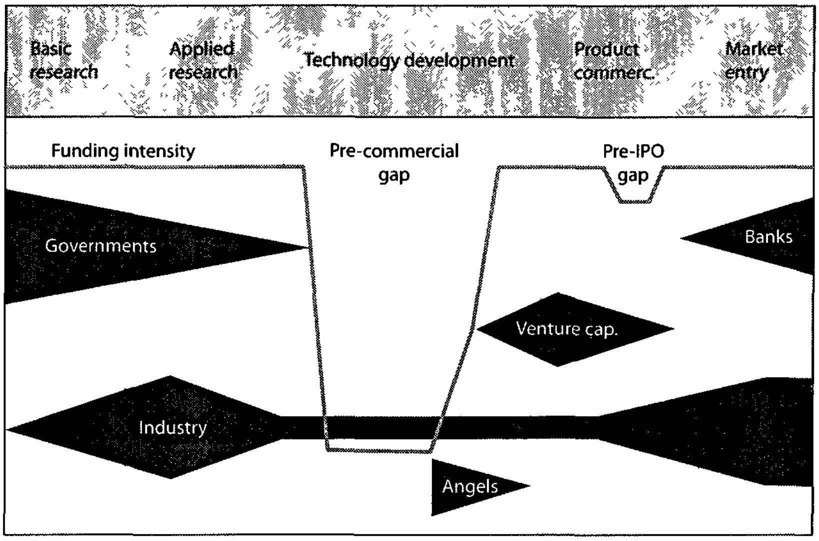

FIGURE 1.2 Schematic illustration of the funding gap in R&D financing. There is a large gap in available financing for technologies that are in the technology development stage. Source: SDTC, 2008 [5].

that must successively take place[1]. This allows policy makers to target specific innovation activities with tailored programs and institutions. The drawback of this model however, is that analysts sometime use it as a convenient way to ignore complex issues related to interdependencies and feedback mechanisms at various points in the process of innovation. With few exceptions, government programs and policies still show signs that they are targeted to very specific silos. Policy makers are left with the problem of having to foster innovations across "commercialization gaps" or "funding chasms" (i.e., specific points in the innovation process that are known to be underfunded in our society); an over reliance on the linear model could be partly to blame. This is illustrated on Figure 1.2 where one can quickly gauge relative funding levels by funding institution for different innovation-related activities. Typically, it is said that Canada lacks funding at the technology development and early product commercialization levels.

Recent work has emphasized the notion of an open (no closed loops) system of innovation as a network of several stakeholders and institutions working in loose collaboration [6]. Although

[1] e.g., Basic research in radiation leads to the postulation of stimulated emission (1917) → applied research in solid state leads to first functional laser (1960) → first commercially successful application is the compact disk player (1982).

more realistic, this model quickly becomes intractable and difficult to conceptualize[2]. The systems terminology is meant to underscore the importance of interactions and the complexity in applying stimuli (and measuring responses) to any one part of the whole. Changes in policy are difficult to measure and can sometimes lead to unanticipated results with dire real world consequences (for example, see [7]). In the managerial sciences, this is often known as a "wicked problem" [8] where lag times, threshold effects, emergent behaviours, and other nonlinear effects dominate. The use of simple models based on largely false assumptions (e.g., perfect rationality of market players) must be revisited in order to explain observed data series [9]. Better models that are based on real-world data could consequently explain the effect of policy changes more accurately. Many current economic models however, are based on 19^{th} century studies of physical thermodynamic systems. One must leave the mathematical elegance presented by these quasi-static systems since the observed systems (e.g., markets, institutions) are not at equilibrium and do not behave statically. This thesis therefore aims to produce a decision support tool based on a statistical interpretation of market phenomena that has endured the rigour of real world data validation.

Regardless of the conceptual model, it is difficult to dispute the role that innovation can play in improving the quality of life over the years - this role also strongly depends on establishing a proper institutional environment. As shown in the following section, there is good evidence showing that innovation is strongly correlated with investments in R&D. Accumulation of knowledge through R&D has been categorized as an endogenous source of growth [3] with the peculiar property of increasing returns. It is therefore critical for nations seeking a competitive advantage to maintain the pace of scientific discovery and

S&T or R&D?

Some of the confusion surrounding matters of S&T policy may additionally come from the fact that people typically see S&T and R&D used interchangeably. Science, or the pursuit of knowledge using the scientific method, can also refer to the current level of knowledge on the natural universe. However, technology is the usage of this knowledge in order to accomplish a specific outcome. On the other hand, research and development refers to the series of activities by which we increase our knowledge store. Basic and applied research, as well as development are typically included in this definition.

---

[2] In fact, the mere act of mapping the Canadian system of innovation with an emphasis on the dependencies of each player is an exercise left for future research that would have great impact in identifying various weak spots (e g , see work of Global Advantage)

to foster mechanisms to encode the knowledge obtained from these discoveries into products and services that increase the quality of life for all.

There has always been a deep ideological divide between those who believe that the government should steer research and those who believe that the government should simply fund science with no guidance as to its outcome. This was reflected in the U.S. as the Bush vs. Kilgore political debate leading to the publication of Vannevar Bush's famous report (described later) [10]. Bush's ideology of "research for the sake of research" was ultimately chosen and the oversight of resource allocation was left to the scientific community (i.e., via the peer review process). Additionally, in terms of ensuring an optimal innovation pipeline in the market, there is a belief that a large pool of basic scientific knowledge and applied research should "push" technology into the market. Conversely, others believe that markets alone create a demand "pull", which forces firms to invest in knowledge creation to meet customer demands (e.g., through increased R&D). Obviously the answer is that a mix of policies aimed at fostering both push and pull strategies is required. The Canadian government has traditionally been associated with the creation of a strong knowledge base. In fact, per capita, Canada is the second largest spender in Higher Education R&D (HERD) and boasts the highest proportion of post-secondary graduates in its workforce among G-7 countries [11]. However, Canada is often criticized for not inducing market pull strategies. Strategic procurement policies in the aerospace and defence sector could have the effect of creating a demand for technologies requiring additional investments in R&D. Adequately rewarding recipients of procurement contracts who invest in innovative activities to fulfill their contractual obligations was therefore be the focus of this research topic.

1.3 The role of innovation in Canada

It seems natural to assume that innovation is a top priority of the private sector. However, the macroeconomic data indicate that markets alone do not provide enough incentives for private firms to optimally invest in R&D [12]. In order to maintain a national advantage, governments can therefore have a tremendous impact on their private sector by helping to form an environment that fosters innovation. This idea is embodied in Canada's current innovation strategy aptly named "Mobilizing Science and Technology to Canada's Advantage" [13] and which will be discussed later.

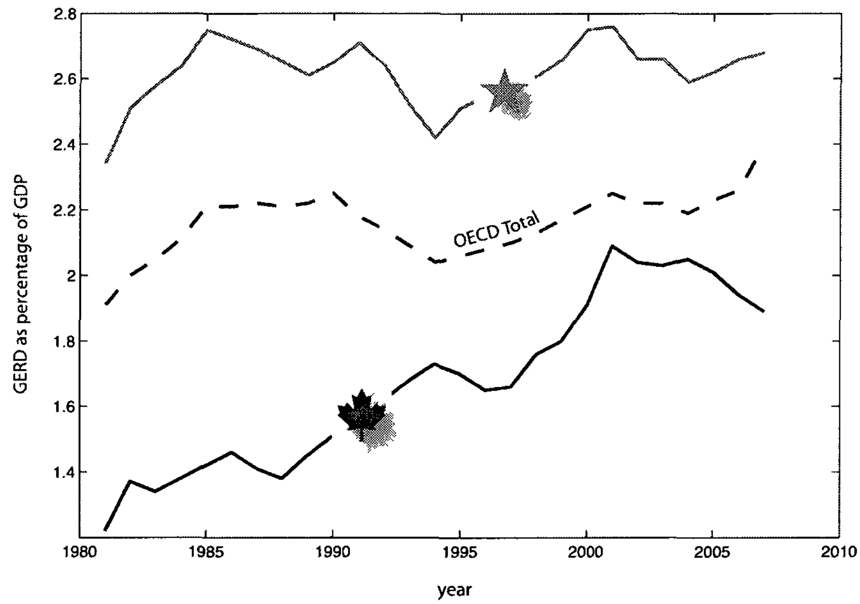

FIGURE 1.3 Gross expenditure on research and development (GERD) over time for the United States and Canada. The OECD total is shown as the black dashed line. Source: OECD Main Science and Technology Indicators Database 2009.

The role of government in fostering innovation through investments in R&D (both directly and indirectly) was brought to the forefront of policy making after the Second World War in the US. It is during this time period that the US government asked Vannevar Bush[3], the director of the Office of Scientific Research and Development, to consider ways of maintaining the levels of "application of scientific knowledge to the solution of technical problems" that were experienced during the War [10]. After this report, many governments (including the Canadian government) began considering the funding of innovation as a net gain for their countries. This ideology was further solidified in North America when Russia demonstrated its technological superiority by being the first nation to successfully launch a satellite (i.e., the launch of the Sputnik satellite in 1957) [14]. This event is known as the catalyst that captured the public's imagination and shifted government attention to the urgent need for active government funding in Science and Technology (S&T). In 1958, the Advanced Research Projects Agency (DARPA), part of the Department of Defense (DOD), was tasked with preventing further Sputnik-type surprises by investing heavily in science and in the development of high-risk research ideas with potentially high payoffs. The National Aeronautics

[3] Incidentally, Vannevar Bush is often credited as being the first to propose the linear model of innovation as a conceptual model.

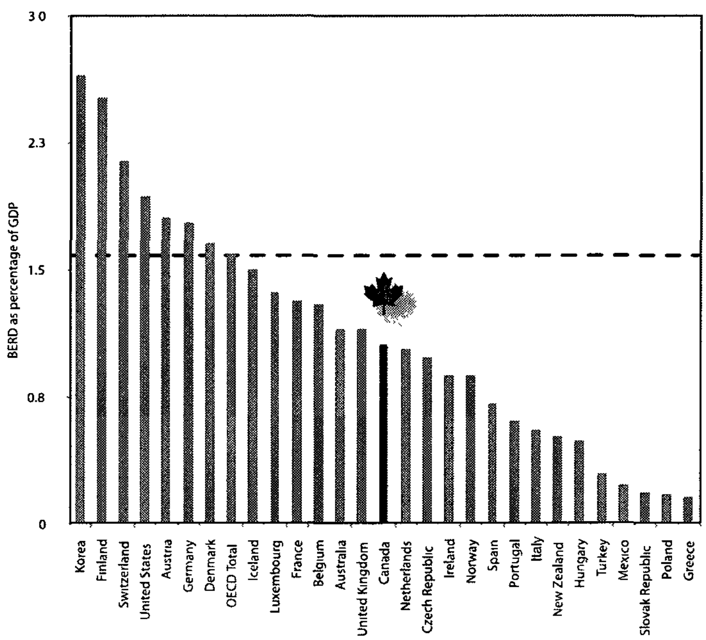

FIGURE 1.4 Business expenditure on research and development (BERD) for various OECD countries. The OECD total shown as the black dashed line is 1.6%. Source: OECD Main Science and Technology Indicators Database 2009.

and Space Administration (NASA) was also formed in the aftermath of Sputnik.

With few notable exceptions (differences discussed in Chapter 2), the Canadian government has typically been a close follower of American policy with respect to innovation. The end results varied however, as seen in Figure 1.3 where the gross expenditures on R&D (GERD) over time are shown for the United States and Canada (the OECD total is shown as the black dashed line). Furthermore, upon closer inspection of the type of funding aggregated into the GERD data, one notices that Canada is also out of step with its comparing nations. Canada's R&D funding is almost entirely in the form of reward-free tax incentives (i.e., the Canadian SR&ED incentive program credits failing firms at the same level as successful ones). This is in contrast with other countries who have a more balanced approach between tax incentives and direct funding. Although Canada has steadily been increasing its GERD toward the OECD total, it has made significant loses following the IT-led recession following the year 2001. In fact, Canada's low GERD ratio has been a source of frustration amongst policy leaders for the past 40 years [15]. The recommendations have always produced poor results partly because they neglected to implement measures that increased private participation in R&D.

Despite myriad policies and programs aimed at fostering innovation, most experts agree that to maintain its competitive advantage, it is imperative that Canada increase the amount of Research and Development (R&D) activities performed by its business sector (BERD) specifically [16]. Canada's businesses collectively spend a mere 1.1% of the national GDP on R&D – much below the OECD average of 1.6% (shown in Figure 1.4). Moreover, countries that are deemed to be 'innovators' tend to have a private sector that spends above 2% of the national GDP on R&D related activities. In Canada, only 54% of R&D is supported by business compared to the OECD average of 68%; Canada ranks poorly in terms of its Multifactor Productivity (MFP) growth[4]. A need was thus identified for Canadian businesses to incorporate innovation as a core business strategy for growth [17]. Additionally, the 2009 Speech from the Throne identified an increase in productivity growth (i.e., accelerated productivity increase) as a key to improving Canada's economic situation [18].

It is also interesting to look at the progression of business expenditures in R&D over the years as shown in Figure 1.5. Although Canada's private sector has made progress with respect to the OECD total values, it is still lagging behind. As mentioned before, the increase of this metric is often cited as key to increasing the productivity of Canadian firms.

Finally, within the private sector, it is important to mention that the typical source of product commercialization funding (as described in Figure 1.2) is lower in Canada than in other comparing nations. This is shown in Figure 1.6 where Canada is seen to be a laggard in terms of access to venture capital funding. American companies, for example, are more likely to invest in innovation as a strategic business decision using venture capital. Innovation as a business strategy therefore gives these companies the competitive option of investing in emerging markets and technologies therefore making them more competitive when compared to their Canadian counterparts.

As mentioned above, economists often wonder about the extent in which the government has any role to play in the affairs of a profit-maximizing private sector. Would the private sector not naturally seek to optimally innovate in order to increase their profit? In fact, research shows that Canadian businesses do not invest heavily in innovation. As seen in Figure 1.7, the Canadian private sector has been, on average, more profitable than its American counterpart despite its low investment in innovation. This is partly due to our vast natural resource extraction capacity and

---

[4] MFP growth is a measure of the rate of growth of output with respect to the rate of growth of all inputs (capital and labour services, energy, materials, and purchased services). It can therefore be used as a rough measure of growth related to innovation in products and services.

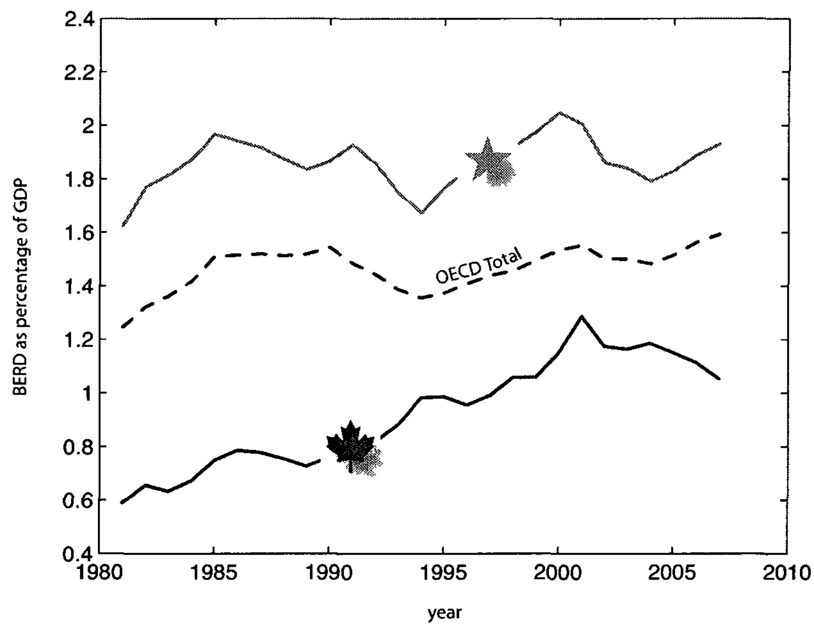

FIGURE 1.5 Business expenditure on research and development (BERD) over time for the United States and Canada. The OECD total is shown as the black dashed line. The BERD time series follows a similar trajectory as the GERD. Source: OECD Main Science and Technology Indicators Database 2009.

large manufacturing sector (e.g., with American headquarters and research centres). These industries typically lack the the need to perform value-adding activities in the country and unfortunately form most of our private sector's business.

It is becoming clear that moving forward, Canada will have to export not only raw materials, but products that are higher in the value chain in order to gain a competitive advantage. This can only be done however, if Canadian companies invest in innovation despite currently being profitable. The government can help to create an environment that assists companies in better managing the risks inherent with innovation. Additionally, using an option-based framework as a tool to do so is justified since investing in innovation can be viewed as giving one a future option of utilizing the obtained codified knowledge for commercial purposes or not. The financial option is therefore transformed into a real option that benefits from the existence of an extensive theoretical framework that can be used to evaluate and rank investment opportunities.

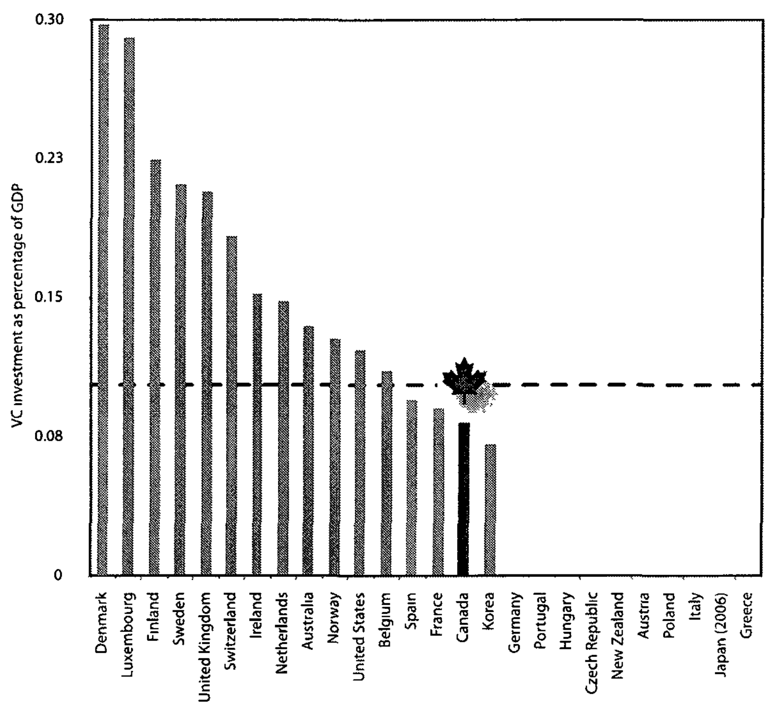

FIGURE 1.6 Venture capital funding as a percentage of GDP for OECD countries. Source: OECD Science, Technology and Industry Scoreboard 2009.

1.4 Research goal

Procurement policies can be used for economic development – the government could make better use of strategic investments (using the offset requirements of procurement contracts) in innovative Canadian-made technologies and services. Currently however, there is no quantitative framework within procurement policies to fairly compensate public or private entities who make investments in innovative technologies. These investments would have a greater impact in technologies or companies that are often in the pre-commercial and/or R&D stages therefore carrying additional risks.

The next chapter will begin with a short introduction of the aerospace and defence sector followed with a description of current procurement policies in this sector. An emphasis is placed on the use of procurement as an economic development tool. Chapter 3 will present a modified financial options model as a way of pricing R&D activities. Once these activities have a reliable price, their value can be leveraged to encourage investments in R&D activities by procurement

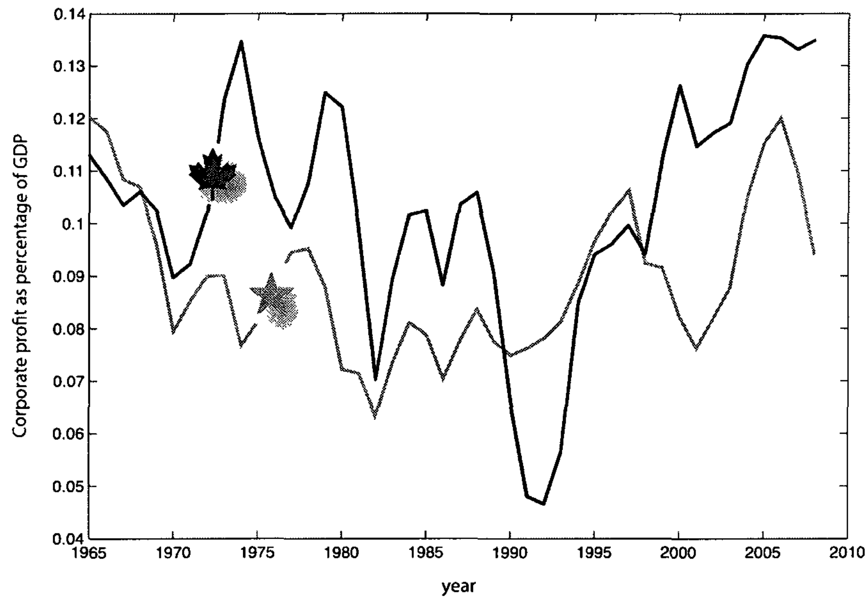

FIGURE 1.7 Corporate profits in the United States and Canada over the years. Canadian business have been profitable despite investments in R&D. The poor access to VC funding is often sited as the reason for poor innovation performance in the private sector. Sources: Statistics Canada, table 380-0014 and U.S. Bureau of Economic Analysis, table 6-16A.

contract recipients. The use of a real options pricing model is thus introduced in the context of procurement policies.

1.5 Contributions

Contribution to theory

This research contributes greatly to the theory of options pricing in general since an analytic formula for pricing options with an underlying whose returns fluctuate according to a power law distribution is found. To my knowledge, such a formulation specifically using the (truncated) Cauchy distribution did not exist prior to this research. The statistical derivations used in this research additionally lend themselves well to further manipulations and refinements of the assumptions and key parameters (e.g., to account for the statistical nature of the risk free interest rate). Another subtle contribution to theory is the reinforcement of the notion that the creation of (economic) models benefits from a development rooted in the statistical interpretation of historical data. This is in contrast with many models, which begin with assumptions, often quickly turned into axioms, which lead to unrealistic results (e.g., the assumption of perfect rationality leads to crash-free markets).

Contribution to practise

This research also contributes to the practise of offset management by offering a decision support tool. This tool is presented in the form of a method for using a mathematical formula to help offset managers in the evaluation of an optimal amount of investment in innovative activities for each of their procurement portfolios. In practise this allow the offset managers to justify a reward structure for prime contractors that encourages investments in innovation. An example showing the usage of this method is provided in Chapter 4 using realistic data drawn from American historical procurement data.

Other contributions

In the course of my M.Sc. studies, I presented the results of my work at various conferences and workshops in Canada and abroad. Chapter 3 will serve as the bulk of a manuscript for submission to a peer-reviewed scientific journal in management or economics by the end of the 2010 Winter term. Below is a summary of other research related activities, in chronological order.

Conference presentations

1) **S Casault**. *Systems of Innovation.* Industry Canada - Science and Innovation Sector (SIS) and Science, Technology, and Innovation Council (STIC), Ottawa, 2008.

2) **S Casault**. *Real Option Pricing Model Applied to Industrial and Regional Benefits Policy.* Defence Research and Development Canada (DRDC) - Centre for Operational Research and Analysis (CORA), Ottawa, 2009.

3) **S Casault**. *Real Option Pricing Model Applied to Industrial and Regional Benefits Policy.* Telfer School of Management Workshop, Ottawa, 2009.

4) **S Casault**. *Putting a Price on It – Using Real Options to Encourage R&D Investments.* American Association for the Advancement of Science, San Diego, 2010. **Winner in the Social Sciences category**.

2

Strategic Procurement Policies in the Aerospace and Defence sector

Innovation has nothing to do with how many R&D dollars you have... It's not about money. It's about the people you have, how you're led, and how much you get it.
(Steve Jobs)

One of the main assumptions driving this research is that for each procurement contract, there is an optimal amount of R&D investment that could be performed to optimize the economic impact of said procurement. This business-led investment can further be rewarded using a multiplier framework layered onto prime contractors' offset requirement. Multipliers, for example, are well suited for this because they are financial rewards that allow the government to mitigate the risk of performing R&D using an established framework. One must however, have a consistent method for evaluating the amount of each transaction that should be allocated to innovation depending on one's risk aversion profile (i.e., the portion of each portfolio that can be at-risk). This chapter will first introduce the aerospace sector in Canada and explain the role that government procurement is having in shaping the sector. The next chapter will then develop a real options methodology, which can enable procurement officers to quickly gauge optimal levels of R&D investments for each procurement contract requiring offset obligations.

2.1 The Aerospace and Defence Sector

The Canadian aerospace sector employs 80,000 people in over 400 firms across the country. The sales of all Canadian aerospace industry firms total over $22B annually while the sector exports nearly 80% of its output. According to the Aerospace Industries Association of Canada (AIAC) [19], "Canadian firms are global market leaders in regional aircraft, business jets, commercial helicopters, small gas turbine engines, flight simulation, landing gear, and space applications." An industrial sector as diverse as this one has direct economic and sociological implications to a broader range of downstream suppliers and to the broader community in general. These firms tend to aggregate in specific regions and form specialized aerospace clusters [20–22]. Initially, researchers assumed that these clusters were of importance because of the knowledge spillovers that can take place between firms of close geographic proximity to each other and to sources of knowledge creation (e.g., between a university and nearby firms engaged in R&D activities). However, it is becoming more likely that spillovers are not the key reason why firms cluster but it is rather the access to localized pools of skilled workers who bring tacit knowledge, skill, and experience with them [23]. In this light, it is apparent that clusters offer a good environment for smaller firms wanting to attract top talent and become suppliers to larger "anchor" firms [24, 25].

Despite annual investments of $1.2B in R&D, innovation remains limited by characteristically long product life cycles in this sector [26]. It is therefore imperative that one understands the contextual dynamics of these regional economic drivers before enacting policies that are both appropriate and conducive to the sustainability of this sector. It is proposed that increasing productivity through R&D in the value networks of SMEs using strategic government procurement policies could help Canada attain its ambitious efforts to become a leader in the aerospace sector by 2025 [27].

In the aerospace sector, the beginning of the supply chain is composed of machining suppliers largely composed of family-owned SMEs with 25 to 60 employees [28]. These SMEs are networked with many other firms (other SMEs and larger firms) since no one player usually offers a completed product or service to the end customer (usually government in the case of the defence sector). Supply Chain Management (SCM) is therefore a critical component of SMEs wishing to be competitive however, the literature also suggests that SMEs do not adopt best practices of supply chain management [28, 29]. This has the overall effect of increasing the rigidity of the existing supply chains of OEMs and offers a challenge to smaller firms or even existing firms that have a

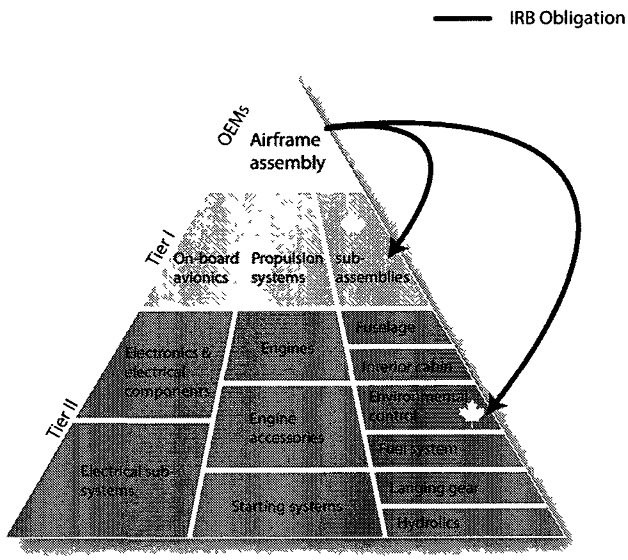

FIGURE 2.1 This represents a typical value network in the aerospace sector. Figure adapted from source: J Niosi and M Zhegu (2005) [20].

new innovative product to offer. The IRB directorate could help mitigate this problem by hosting SCM "teaching sessions" for innovative SMEs.

Newly formed SMEs typically enter the sector at the bottom of the supply chain by offering a specific product or service to firms located higher in this pyramid (shown in Figure 2.1). In this sector, SMEs are typically indirect recipients of procurement contracts by conducting "lower level" activities that cater to larger firms in the network. It is at this level that the government imposes contractual obligations for OEMs to deal specifically with Canadian companies in large defence procurements (known as an Industrial and Regional Benefit [IRB] or offset). In this figure the contractually mandated obligations are illustrated as solid arrows showing an OEM (or prime contractor) fulfilling its obligation of Canadian content in its supply chain. To be valid, the transaction must also be shown to be causally related to the procurement contract. As mentioned, there is a strong hierarchy in this sector due, in part, to the fact that the end product is technologically complex. Most studies unfortunately tend to concentrate on the large players neglecting to understand the basic foundation of this supply chain scheme [28].

One of the main challenges here is that value in the supply chains may be under utilized and this may be partly due to the fact that government typically procures market-ready goods and services while discarding potentially valuable innovations that require further product development (more on this in Section 2.2). As mentioned before, it may be possible to enhance the IRB policy to increase OEM support for innovative activities within the SMEs in their Canadian supply chains. This would help focus R&D initiatives of SMEs as well as share development risk between the larger firms and their SME suppliers.

2.1.1 Role of intermediary institutions

Because supply chains require a close integration in this sector, a number of intermediary institutions provide targeted support in terms of co-ordinating the efforts of key players at various stages of the R&D spectrum [30]. Consider the supporting organizations in Montréal as an example, the "Consortium for Research and Innovation in Aerospace in Québec" (CRIAQ) provides early research support to firms, the "Centre d'adaptation de la main-d'oeuvre aérospatiale au Québec" (CAMAQ) co-ordinates labour issues, the "Association Québécoise de l'Aérospatiale" promotes the Montréal SMEs internationally while "Sous-Traitance Industrielle Québec" fosters collaborations between OEMs and suppliers by promoting networking events. These organizations currently facilitate the integration of SMEs into existing value networks. Although there are institutions that cover most of the innovation spectrum, there is no overarching organization and little government leadership in co-ordinating their efforts. This leads to the potential for gaps in the innovation spectrum.

There are various governmental programs that enhance the synergistic value of co-ordination in the aerospace and defence sectors. For example, the "Strategic Aerospace and Defence Initiative" (SADI) was launched in 2007 as a repayable contribution program with a mandate to "support strategic R&D that result in new products, processes and services". There is currently a lack of alignment between fundamental and applied research in aerospace defence and National Defence's strategic needs (more on this topic in Section 2.2). There may be a tremendous opportunity to use this new institutional framework to co-ordinate future government procurement needs with R&D programs in the defence sector at the local level [31]. With little changes to procurement policies (discussed in the next few sections), the government could encourage investments in innovation by prime recipients of contracts. For example, areas of potential interest to prime contractors could first be identified by SADI. After which, prime contractors would be encouraged (through offset credits) to invest in Canadians firms undergoing research in these areas.

2.2 Procurement policy

Since there is no all-encompassing Canadian procurement policy, individuals follow a set of process conventions when purchasing a military product or service in the aerospace and defence sector. First, the Treasury Board initiates the procurement process on behalf of the Department of National Defence (DND). DND is required to place IRB obligations into all defence contracts above $100M (sometimes in smaller contracts depending on the context) [32]. Following this, Industry Canada incorporates these IRBs into tendering contracts with prime suppliers. The contracts are written by Public Works and Government Services Canada (PWGSC) following Industry Canada's (IC) IRB-based modifications specific to each procurement contract. IC is then responsible for follow-up and the enforcement of obligations (e.g., through the application of liquidated damages, or other contractual instruments) [33].

Figure 2.2 presents a multidimensional schematic diagram describing government procurement. This figure illustrates a risk-based procurement strategy where the risk associated with a technology is seen to diminish as the market share increases and the technology matures and is more broadly adopted (more information on the technology adoption curve in [34]). The risk threshold (horizontal grey dotted line) can be adjusted depending on the government's risk aversion profile. As shown in this figure, the government would only acquire a technology nearing full commercial deployment once a late majority of people have already bought it - this is quite typical of the Canadian government. For example, Canada has not acquired cutting edge fighter jet technology but is rather sitting as an interested party until the technology has been proven (e.g., Canada's involvement with the F-35 Joint Strike Figher development project [35]). On the other hand however, one must exercise caution when acquiring pre-commercial technologies – large cost overruns and schedule delays are becoming increasingly problematic in the US due, in part, to their insistence on procuring immature technologies [29] and the usage of a fixed profit margin policy.

More importantly, the diagram illustrates the proverbial 'glass ceiling' for companies receiving some form of government funding to develop pre-commercial technologies (i.e., the line situated at the product development and demonstration level in the innovation spectrum). Companies receiving government funding are usually prevented from bidding on government contracts due to policies preventing unfairness in the competitive bid process. Therefore, Canadian firms who have worked closely with the military in development phases of a product are often unable to sell their resulting products domestically. This is in direct contrast with particular agencies in the United

States, for example, that foster innovation and entry to market by procuring new technologies that result from direct investments in R&D (e.g., the Defense Advanced Research Projects Agency, DARPA). It is clear that a better balance between competitive fairness and the encouragement of domestic technology must be established.

Also shown on this figure are two main strategic considerations in government procurement matters. The government can procure R&D services or it can obtain fully commercialized goods and services. When procuring a good or service, the government typically uses a commodity pricing model in order to assess its potential contractors. As mentioned above, the government does not have a consistent model that can be used to gauge the relative importance of pre-commercial goods and services. This thesis assists in filling this gap by developing a real option methodology to valuate such goods and services. The issue of unfairness in the bidding process should be resolved since the real options pricing model will be used to reward the investment in pre-commercial technologies by prime contractors and not directly by the government.

Several key institutions in the aerospace and defence sectors along with their respective audiences based on their areas of expertise in the innovation spectrum are also represented. The Natural Sciences and Engineering Research Council of Canada (NSERC) is heavily involved in basic and applied research whereas the AIAC is concerned with improving the visibility of established firms. SMEs are particularly affected by institutions, such as IRAP and SADI, that have a mandate to help them breach the typical funding gap. These organizations may be in a unique position to help foster innovation by co-ordinating with government procurement programs so that firms may have a stable initial customer while they are pushing technologies through their initial pre-commercialization growth phases.

2.2.1 Industrial and Regional Benefits as an economic development tool

In 1986, the Industrial Regional Benefits (IRB) policy was enacted for all defence procurements with values over $100M. According to the World Trade Organization (WTO), IRBs or "offsets" are "measures used to encourage local development or improve the balance-of-payments accounts by means of domestic content, licensing of technology, investment requirements, counter-trade or similar requirements" that are imposed in the procurement process [37]. In Canada, all major defence procurement tenders contain an offset obligation in the form of a reinvestment requirement[1].

[1] For the purposes of this study, the terms IRB, offset obligation, and reinvestment requirement will be used interchangeably.

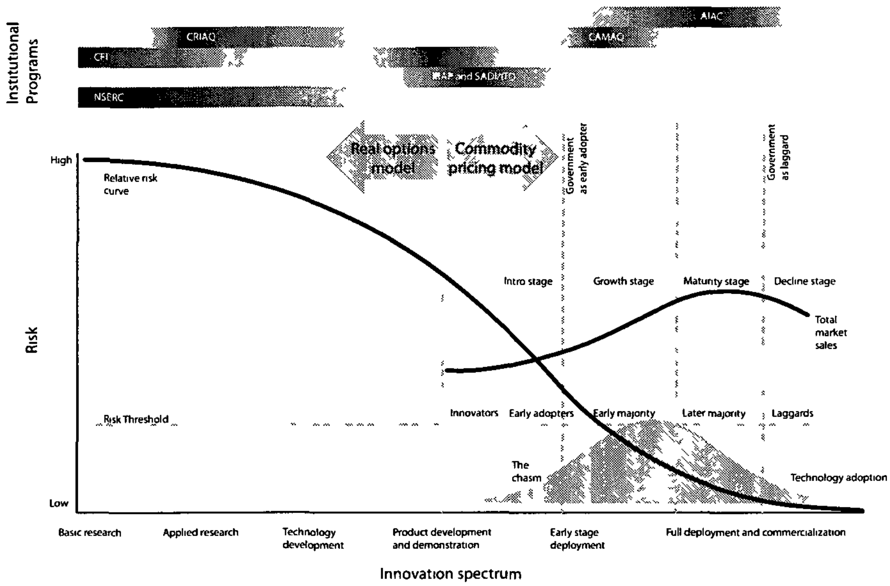

FIGURE 2.2 Schematic diagram showing various government procurement strategies based on the stage of development of a technology. Source: D Duguay and S Casault (2009) [36].

This reinvestment requirement dictates that the primary recipients of procurement contracts make investments in worthy[2] (or high value adding) sectors of the Canadian economy (typically by acquiring goods or services from suppliers) in a dollar amount equal to the contract that they have won. This is where aerospace defence SMEs can indirectly benefit from government procurement. SMEs typically do so by closely aligning their supply chains in order to become suppliers for large firms [20]. There is currently limited mechanisms to target specific economic activities (e.g., investments in R&D and university partnerships) using the current offset obligations framework.

Creating a strategic framework for the use of targeted offsets aimed at increasing value adding activities is the primary motive of this thesis. Updating the IRB policy to foster such activities has also been identified in 2009 by the Minister of Industry as a corporate priority. Such a framework will help to efficiently align innovative research activities with procurement needs (e.g., Strategic Aerospace and Defence Initiative [SADI], Industrial Research Assistance Program [IRAP]) with future defence needs in the aerospace sector as set by DND. The use of offset programs may also to be an efficient tool in promoting a "market-pull" (or demand-side) approach to focus R&D projects

[2] The definition of a worthy reinvestment is ambiguous and currently depends on the judgement of IRB agents who oversee individual investment transactions.

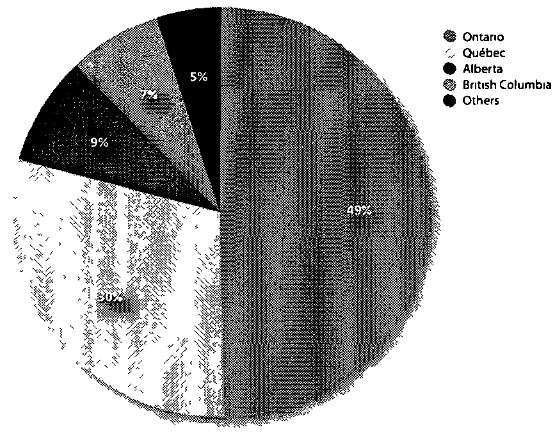

FIGURE 2.3 Business expenditure on research and development (BERD) by province. Despite programs aimed at increasing innovation in all regions, nearly half of all R&D in Canada is performed in Ontario. Source: Statistics Canada, table 88-001.

[31]. Additionally, strategic offset obligations may generate a talent pool of domestic expertise as well as ensure a stable domestic market for firms in the aerospace and defence sector.

The IRB policy is also meant to strategically introduce high quality work in various locations throughout Canada. In terms of regional development, one can see in Figure 2.3 that most of the private sector funding of R&D is concentrated in Ontario and Québec. This is important to consider in the context of the Industrial and *Regional* Benefits policy (emphasis to indicate the dual nature of the policy established as a core principle). It may not be reasonable to assume that innovative activities can be performed anywhere in the country. Policies aimed at increasing innovation must therefore understand the capacity gap across regions before imposing specific regional requirements.

Additionally, the IRB policy was created in order to help SMEs access the benefits of procurement contracts by indirectly incorporating SMEs in defence procurement contracts. The current IRB Policy provides a means for Canadian SMEs to supply prime contractors that hold contracts with the Government of Canada. However, in their current iteration, IRBs are not mandated beyond requiring OEMs to ensure a Canadian content equal to at least 100% of the value of the procurement deal. This process may be improved by implementing policies that foster sustainable value networks within aerospace clusters.

The nature of IRBs in the form offset obligations are always challenging since they are a form of trade protectionism. According to *article XIV* of the Agreement on Government Procurement "[e]ntities shall not, in the qualification and selection of suppliers, products or services, or in the evaluation of tenders and award of contracts, impose, seek or consider offsets [37]." According to the WTO, offsets are "measures used to encourage local development or improve the balance-of-payments accounts by means of domestic content, licensing of technology, investment requirements, counter-trade or similar requirements." The use of offsets is however commonly used in defence procurement deals since there is only a handful of countries that supply defence products and offsets are a tool used to "level the playing field".

Because of their protectionist nature, IRB policies have to obey rigorous transparency standards and cannot unjustifiably favour domestic firms (the World Trade Organization has strict rules of conduct on these issues). However, in the aerospace sector, this is always prone to challenges in terms of managing the public perception. For example, in 2009, Canada was considering the procurement of C-27J fixed wing search and rescue planes built by the Italian Consortium Alenia [38]. Public pressure has delayed the project due to a perception that the Canadian Government handing out the lucrative $3B deal to a foreign country with little domestic consideration. A clear and transparent IRB framework specifically indicating the economic impact that OEMs are having on the Canadian economy while fulfilling their offset obligations could therefore function as a tool to justify the procurement of equipment with foreign suppliers to taxpayers.

3

Real Option Valuation Methodology

When the number of factors coming into play in a phenomenological complex is too large, scientific method in most cases fails us.
(Albert Einstein, 1879–1955)

3.1 Financial Options

Financial options belong to a class of financial instruments called derivatives. That is, instruments whose values depend on the values of other underlying variables. Options are used extensively in the financial field for stocks, bonds, and futures markets. For decades however, the purchase and sale of options (i.e., rights of purchase) was unusual and infrequent. The lack of popularity of options was largely due to the complexity and uncertainty of how to price them appropriately. Consequently, sellers tended to overprice options to ensure that they did not lose money and buyers tended to undervalue options to ensure that they did not overpay. Following the publication of a formula for determining the price or cost of an option [39], this problem of buyers and sellers disagreeing on the cost or price of an option was resolved because everyone could agree on the same economic value being offered by an option. The resulting formula, known as the Black-Scholes model, was widely adopted to assign the value of an option. Due to the tremendous impact of this discovery to the field of finance and to financial markets, Scholes and Merton received the

1997 Nobel Prize in recognition of their contribution[1]. However, note that an over-reliance on the Black-Scholes equation (and its assumptions on market behaviour) is blamed for the widespread 'program trading' that led to the market crash of 1987 [40].

In its general sense, an option is a contract worth a premium C between a buyer and a seller giving the buyer (seller) the right to buy (sell) an underlying asset, X, after a given time T for an agreed "strike" price $x(T) \equiv x_S$. In the case of a call (put) option, the option seller (buyer) is obligated to sell (buy) the asset if the buyer (seller) decides to exercise their right to buy (sell) the underlying asset. There are various types of options however, the most common ones are of the European type; defined as options that can only be exercised on expiration. Additionally, options can be of the American type; defined as options that can be exercised at any time prior to their expiration time. For simplicity, the former is assumed in this thesis.

The use of derivatives is an important tool to minimize one's risk in trading with underlying instruments that have a tendency to fluctuate stochastically. A trader typically builds an option portfolio following various hedging strategies to leverage uncertainty. Most financial books on the subject explain option payoff scenarios by constructing risk-free hedging strategies[2] [42, 43].

Contrary to real world situations however, most conceptual models assume the final price of the option to be of equal price to the hedging strategy with no associated uncertainty. The use of these idealized scenarios do not take into account the statistical nature of markets and will be avoided here. A more accurate way of describing the price of an option is to look at it as a distribution $P(\Delta W)$ of the trader's wealth balance ΔW rather than assuming that the price is uniquely identifiable (i.e., described as an infinitely sharp δ-function). This distribution can then take on many functional forms; it can be narrow if the option portfolio is well-hedged, or it can be wide if the market is volatile. The main point is that we are dealing with statistical entities that inherently carry information about risk in their higher moments. Consequently, the pricing of options has no unique solution since it explicitly depends on the shape of the targeted distribution (i.e., the risk tolerance of each trader).

In statistical theory, observables (e.g., $A(x,t)$) are measured as averages (denoted with $\langle\rangle$)

---

[1] The then late Black was mentioned as a contributor by the Nobel Foundation.

[2] A hedge represents a risk minimizing strategy whereby a person trades in one market while, at the same time, offsets exposure to volatility by trading in some opposite position in a different market [41].

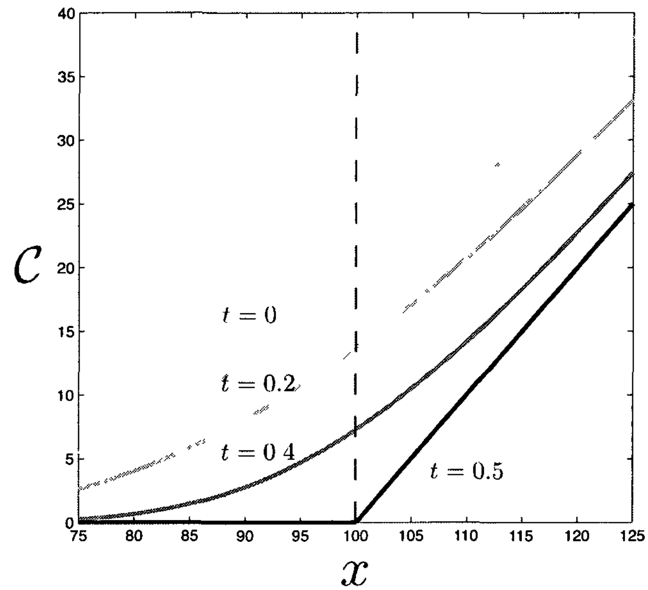

FIGURE 3.1 Call option price as a function of the underlying asset's price shown for various times before the option expires. In this example, the risk free rate of return $r = 0.002$, the expiry time is $T = 0.5$, the strike price is $x_S = 100$ (shown by the dashed line), and the underlying's variability is set to $\sigma = 0.5$.

over their respective probability distributions

$$\langle A(x,t) \rangle \equiv \int P(x,t|x_0,0)\, A(x,t)\, \mathrm{d}x \,, \tag{3.1}$$

where $P(x,t|x_0,0)$ is the probability function describing the probability that the price of an underlying is x at time t given that it was x_0 at $t = 0$. As we shall see in the following sections, the problem boils down to finding a distribution function that is both suitable for the situation (i.e., adequately fits observed macro-economic data) and that can be explained using a theoretical model of micro-economic interaction. However, most economic texts start by assuming a specific distribution function (e.g., Gaussian distribution) and later posit models to justify that function (regardless of its appropriateness in fitting existing data).

In the context of our option model, this means that we will be starting the derivation from a purely statistical point of view as described in [44]. The Black-Scholes "limit" can then be extracted and discussed as a special case of a generalized framework that allows for the use of potentially any distribution of underlying fluctuations. For illustrative purposes, Figure 3.1 shows the call prices obtained using the Black-Scholes limit in pricing a European call option for an underlying stock with a strike price of $x_S = 100$. The risk free interest rate, $r = 0.002$, is based on a 1 year treasury rate as observed in the Fall of 2009 (Chapter 4 shows the effect of varying this rate on the call price). The formula will be derived later however for now, the figure shows call option pricing as a function of the price of the underlying for different times prior to the exercise date. Note that for times $t < T$, the high variability used of $\sigma = 0.5$ makes it possible for out of money options to become profitable after expiry. This is reflected by call prices $C(t) > 0$ even though the projected value of the stock is still below the strike price $x(t) < x_S$. This pricing scenario allows managers the flexibility to invest in costly innovation as a "hedge" against future uncertainty (e.g., competitor developing advanced product). A call option is said to be "out of the money" when its strike price is higher than that of the underlying. Vice versa, a call option is said to be "in the money" when its strike price is lower than that of the underlying.

3.1.1 Generalized Real Option Pricing model

More recently, financial options were successfully applied to non-financial, or real assets. The term "real option" was coined by Myers in 1977 who postulated that growth opportunities such as R&D expenditures could be viewed as call options [45]. Many have later applied models traditionally used to price financial options and extended them to quantify the economic value of research in terms of future implementation of derivative technology [46–49]. Wang and Hwang developed a fuzzy R&D portfolio selection model based on real options to hedge against the R&D uncertainty [50].

Therefore, as a natural extension to the concept of financial options, real options can be useful for justifying some business decision (e.g., the option to make, abandon, expand, or shrink an investment). In our case, the opportunity to invest in a specified commercial innovation, or alternatively to abandon research or sell the resulting intellectual property, is a real option. As a decision support tool, real options can therefore quantify the value of decision flexibility in responding to environmental changes. This allows innovation to be viewed as strategic investments with real value. Historically, firms have typically relied on Net Present Value (NPV) techniques to appraise long term projects however, this method fails to capture the value of managerial flexibility in uncertain environments [51, 52]. Management flexibility and its ability to react to new information is often key to success, especially when a company is considering investing in innovation. The use of Real Options therefore encompasses the ability of management to alter the its environment as a means of leveraging value [53]. For these reasons, this tool is used in this study in order to evaluate an appropriate level of "at risk" investments in future offset portfolios.

The rest of this section is devoted to presenting analytical support for large fluctuation option pricing. Although the need for large fluctuation analysis has been repeatedly identified in economic theory, there are unfortunately few papers that attempt to build an analytical framework based on real data (see [54–56] for background information).

The theoretical methodology contained herein is based on previous work by Bouchaud and Potters [44]. We start by looking at a discretized[3] wealth balance equation. This equation describes the wealth obtained by an option seller after N specified time intervals

$$W_N = [W_0 + \mathcal{C}](1+\rho)^N - \max(x_N - x_S, 0) + \sum_{i=0}^{N-1} \psi_i^N (x_{i+1} - x_i - \rho x_i) \ , \tag{3.2}$$

where W_0 is the initial capital and $\mathcal{C}$ is the value of the call option, which the issuer gains immediately at $t = 0$. The issuer can immediately place these into bonds where they gain interest at a rate of ρ (i.e., ρ is related to the risk free interest rate, $\rho = r\tau$). The second term refers to the incurred loss if the option is exercised (there is a loss of 0 if the buyer does not exercise his right of purchase if the asset's price drops below the strike price). The third term, ψ_i, is the hedging strategy or option portfolio. This is a value that corresponds to the number of assets converted to bonds (and vice-versa) at each time step in order to minimize risk.

The call price is then obtained from this general balance equation by requiring that the average return be set to zero to ensure that no arbitrage opportunities exist (i.e., risk-free strategy with positive return),

$$\langle \Delta W \rangle = \left\langle W_N - W_0 (1+\rho)^N \right\rangle = 0 \, . \tag{3.3}$$

Using equations 3.2 and 3.6, we can write the call price as

$$\mathcal{C} = (1+\rho)^{-N} \left[\langle \max(x_N - x_S, 0) \rangle - \sum_{i=0}^{N-1} \left\langle \psi_i^N (x_{i+1} - x_i - \rho x_i) \right\rangle \right] . \tag{3.4}$$

Let us first assume that the price increment process is multiplicative and can be written as

$$x_{i+1} - x_i = \rho x_i + \delta x_i \ , \tag{3.5}$$

[3] In continuous units, time evolves from $t = 0$ to the contract expiry at $t = T$. In discretized units, time increases to $N = \frac{T}{\tau}$ where τ is the discretized time interval.

where the term $\delta x_\imath = \sigma_\imath \epsilon_\imath x_\imath$. We can also define the relative price increment as the return

$$\eta_\imath = \frac{\delta x_\imath}{x_\imath} \approx \log x_{\imath+1} - \log x_\imath \; , \tag{3.6}$$

where the approximation holds for small price increments. Let's further assume that the random number ϵ is taken from a probability distribution that has a first moment equal to 0 for simplicity (i.e., $\langle \epsilon_\imath \rangle = 0$). Therefore,

$$\langle \psi_\imath \delta x_\imath \rangle = \langle \psi_\imath \sigma_\imath x_\imath \rangle \langle \epsilon_\imath \rangle = 0 \; , \tag{3.7}$$

which makes the hedging strategy disappear from 3.4. We can therefore write the call price as

$$\begin{aligned} \mathcal{C} &= (1+\rho)^{-N} \langle \max(x_N - x_S, 0) \rangle && (3.8) \\ &= (1+\rho)^{-N} \int_{x_S}^{\infty} (x - x_S) \, P\,(x.\,N|x_0, 0) \, \mathrm{d}x \; , && (3.9) \end{aligned}$$

which depends entirely on the price increment probability distribution, $P\,(x, N|x_0, 0)$. This function gives the probabilistic price of the asset x after N time intervals given that the asset's price is initially x_0. In this form, Eq 3.4 can be used with any distribution functions.

3.1.2 Black-Scholes limit

The distribution function describing the market returns, $P\,(\eta)$, is typically what is observed and measured (e.g., the returns are independent and identically distributed (iid) according to a Gaussian distribution leading to price increments that behave as a geometric Brownian walk). We, however, need a distribution describing the behaviour of the price itself, $P\,(x, N|x_0, 0)$ to insert it into Eq 3.4. In order to solve this equation in terms of the iid variable, we first shift the probability distribution function by making a change of variables $x \to x_0\,(1+\rho)\,\mathrm{e}^y$, which allows us to write

$$\mathcal{C} = x_0 \int_{y_S}^{\infty} (\mathrm{e}^y - \mathrm{e}^{y_S}) \, P\,(y, N|0.\,0) \, \mathrm{d}y \; , \tag{3.10}$$

where $y_S = \log\left(x_S/x_0\,[1+\rho]^N\right)$ and represents the fraction of the strike price with respect to the forward price of the underlying asset. After the change in variables and a series expansion for small fluctuations $\eta_k = 0$, the evolution of the underlying is given as (see Appendix A.1)

$$y_{k+1} - y_k \simeq \frac{\eta_k}{1+\rho} - \frac{\eta_k^2}{2} + \cdots \; . \tag{3.11}$$

The quantity y_N can now be written as

$$y_N = \sum_{k=0}^{N-1} \frac{\eta_k}{1+\rho} - \frac{\eta_k^2}{2} \; . \tag{3.12}$$

Since we are assuming that y_k values are independent and identically distributed, the sum of N variables is simply the N^{th} convolution of the characteristic function in z space with itself and can be obtained simply from the identity

$$\hat{P}_N(z) = \left[\hat{P}(z)\right]^N , \tag{3.13}$$

where the Fourier transform of $P_1(\eta)$ is written as a function of the evolution of the y_k values obtained in Eq 3.11,

$$\hat{P}_1(z) = \int P_1(\eta) \exp\left[iz\left(\frac{\eta_k}{1+\rho} - \frac{\eta_k^2}{2}\right)\right] \mathrm{d}\eta . \tag{3.14}$$

Taking the inverse Fourier transform of Eq 3.14 therefore gives us the shifted distribution function, $P(y, N)$, needed to solve Eq 3.10. This slightly convoluted (pun not intended) way of solving for the call price has the advantage of being compiled from the observed distribution of returns, $P(\eta)$.

Many textbooks make use of the Black-Scholes model for all options-related pricing valuation without testing for the validity of its assumptions in their particular situations [57]. One of the assumptions of particular interest in the case of real options is that the underlying returns follows a normal distribution

$$P(\eta) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\eta-\mu)^2}{2\sigma^2}} , \tag{3.15}$$

where σ is the volatility of the underlying and μ is the drift rate. We begin by assuming that the mean is zero and the variance is equal to $\sigma_1 = \sigma\sqrt{\tau}$. We then find that the distribution of quantity y_N can be written as

$$P_N(y) = \frac{1}{\sqrt{2\pi N \sigma_1^2}} \exp\left(-\frac{\left(y + N\sigma_1^2/2\right)^2}{2N\sigma_1^2}\right) . \tag{3.16}$$

The Black-Scholes limit is obtained by making the elementary time interval go to zero $\tau \to 0$, $N = T/\tau \to \infty$ while keeping the product $N\sigma_1^2 = T\sigma^2$ finite. Plugging Eq 3.16 into Eq 3.10 yields

$$\mathcal{C}_{\text{BS}} = \int_{y_S}^{\infty} \frac{(e^y - e^{y_S})}{\sqrt{2\pi\sigma^2 T}} \exp\left(-\frac{\left(y + \sigma^2 T/2\right)^2}{2N\sigma^2 T}\right) \mathrm{d}y , \tag{3.17}$$

where $y_S = \log(x_S/x_0) - rT$ and which can be analytically solved by integration

$$\mathcal{C}_{\text{BS}} = x_0 \Phi\left(\frac{y_-}{\sigma\sqrt{T}}\right) - x_S e^{-rT} \Phi\left(\frac{y_+}{\sigma\sqrt{T}}\right) , \tag{3.18}$$

where $y_\pm = \log(x_S/x_0) - rT \pm \sigma^2 T/2$, and Φ is the normal cumulative distribution function. To summarize, equation 3.18 readily gives us the value of optimal investment in R&D for a given technology estimated to have value $x(t)$ that fluctuates with a variability of σ.

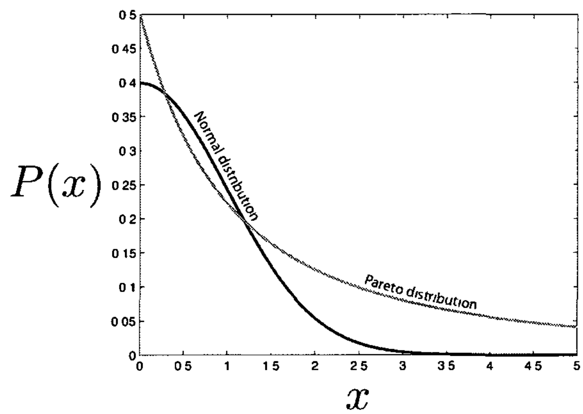

FIGURE 3.2 Illustrative figure comparing the tail of the normal and Pareto distribution functions. The probability, $P(x)$ of observing a large price x is much higher if the distribution follows a power law. High fluctuation events are highly improbable when using the normal distribution however, these events are observed in real markets. This is also known as the "fat tail" effects observed in market fluctuations [58].

3.1.3 Cauchy distribution development

A generalized call option model is derived in order to price R&D activities in sectors where technology returns are not distributed following a normal function. Because of exponentially decaying tails, a normal distribution makes large fluctuations in underlying variation highly unlikely. In reality however, such outliers are observed and need to be incorporated in the model since they often characterize the state of the market (e.g., market crash). For this reason, many economists are now turning to distributions with "fat tails" making large shift in price changes more probable, depending on "tuning" parameters. This is illustrated in Figure 3.2 where a typical normal distribution is compared with a distribution obeying a power law – the Pareto distribution here. This figure shows larger price fluctuations (> 1.5) to occur with higher probability using a power law distribution compared to the normal distribution.

Financial systems are a great example of complex systems of interaction. However, contrary to physical system, vast stores of data depicting their state exist and are accessible (with little need to perform laboratory work) for analysis (this property is probably what makes economic studies appealing to physicists who study similar statistical systems). There is a growing literature base that explain why power laws best characterize real world observations in systems (e.g., financial

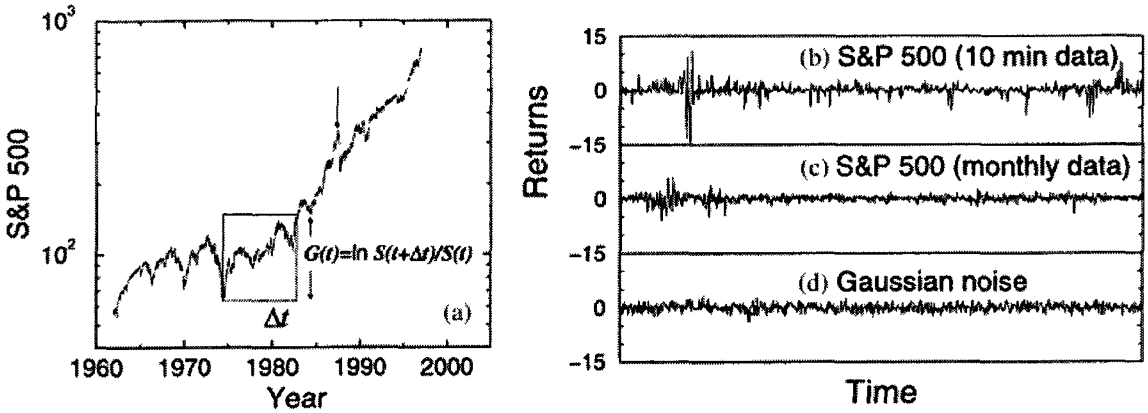

FIGURE 3.3 (a) The daily records of the S&P 500 index for the 35-yr period 1962–96 on a linear-log scale. Note the large jump which occurred during the market crash of 19 October 1987. Sequence of (b) 10 min returns and (c) 1 month returns of the S&P 500 index, normalized to unit variance. (d) Sequence of i.i.d. Gaussian random variables with unit variance, which was proposed by Bachelier as a model for stock returns [61]. For all 3 panels, there are 850 events – i.e., in panel (b) 850 min and in panel (c) 850 month. Note that, in contrast to (b) and (c), there are no large events in (d). Reprinted from **Physica A**, **279**, Plerou et al., *Econophysics: financial time series from a statistical physics point of view*, 443–456, Copyright (2000), with permission from Elsevier.

markets) that exhibit long range correlation between a number of complex interacting agents [58–60]. Stock price fluctuations are seen to occur in all sizes, similarly to earthquakes - from small to large events, such as market crashes. The distribution of returns is also shown to decay with a similar power-law. This is in contrast to the standard assumption that returns decay exponentially (i.e., coming from a Gaussian distribution). This is illustrated on Figure 3.3 where real world S&P returns are presented on different time scales and compared to Gaussian noise.

Models that try to mimic market behaviour using a large number of agents interacting following a set of rules have been shown to produce market returns that reproduce certain characteristics of real market data [58, 62]. These 'micro-economic' models are of interest because they allow researchers to understand how broad types of behaviour can alter emergent properties at the macro-economic scale. Alternatively, there are studies looking into jump-diffusion processes. These are processes that follow a standard normal diffusion process with the additional property of occasionally undergoing larger jumps (i.e., the addition of a stochastic, Poisson-distributed, term to the standard Fokker-Planck diffusion equation) [63, 64]. The two areas of study briefly presented here are both shown to reproduce the features observed in market data such as heavy tailed distributions that decay following power law and the infamous "volatility smile[4]".

For the purposes of this study, the symmetric Lévy distribution with $\alpha = 1$ (i.e., the Cauchy distribution) was found to best fit historical data on military acquisition values (this is shown in Chapter 4). The Cauchy distribution describing the iid returns η is

$$P(\eta) = \frac{A}{\pi\left(A^2 + (\eta - \eta_0)^2\right)}, \tag{3.19}$$

where A and η_0 are variables controlling the peak height and location of the distribution, respectively. Once we know (from observing historical returns) the distribution of returns, it is a simple matter to re-construct the distribution $P(x, N|x_0, 0)$ needed to calculate the call price.This power-law distribution has the characteristic function

$$\hat{P}(z) = \int e^{izx} \frac{A}{\pi\left(A^2 + (\eta - \eta_0)^2\right)} \mathrm{d}x. \tag{3.20}$$

The sum of N iid Cauchy variables can be obtained as the N^{th} convolution of the characteristic function with itself. This distribution is said to be stable since a linear combination of independent Cauchy variables is itself a Cauchy distribution. An inverse Fourier transform finally gives the resulting Cauchy distribution of the underlying, x, after N time steps (i.e., years)

$$P(x, N|x_0, 0) = \frac{NA}{\pi\left((NA)^2 + (x - x_0)^2\right)}, \tag{3.21}$$

where formally, $x_0 = N\eta_0$. Alternatively, it is more logical to use the underlying's starting value at $t = 0$, therefore, x_0 can be found directly using a technology valuation technique (e.g., NPV) in order to shift the distribution. Due to the Cauchy distribution's stability property, we can state that the underlying is now the iid variable of interest (as opposed to the return). This probability distribution can therefore be inserted into Eq 3.8 and solved using Maple™ in order to obtain the optimal R&D investment level

$$\mathcal{C} = (1+\rho)^{-N} \int_{x_S}^{\infty} (x - x_S) \frac{NA}{\pi\left((NA)^2 + (x - x_0)^2\right)} \mathrm{d}x \,. \tag{3.22}$$

Unfortunately, the integral presented in Eq 3.22 does not converge. One possible way to quickly remedy this is to exponentially truncate the integral for values of x that are far from x_0

[4] The volatility smile is the empirical property of at-the-money options to have lower implied volatilities than in- or out-of-the-money options – producing a 'smile' when graphed [65].

(more on truncated Lévy processes in [55, 66–68]). Essentially, an exponential terms is added to Eq 3.22, which has no effect on the shape of the distribution for smaller returns. The identity $(1+\rho)^N \approx e^{rT}$ is used and $x_0 \longrightarrow x_0 e^{rT}$ to reflect accumulated wealth in bond. The discrete variables are replaced with continuous ones with $T = \tau N$ and $\tau = 1$,

$$\mathcal{C}_{\text{Cauchy}} = e^{-rT} \int_{x_S}^{\infty} \frac{TA(x - x_S)}{((TA)^2 + (x - x_0 e^{rT})^2)} \exp\left[\frac{-(x - x_0 e^{rT})^2}{x_C}\right] \mathrm{d}x \,, \tag{3.23}$$

where an upper cutoff, x_c, is introduced in order to force the integral to converge for larger values of the underlying as illustrated in Figure 3.4. The exponential term does not alter the shape of the distribution around x_0 and simply serves as a tuneable numerical parameter to ensure the convergence of the integral. Please refer to Appendix A.2 for the complete algebraic steps leading to the analytical solution given as

$$\mathcal{C}_{\text{Cauchy}} = \frac{1}{2} \exp\left[\frac{(TA)^2}{x_C}\right] \left(\text{Ei}\,(1, z) + \pi \left(x_s - x_0 e^{rT}\right) \left(\text{erf}\left(\frac{TA}{\sqrt{x_C}}\right) - 1\right)\right) \,, \tag{3.24}$$

where $\text{Ei}\,(1, z)$ is an exponential integral as defined in the appendix and where $\text{erf}()$ is the standard form of the error function.

3.1.4 Monte Carlo simulations

A personal favourite alternative in solving difficult equations analytically is presented here using a Monte Carlo technique that can be adapted to be used with any distribution function or even de-trended historical data itself (i.e., bootstrap Monte Carlo). Once the probability distribution function is known (or at least chosen), one can generate M price evolution paths in order to perform a simulation that can be used to provide an estimate of the call price - in our case, the optimal investment in R&D that minimizes risk (removes all risk in the Black-Scholes limit). A path is the set of successive positions of the price $x_0, x_1, ..., x_N$ such that $x_{k+1} - x_k = x_k \eta_k$ and where η_k is drawn from any distribution (e.g., Eq 3.15 or Eq 3.19). For this study, the results obtained using a Gaussian distribution is compared to those obtained using a Cauchy distribution - tuned using historical data. Fluctuations obtained using the Cauchy distribution are manually confined to the range $-1 \leq \eta_k \leq 1$ in order to keep the price paths from taking unrealistic values (e.g., values less than 0). Tuning these parameters affects the results of the Monte Carlo simulation and could be the object of further studies in redressing the convergence issue between the analytical and simulation results using a Cauchy distribution.

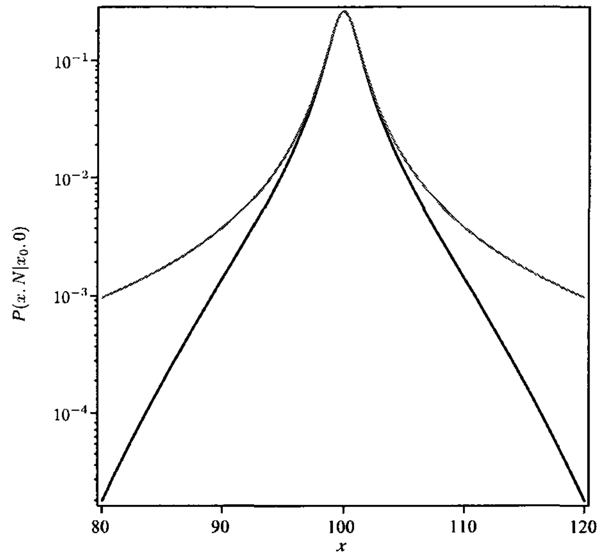

FIGURE 3.4 Comparison of the truncated (black) and standard (grey) Cauchy distributions for values: $A = 0.048$, $r = 2.5\%$, and $x_S = x_0 = x_c = 100$ on a semi-log plot (these values were chosen to correspond to historical data presented in Chapter 4). The cutoff value can be tuned to incorporate more or less of the large fluctuations encompassed in the tails.

The number of steps is $N = T/\tau$. Using the Monte Carlo method, the call price is obtained by simply taking the average over realizations of the generated price paths,

$$\mathcal{C}_{\mathrm{MC}} = \frac{\mathrm{e}^{-rT}}{M} \sum_{i=1}^{M} \max\left(x_N^i - x_s, 0\right). \tag{3.25}$$

To account for the interest rate over the technology development period, one must additionally shift the initial price to $x_0 \rightarrow x_0 e^{rT}$. Eq 3.25 gives an optimal investment in R&D given a technology that is expected to yield a stochastically varying value of $x(t)$. Using historical data of technology value fluctuations and the appropriate distribution, one can obtain an optimal value of R&D investments for each procurement contract. The optimal investment in R&D is smaller using the Cauchy distribution as compared with the normal distribution. The larger value fluctuations allowed by the fatter tails moderate the risk that one should be taking with R&D investments.

3.2 Applying the Black-Scholes model to value R&D

As a first approximation, one can transpose almost directly the concepts used to value a European financial option to the field of real options using the B-S model as shown in Table 3.1. As shown here, the decision to start an R&D project or not becomes a quantifiable exercise characterized by choosing the right distribution describing the movement of the underlying asset. One is then required to obtained several operational parameters and applying them into either Eq 3.18 or Eq 3.23 in order to obtain an estimate of R&D expenses. Due to its complexity and relative lack of empirical testing however, ROP has not yet been widely adopted by managers in order to evaluate the risk of investing in R&D. Some attempts have been made to codify ROP "best practices" in a guide to help managers reliably estimate parameters for use with a real options methodology[51].

TABLE 3.1 Comparison of operational variables and concepts between real and financial options.

	Financial option	Real option
C	premium on option	costs to perform R&D
$x(t)$	value of stock	estimated value
x_S	fixed stock price	present value of investment
T	fixed date	time to commercialize
r	risk-free interest rate	risk-free interest rate
Risk	uncertainty in underlying value	project value uncertainty

Unlike financial options, real options do not have active markets where one can perform a time series analysis in order to obtain volatility values and estimates for future underlying asset prices. There are however several techniques to estimate the expected value of a future product and/or service, $x(t \geq T)$. One of the commonly used technique is a Net Present Value (NPV) analysis based on discounted projected cash flows. This technique allows one to obtain a time series of future cash flow estimates for use in appraising long-term projects. However, as described earlier, it is usually said to be limited in its inability to account for management flexibility and for relatively long-term, risky projects [51]. In this research, historical market data is substituted with past procurement costs since those returns are deemed to accurately reproduce the features that would be observed in market data. For these reasons, sensitivity analyses are additionally conducted to assess the impact of several price estimates on the model.

It is unreasonable to assume that no large fluctuations in technology valuation occur since disruptive competition is what drives the market. For example, product development is riddled with relatively frequent large fluctuations in estimated technology value due to the introduction of disruptive innovations in the form of revolutionary products or services. As shown in Figure 3.2 however, the normal distribution makes such large fluctuation exponentially improbable. In economic terms, such outlying events are usually disregarded although they appear to be constantly keeping the market out of equilibrium [69]. The next section introduces a data set that contains information on technology cost (i.e., value) in the aerospace and defence sector specifically. Analysis of this dataset served as the impetus for the development of a theory of options that accounts for large fluctuations in returns.

As with any financial model, the results are as good as the assumptions that are made in the behaviour of the dynamic variables. In the case of real options for example, we are assuming (for simplicity) that the manager may only begin commercialization after a pre-determined time lapse (i.e., we are assuming European-type options). In real world situations however, managers may wish to phase in results and lessons learned from R&D efforts or may decide to release certain products earlier. Future studies may therefore look into the added flexibility offered by using an American-type real option framework.

3.2.1 Source of data

The data used to calibrate the ROP model have come from American Selected Acquisition Reports (SARs). These annual reports are prepared to coincide with the budget by the Department of Defense and contain acquisition program cost and schedule changes. SARs contain summarized data on cost, schedule, and technical status for most platforms (see Appendix B for the December 2007 SAR). Therefore, once calibrated using these historical data, the economic estimate obtained from ROP embodies the inherent managerial process (e.g., political changes in military priorities).

Although the format of the report and the standards for reporting data has often changed throughout the years (e.g., inconsistency in applying inflation), it is nevertheless possible to obtain a relative yearly cost estimate difference for each military program that is sufficient for this research [70]. The aggregated SAR reports forms a data set that spans roughly four decades and offers a rich account of military R&D costs together with the resulting platforms. This allows one to analyze fluctuations in cost and quantity in order to assess future risk exposure. The reports include procurement quantities as well as total costs. For this research, the total costs were used to measure fluctuations that include fluctuations in the number of acquired units. The idea is that this justifiably adds to the uncertainty in the final value of the program. The distribution of the fluctuation therefore embodies managerial uncertainty and other inherently "political" aspects. Given these limitations, SARs are nevertheless suitable for identifying broad trends and time-series analysis across a number of programs.

Program costs are typically divided into product evaluation (PE), development (DE), and production estimate (PdE) categories. The latter representing the most accurate available data describing the actual cost (or value) of military programs in the United States. Probability distributions for the arithmetic returns of program values, $P(\eta)$, were compiled using Eq 3.6 (without using the approximation, called logarithmic returns). For this research, information on 43 military programs were used (e.g., AH-64 Apache attack helicopter, B-1 Lancer bomber, F-35 Lightning II fighter, and others) with each program being active for an average of 13 years between 1969 and 2007. A sample of the data on five procurement programs is shown in Table 3.2. One of the striking feature evident from these data is the large variations in procurement quantity estimates throughout the years. The return distributions obtained using these data contain information on this type of managerial variability and is important to consider for use in predictive models. When using a real option model, we typically use a firm's share price as a proxy for an innovation's Net Present Value (NPV) estimation of income and expense streams[5]. In this research, the production estimate costs (PdE) will be used as our underlying. Since we are looking at historical data, the PdE costs can be imagined as 'perfect' NPV estimates. The American military usually follows a 'margin profit' policy whereby the government purchases equipment at a Firm Fixed Price (FFP) that is designed to cover contractor costs plus a margin (in the range of $3 - 7\%$ with additional points for use of innovative technology) [71]. This has the market distorting effect of encouraging prime contractors to over-budget on government procurements as a means of increasing their absolute profits. Since only returns (i.e., relative yearly price differences) are of importance in this research, the data obtained from the PdE column should offer returns that are of a similar nature to what one would expect from market price data.

The PdE estimates are typically given over a period of a few years and the returns tend to fluctuate according to the Cauchy distribution although a normal distribution fits the data relatively well. This will be shown in Chapter 4. Additionally, the SARs give us access to R&D costs as they are incurred by the prime contractors. Taken alone, development costs fluctuate differently

[5] Not shown in this research, however, there is a strong immediate time correlation between military funding and respective prime contractors' share prices.

TABLE 3.2 Sample of raw data aggregated from the American Selected Acquisition Reports. This table show information on the phase, quantity, estimate (in million USD), and the yearly arithmetic returns for five procurement programs in the aerospace and defence sector.

	F/A-18E/F Super Hornet				F-22 Raptor				F-35 Lightning II				NAVSTAR GPS				V-22 Osprey			
Year	Phase	Qty	Estimate	Return	Phase	Qty	Estimate	Return	Phase	Qty	Estimate	Return	Phase	Qty	Estimate	Return	Phase	Qty	Estimate	Return
1980													DE	40	2306 7					
1981													DE	40	2517 4	0 0913				
1982													DE	40	2481 9	-0 0141				
1983													DE	40	2588 8	0 0431				
1984													DE	40	2524 6	-0 0248				
1985													DE	40	2611 6	0 0345	PE	0	20304 7	
1986													DE	40	2378 1	-0 0894	PE	919	29662 3	0 4609
1987													DE	60	4280 2	0 7998	DE	688	23666 3	-0 2021
1988													DE	60	4040 4	-0 0560	DE	663	25855 4	0 0925
1989													DE	66	4366 5	0 0807	DE	0	2639 5	-0 8979
1990													DE	65	4411 9	0 0104	DE	0	3042 4	0 1526
1991	PE	0	5109 9		PE	648	96395 4						DE	65	4340 5	-0 0162	DE	0	3587 1	0 1790
1992	DE	1000	80584 2	14 7702	DE	648	86631 3	-0 1013					DE	61	4130 8	-0 0483	DE	0	5107 8	0 4239
1993	DE	1000	89128 1	0 1060	DE	442	71590 9	-0 1736					DE	69	4846 0	0 1731	DE	0	6636 4	0 2993
1994	DE	1000	89154 5	0 0003	DE	442	73521 1	0 0270					DE	118	11163 1	1 3036	DE	523	52955 4	6 9795
1995	DE	1000	80958 7	-0 0919	DE	442	70093 1	-0 0466					DE	118	10249 5	-0 0818	DE	523	46599 7	-0 1200
1996	DE	1000	79491 6	-0 0181	DE	440	70865 0	0 0110					DE	118	9613 2	-0 0621	DE	523	45528 0	-0 0230
1997	DE	548	46064 1	-0 4205	DE	341	63806 5	-0 0996	PE	0	22329 0		DE	118	9577 2	-0 0037	DE	458	37334 4	-0 1800
1998	DE	548	47007 8	0 0205	DE	341	62740 1	-0 0167	PE	0	23362 5	0 0463	DE	115	10151 4	0 0600	DE	458	36220 3	-0 0298
1999	DE	548	46988 6	-0 0004	DE	341	61940 1	-0 0128	PE	0	23179 7	-0 0078	DE	109	11549 5	0 1377	DE	458	38112 2	0 0522
2000	DE/PdE	548	46825 7	-0 0035	DE	341	61940 1	0 0001	PE	0	23179 7	0 0001	DE	109	11549 5	0 0001	DE	458	38112 2	0 0001
2001	PdE	548	48791 1	0 0420	DE	341	69721 4	0 1256	PE/DE	0	229791 7	8 9135					DE	458	46240 8	0 2133
2002	PdE	552	50750 2	0 0402	DE	278	71785 3	0 0296	DE	2457	199736 4	-0 1308					DE	458	48262 7	0 0437
2003	PdE	462	43845 2	-0 1361	DE	279	71693 2	-0 0013	DE	2457	244834 3	0 2258					DE	458	48024 7	-0 0049
2004	PdE	462	43982 9	0 0031	DE	181	61323 7	-0 1446	DE	2458	256617 6	0 0481					DE	458	50486 1	0 0513
2005	PdE	462	44030 5	0 0011	PdE	185	62600 0	0 0208	DE	2458	276458 9	0 0773					DE/PdE	458	50497 1	0 0002
2006	PdE	494	46388 8	0 0536	PdE	184	65292 7	0 0430	DE	2458	299824 1	0 0845					PdE	458	54636 8	0 0820
2007	PdE	493	46344 8	-0 0009	PdE	184	64539 9	-0 0115	DE	2456	298842 8	-0 0033					PdE	458	54226 9	-0 0075

than PdE costs since they contain large fluctuations in cost estimates (e.g., program cancellations) requiring a distribution with fatter tails. A Cauchy distribution was found to offer a better fit for these data.

As opposed to American military procurement, the Canadian government does not typically acquire pre-commercial technology and thus does not directly bear the risks associated with R&D (i.e., any required R&D becomes the responsibility of the prime contractor). Therefore, prime contractors involved in Canadian government military procurement do not typically take on additional risk by investing in R&D - this is exactly the gap that this research is addressing by mitigating prime contractor risk using financial incentives. Unfortunately, unaggregated raw data on Canadian military procurements are not readily available, therefore, American military programs were considered to offer the best available data to apply the real options pricing model for Canadian prime contractor investments in R&D although there are significant differences between the two defence industries. Data on Canadian military contractors' spending on innovation would greatly enhance the quality of the observations made in future studies.

3.3 Application to Industrial and Regional Benefits

This short section offers a summary of the theoretical foundation needed for this thesis with the purpose of clarifying the goal now that all relevant concepts have been presented. In Chapter 1, innovation was introduced through a commercially driven R&D framework and as a critical component of our functioning economy. Among others, the lack of reliable return on investment tools for pricing R&D outcomes was identified as an important contributor to the reluctance of the private sector to invest in R&D activities. Due to its strong hierarchical structure, the aerospace and defence sector was targeted as an ideal testbed candidate for the use of real options pricing of innovation. A new paradigm in procurement strategy was identified in this chapter as a means of using offset credits to encourage private sector-driven innovation.

This chapter introduced the use of a quantitative tool for obtaining R&D pricing information based on expected return of commercializing outcomes. Companies have themselves identified that they would invest more in Canadian innovative activities if they were properly rewarded using offset credits. This would seem to indicate that offset policies do in fact create opportunities that would not take place otherwise. In this case, the desired outcome is an increase in Canadian R&D

with ensuing spill over effects[6] and supply chain integration and maintenance. Unfortunately, issues of offset causality as defined by the IRB policy become blurred since it would seem obvious for companies to invest in activities that were commercially sound regardless of government reward frameworks. For the most part however, offsets ultimately force firms to form economically sub-optimal partnerships with an added financial burden (e.g., certification requirements, training, exchange rate exposure). As a result, the economic value added by (or cost of) IRB requirements is difficult to measure.

The goal of this study was to find an appropriate theoretical framework justifying the creation of an offset portfolio that contained a certain amount of "at-risk" offset credits in the form of innovation. That is, for each offset transaction, what is the ideal amount that should be invested in R&D, for example? Once this ratio is found, the investments are then made by the prime contractors (of procurement contracts) who conduct such activities either internally, or within their supply chains. A real option framework is proposed as a way to initially evaluate the amount of investment in R&D. A multiplier could then allow the government to help mitigate the risk taken by a prime contractor in investing in pre-commercial technologies by essentially reducing the prime contractor's reinvestment requirement.

A generalized Real Options Pricing (ROP) framework is presented as a decision support tool used to extract an optimal level of R&D that should accompany each offset transaction (i.e., an amount of R&D that minimizes risk due to potential loss of revenue from commercial product). The importance of this study is illustrated in a workflow diagram presented in Figure 3.5. In this diagram, the traditional IRB obligation, x_S is shown to be split into two components using the ratio obtained from the ROP model, $\mathcal{C}$: traditional IRB; and IRB in the form of innovation investments. Traditional IRBs are said to offer an overall direct benefit to Canada's private sector and this impact is typically measured using standard input/output models. On the other hand, investment in Canadian R&D capacity has the potential to have a much larger economic impact, denoted as $x(t)$, however, it is much more difficult to measure. For example, investments in R&D take many years to manifest themselves as successful commercial products. In fact, this lag time can be on the order of 10 or more years [72].

Further, it is logical to assume that the Cauchy ROP gives one a lower estimate of R&D investment than its Gaussian counterpart based on economic risk arguments. However, there are

[6] For military procurements, this is commonly known as dual use technologies (i.e., technologies that have military and civilian uses).

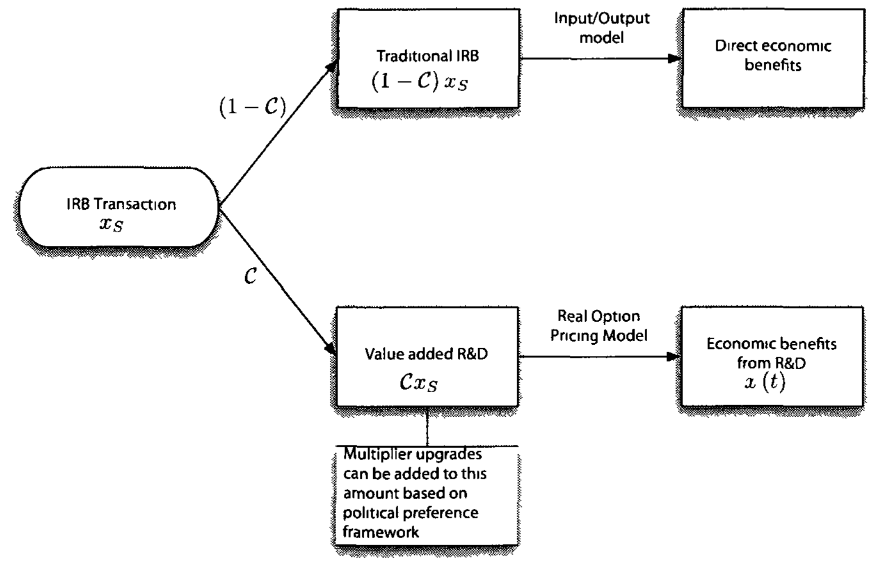

FIGURE 3.5 Workflow diagram illustrating the use of the real option pricing model in an IRB context and from the point of view of military procurement as an economic driver. This diagram also defines the variables used in the real option pricing methodology.

instances where the government would want to reward certain strategic investments using more than a simple economic argument. For example, the government may wish to reward a prime contractor who engages a SME to perform R&D at a university while training graduate students. In which case, a simple economic argument would probably not produce a multiplier that is appealing enough for the company. Additional multiplier "upgrades" can be applied to some of these valued R&D activities to encourage certain behaviours that are deemed to be advantageous. Although these upgrades could appear random at first, they allow the government to apply multipliers in a consistent and transparent fashion. The value of the upgrades should be fine-tuned as more data becomes available. Stay tuned to ongoing research in the IRB directorate to establish a multiplier framework based on the "value" of each innovation transaction (e.g., using guidelines for risk involved with technology in various stages of readiness [73]). In fact, perceived quality in military procurement is often an ambiguous umbrella term reflecting different criteria such as sovereign capacity, economic value of purchase, and ability to perform task in actual operational scenarios [74]. Often, one of these criteria is seen to trump others for political reasons and so any value-attributing framework needs to take into account government priorities in its reward scheme.

Application of this technique is proposed as a tool to inform strategic procurement policies and could prove of significant use for Canada's IRB policy framework using data on the investment profiles of Canadian contractors in this industry. Firstly, the options pricing model can be used by a prime contractor to quantify the expected returns of its investments in a given research portfolio (e.g., investing R&D money in Canadian companies and/or research institutions to fulfil a procurement contract). Secondly, the model can also be used by the IRB directorate when determining an optimal IRB portfolio. This framework would need to consistently reward companies who invest in Canadian innovative activities while fulfilling their offset obligations (i.e, mitigating risks associated with early technology investments). Offset obligations can therefore be better tailored to encourage value adding innovative activities within prime contractors' value networks. As mentioned above and for simplicity, this research has focussed on the Aerospace and Defence sector although the findings should be generalizable to all procurements where IRB obligations are incorporated.

4

Results and discussion

Economics needs a scientific revolution – financial engineers have put too much faith in untested axioms and faulty models.
(Jean-Phillippe Bouchaud)

4.1 Analysis of cost variability

When using the ROP model, it is important to understand the nature of the volatility in the underlying's value. In this case, we need a proper understanding of the value (or cost) estimate fluctuations undergone by the various military programs. As mentioned in Chapter 3, the American Selected Acquisition Reports (SAR) can provide a good first order estimate on the distribution of these returns. The assumption is that the general properties of this variability will be similar to military procurements in Canada (such data are not readily available for military procurements in Canada).

Using historical data on aerospace and defence sector procurement costs, it is possible to identify the general distribution of these fluctuations. It is essential to analyze past procurement information in order to construct a theoretical model that can replicate important characteristics observed in the real data in order to build our so called offset portfolios. For an example of a procurement program that exhibits large variations due to political decisions, refer to Figure 4.1 where funding for the V-22 Osprey is shown. This figures shows large fluctuations in funding associated with changes of administrations over the years of this particular procurement's funding. Since the ROP model requires one to estimate the variability of future values, it is essential to

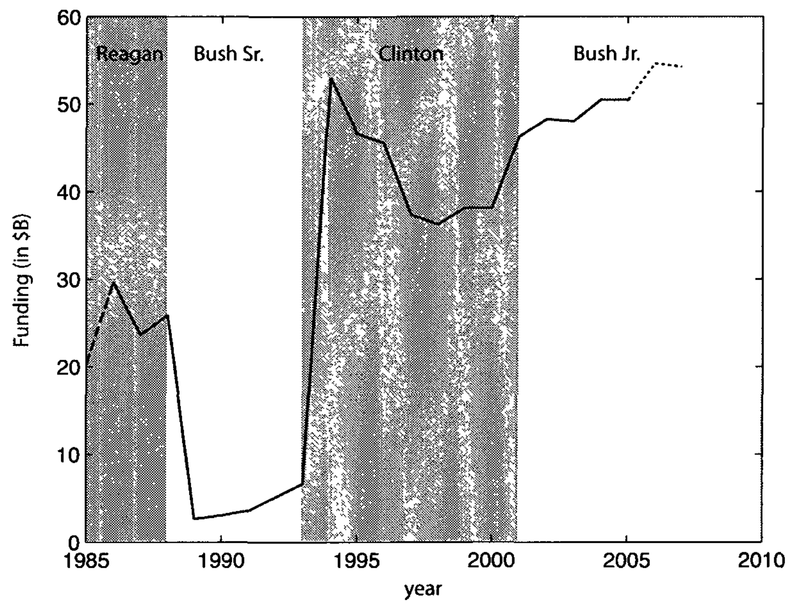

FIGURE 4.1 Historical funding for the V-22 Osprey military platform in the U.S. One can readily observe the political impact on funding as the election of a new President is strongly correlated with large changes in funding. The dashed line represents the product evaluation estimate, the solid line shows the development estimate and the dotted line shows the production estimate.

understand how this variability behaves. Many distribution functions were used in an attempt to fit the data however, it was found that both the traditional normal and the Cauchy distributions were the best candidates to fit the data over different scales.

There is a strong theoretical foundation arguing for normally distributed underlying returns (i.e., fluctuations that follow a geometric Brownian diffusion process), however a growing number number of researchers are considering the use of other distributions (mainly power laws) to describe data over various timescales. In the case of military procurement where the underlying's value is re-evaluated yearly yet still highly correlated, it is not clear a priori which regime (if any) will best describe the actual variations in price.

Figure 4.2 shows price fluctuations in the development and production estimate phases (DE and PdE). The distribution is slightly asymmetric due to the fact that there are fluctuations greater than 1, $\eta > 1$ (since we are looking at the arithmetic returns, there cannot be fluctuations smaller than -1). Further, the volatility was capped at 1 although there were some observed points that

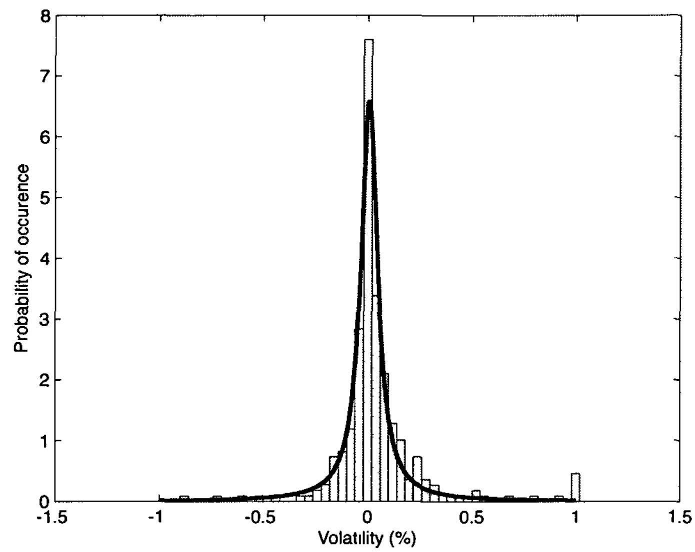

FIGURE 4.2 Histogram of the price fluctuations observed in aerospace sector procurement in the American SAR for platforms in the development and production estimate phases (DE and PdE). The data are fitted with a Cauchy distribution with parameters $A = 0.048$ and $\eta_0 = 0.0075$.

represented cost increases well over 100% (see Figure 4.1 for an example). The Cauchy distribution (Eq 3.19) is shown to offer a good fit for the data. Figure 4.3 shows a similar histogram except that it only presents data on the production estimate phase (i.e., best data estimates on market price variations). One can readily notice that a Gaussian distribution is inadequate in its representation of observed data - specifically the tails of the distribution. Although the smaller sample size is noticeable using only these data, the shape of the distribution remains characteristically similar to the one observed in Figure 4.2. This similarity is welcomed since it establishes a correlation between the behaviour of fluctuations in the development phase as being similar in nature to the types of fluctuations in value estimates associated with technology commercialization (or market price). One could therefore use the variability information obtained in the development phase data as a proxy of future technology market price.

Figure 4.4 presents the production estimate only data (PdE) on a log-log histogram for the absolute returns (i.e., $\eta \rightarrow |\eta|$) in order to increase the sampling and the resolution in the tail for

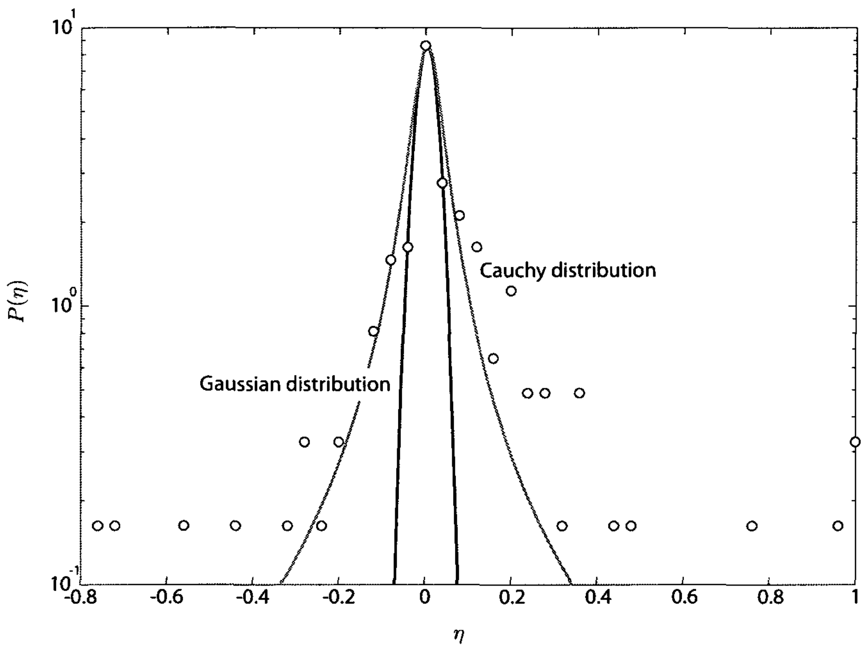

FIGURE 4.3 Histogram (bin width of 0.04) showing the cost returns for 43 major US aerospace sector procurement contracts in the production estimate (PdE) phase. The observed data (shown as ○) were fitted with a normal ($\mu = 0.0038$, $\sigma = 0.025$, and $R^2 = 0.87$) with a Cauchy power law ($A = 0.037$, $\eta_0 = 0.0043$, and $R^2 = 0.92$) distributions. As shown here, the Cauchy distribution offers the best fit.

visual inspection. The Gaussian distribution is shown to offer a good fit for small returns although the Cauchy fit is superior in characterizing the tail of the return distribution – this explains the Gaussian distribution's ubiquitous presence in economic analysis for well behaved markets (i.e., no crashes). Parameters for the fits are $A = 0.098$ and $\eta_0 = -0.070$ for the Cauchy distribution and $\mu = -0.54$ and $\sigma = 0.27$ for the normal distribution. The Cauchy fit does not decay as rapidly as the normal fit allowing for the observed possibility of larger fluctuations in value of procurements. However, the remaining sections will compare results obtained using both distributions since the normal distribution is not entirely terrible and since there is a closed-form analytical solution for its use. As explained in the previous section, it is crucial to capture the behaviour of our observed data with an appropriate distribution function that will subsequently be used to make future predictions for use in offset portfolio management.

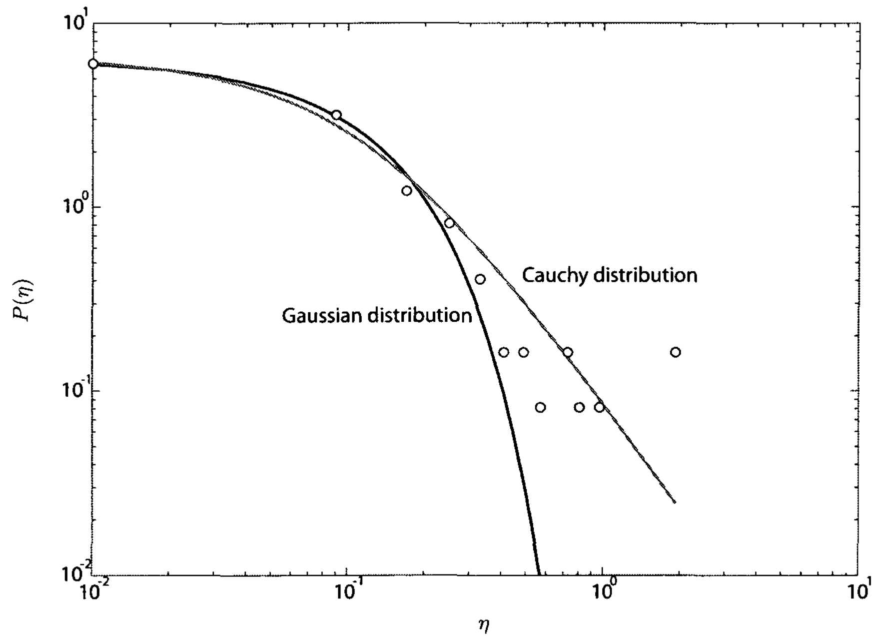

FIGURE 4.4 Histogram (bin width of 0.08) showing the absolute cost returns for 43 major US aerospace sector procurement contracts in the production estimate (PdE) phase. The observed data (shown as ∘) were fitted with a normal ($\mu = -0.54$ and $\sigma = 0.27$) together with a Cauchy power law ($A = 0.098$ and $\eta_0 = -0.070$) distributions. As shown here, the Cauchy distribution offers the best fit.

4.2 Using ROP in IRB portfolio management

This section will present various methods of obtaining the ratio of 'at-risk' innovative investments, C, in offset portfolios using volatility distributions curves that were obtained in the previous section. Sensitivity analyses will also be shown in order to provide the reader with a sense of the importance of the variables involved in these calculations (e.g., effect of changing the risk free interest rate). Results obtained using the log-normal will be compared to the results obtained using the Cauchy distribution.

4.2.1 Usage of Monte Carlo data

This section will test the stability of results obtained using a bootstrap Monte Carlo method (i.e., creating new data series based on historical distributions). Please refer to Eq 3.25 for details on the application of the Monte Carlo technique. Technology value time series are created using the following simple iterative equation (multiplicative price model):

$$x_{k+1} = x_k[1 + \text{rnd}\,(P(\eta))] \,, \tag{4.1}$$

where $\text{rnd}\,(P(\eta))$ refers to a randomly generated number taken from the distribution $P(\eta)$[1]. For this section, unless otherwise specified, calculations of $\mathcal{C}$ will be based on projects that have a strike price of $x_S = x_0 = 100$ and a time to expiry of $T = 25$. The risk-free interest rate will be based on five-year treasury bond rates as of January 2010, $r = 0.025$. Table 4.1 shows a comparison of using the normal versus the Cauchy distributions for Monte Carlo simulations of various shown number of iterations. The distributions are generated using the parameters obtained from Figure 4.3. Furthermore, the analytical result using the Cauchy distribution was found using the truncated Cauchy solution described in Eq A.17 with a cutoff value of $x_c = x_0$ (effectively limiting the returns to $-1 \leq \eta \leq 1$).

TABLE 4.1 Comparison of $\mathcal{C}$ for various Monte Carlo iteration numbers, M, and for value fluctuations distributed according to the Gaussian (G) and Cauchy (C) distributions.

M	$\mathcal{C}_G$	$\mathcal{C}_C$
10^2	46.47	44.83
10^3	46.15	44.83
10^4	46.65	45.67
10^5	46.45	45.88
10^6	46.49	-
analytical	46.47	40.79

The Monte Carlo data converge extremely fast to the analytical solution in the case of the Gaussian distribution however, it is not readily clear why the Monte Carlo data do not converge to the analytical solutions in the case of the Cauchy model. One must be extremely careful when truncating the Cauchy distribution to be consistent between the analytic and Monte Carlo solutions – this is probably the source of the discrepancy here. However, the data were presented in order to ensure the viability of using a Monte Carlo method to price options for underlying with atypical return distributions. In this example, the Cauchy valuation model suggests that one should invest roughly 15% less in R&D when compared to the Black-Scholes model. One should invest either

[1] The Mersenne Twister algorithm was chosen for its overall efficiency and quality to generate pseudo-random numbers [75].

$\$41$ or $\$47$ at $t = 0$ depending on whether the underlying's returns follow a Cauchy or a Normal distribution, respectively. As Section 4.1 suggests however, a Cauchy framework best describes the historically observed returns in this sector. These results were obtained using an estimated technology present value of $\$100$ and a 25 year development time (the model adjusts this present value to account for interest over the development cycle).

One of the main implication of this study is embodied in the result that sees the call price obtained using the Cauchy framework to be lower than its Gaussian counterpart. This is due to larger fluctuations in the underlying permitted by the fatter tails of the Cauchy distribution. The use of the Cauchy distribution therefore has the effect of moderating one's exposure to risk due to potential crashes. As seen in the previous section, such large fluctuations (funding crashes) are typical of military procurements, especially given that the equipment is usually developed over long periods of time. The relative difference in investment between the two models will vary depending on the nature of the underlying's returns. Therefore, it is important to have an understanding of the distribution of the underlying before using a certain predictive model. No general "rule of thumb" real option pricing estimate can be extracted from this research since this estimate depends on sectorial factors. For example, it is possible that a certain well-behaved sector (i.e., no large fluctuations and crashes) has underlying returns that are normally distributed and where the Black-Scholes model is more accurate.

As a decision support tool in the aerospace and defence sector, the real option pricing model therefore gives one a best practise estimate for the amount of investment at risk in the form of innovation for a particular offset transactions. In this example, where the technology was estimated at a value of \$100 in the next 25 years, it is suggested that an investment of \$41 would be optimal.

4.2.2 Sensitivity analyses

Since we have now obtained the 'tuning' parameters describing the typical distribution of return variability in the aerospace sector, we will now turn our attention to the effect of the risk free interest rate, r, and the development time, T, on the call price. Only the Cauchy distribution will be considered here with $A = 0.048$ and $x_0 = x_S = x_c = 100$. Figure 4.5 shows the effects of varying the time to expiration, T (with $r = 0.04$), and the interest rate, r (with $T = 10$), on the call price using Eq 3.23.

As seen on this figure, an increase in the risk free interest rate has the effect of increasing the price of our call option in a diminishing return relationship. This is due to the fact that our

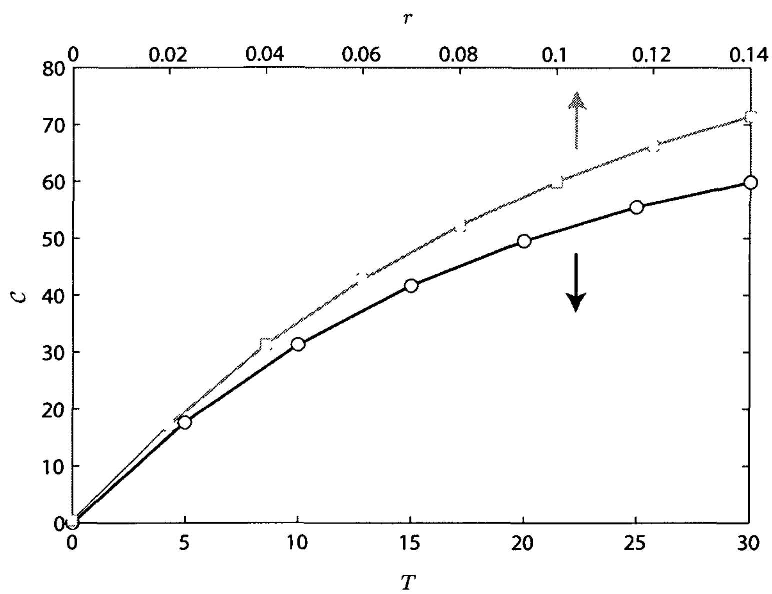

FIGURE 4.5 Sensitivity of call price to variations in interest rate (top axis in grey) and time to complete the project (bottom axis in black). Both parameters have a diminishing return in terms of their effect in increasing the value of the option.

pricing model is based on risk neutral, zero arbitrage assumptions. That is, long positions would be automatically paired with revenue generating short positions in our optimized portfolio (see Eq 3.2). Increases in interest rates therefore make the option worth more due to the short position. In real options terminology, investments in innovations are typically less costly than investing in the actual commercialization of the future outcomes of this innovation (i.e., $C \leq x_S$) or alternatively, the purchase of intellectual property rights. Therefore, firms are more likely to invest in R&D when rates are higher because the difference in capital required between the two options can be invested in bonds. The interest rate therefore appears to be a critical factor in determining whether to invest in R&D or not. This is also true in a Gaussian world using the Black-Scholes equation.

Of course interest rates are not constant in practice - especially over a long time period as described here. Since there is a strong dependence of the price of the option on the interest rate, future studies on the use of real options will therefore need to incorporate statistical properties of the fluctuations in interest rate in the development of the formula. For example, one could use a functional variable, $r(r_0, t)$, drawn from an appropriate distribution function, $P(r(r_0, 0))$ to better describe the fluctuating effect of one's exposure to interest rates over longer periods of time. Conversely, one could instead simply use 30 year bond rates and assume a fixed value over the whole period.

Increasing the time horizon of such a call option increases its value. This is not surprising since increasing the time to commercialize an innovation would increase its likelihood of being successful. This likelihood of being successful, however, is moderated by the risk of a 'crash' in final value of the technology as described by our chosen distribution function. Also, increasing the time horizon deepens one's exposure to interest rate risk - again stressing the importance of being able to incorporate the predicted changes in interest rates for future research on the use of this model.

Finally, one may want to investigate the stability of the distribution in adequately describing the fluctuations in R&D investments over time. Akin to the observed variability in σ when using the Black-Scholes model, it is possible that the Cauchy parameters describing the distribution of returns changes over time (e.g., as the sector evolves and matures). Accounting for this distribution drift would add slight correction terms to the results of the call price.

4.3 Summary and limitations

This research presented some of the first conclusive steps of the research required in utilizing a quantitative decision support tool to help offset managers create innovation portfolios with the various prime contractors of defence sector procurements. The use of a real option pricing methodology can give these offset managers a series of best practise values when evaluating how much of each procurement contract should be allocated to innovative activities and consequently acknowledged as offset credits. Since the fluctuation in the underlying's value in this sector does not fluctuate according to a Gaussian distribution, this study additionally presented a general method of pricing options that does not assume an underlying return distribution. The Cauchy distribution was shown to offer 'good' results although the distribution must be tuned (e.g., using historical data) for each sector much like the Black-Scholes equation requires one to input a standard deviation, σ, before calculating the call price.

Future studies could analyze the stability of the distribution with respect to the various parameters that are used to tune and to cut off its algebraically diminishing tails. This would help improve the convergence of the results obtained using the Monte Carlo simulation toward the analytical solution, which as it is, does not converge due to cutting the tails of the distribution somewhat differently between the two techniques. Presently, the use of the real option methodology as presented in this study is limited to evaluating the cost of R&D in the American aerospace and defence sector. Access to different data may help resolve this issue by allowing the distribution to be tuned to a different sector.

5

Conclusion

People do not like to think. If one thinks, one must reach conclusions. Conclusions are not always pleasant.
(Helen Keller, 1880–1968)

In this study, a real option pricing methodology based on historically observed data is developed for use in supporting decision making in aerospace and defence sector procurement contracts that have an offset component. The goal of this study was to create a quantitative tool that can be used to effectively gauge an appropriate level of investment in innovative activities for each aerospace and defence sector procurement. Only then can an incentive structure to reward the associated prime contractors be developed to help these contractors fulfill their offset requirements by investing in business-led Canadian innovation.

This thesis began with an introduction to innovation and why it is an important contributor to our society's well-being. A strong case was made for a correlation between a nation's investment in innovation and the resulting quality of life as measured by the Gross Domestic Product (GDP). The need for a strong private sector participation was identified as a key component of our nation's innovation ecosystem. Consequently, the low performance of the Canadian private sector in R&D related activities was therefore targeted as a main challenge in the coming decades. This research helps to address this weakness by using one of the government's main influence lever (i.e., procurement) to effectively reward innovation in specific defence related sectors.

In order to help with the focus of this research, the aerospace and defence (A&D) sector was chosen as a 'pilot study' in order to evaluate the methodology. As discussed in Chapter 2, the aerospace and defence sector was a great candidate because it is a sparse, vertically-structure sector with relatively few end products that are developed over long periods of time. Many bottom tier suppliers could therefore greatly benefit from investments in innovation (in various forms) by their direct upstream clients. In order to put all the pieces together, a simple introduction to offset requirements in defence sector procurement was given with an emphasis on utilizing this resource to positively influence the private innovation ecosystem. A potential conflict was identified in the sense that innovation, especially in a closely integrated sector such as the A&D sector, tends to be location-dependent (i.e., clusters, regional innovation systems). This will be a challenge to address in terms of a regional and industrial benefits policy which, by mandate, is asked to spread industrial capacity across the country.

The real option pricing methodology was introduced in Chapter 3 as a tool to effectively quantify optimal levels of investment in innovation. The need to ensure that economic models are able to described historically observed data was identified and this led to the creation of a totally new options pricing formula. A generalized theory of option pricing was developed since fluctuations in this sector's value markers do not obey the standard geometric Brownian motion. Using historical data, these fluctuations were shown to be reasonably well described by a Cauchy distribution. Therefore, a closed-form analytical solution for a call option was given for underlying data that evolve according to this distribution. Furthermore, a Monte Carlo-type methodology for finding call prices was offered in order to price options using any possible set of historical data. The historical data used to illustrate the use of real options in defence procurement were taken from freely available American Selected Acquisition Reports.

The theoretical framework was then completed such that Section 3.3 could provide a methodological workflow for evaluating the importance of investment in innovation on a transaction basis in offset portfolios. This attempt at operational policy development neatly ties together the rhetoric of the previous sections. The real option model is placed in context as a tool to help offset managers provide offset credits to prime contractors for their investments in private Canadian innovation. The idea is that these investments would be very effective because they are demand-driven by the very companies who would benefit from their commercialization.

Finally, the real option pricing methodology was used to provide data on innovation investments in the A&D sector in Chapter 4. First, historical data on military platforms' value returns (i.e., real option underlying) were shown to be well described by a Cauchy distribution. The Monte

Carlo method for option pricing was shown to (albeit sluggishly) converge toward the analytical solutions making it an effective way to price call options that have underlying values that behave in a non-standard fashion. One can always de-trend historical returns and randomize them to create a new set of pseudo-random variables for use in option pricing. Therefore, one does not need to fit data to a particular distribution, which can be useful if there are few (but meaningful) outliers.

Call prices using the developed Cauchy framework were shown to be lower than the prices obtained using a straight forward Black-Scholes equation. Since the Cauchy distribution permits large fluctuations, its use in pricing options has the effect of moderating one's exposure to the risks of commercialization failure and of political interference. Both of which are commonly observed in defence sector procurements. The call price was additionally shown to be quite sensitive to changes in the risk free interest rates. Future work would need to include the statistical variability of interest rates especially since most defence sector procurements take place over the course of several years.

Future work would involve the generalization of this methodology to other sectors (e.g., marine and land vehicles). This work could also apply to the management of single firms that question the importance of strategic investments in innovation. As mentioned before, historical data of commercialization value is practically non-existent in private markets therefore the use of proxies could be studied. For example, and not shown in this thesis, a strong temporal cross-correlation was seen between major military procurements expenditures and prime contractors' stock prices. A real option pricing framework relying on the behaviour of potential contractors' stock price returns as indicators of their innovative potential could be a relatively easy way to price future innovation investments. Who knows, in a similar pattern as observed following the creation of the Black-Scholes equation for financial options, maybe "innovation trading" on an open market will make its debut now that a quantifiable measure of risk-minimized innovation investment is developed.

6

References

[1] Government of Canada. *National aerospace and defence strategic framework*, ***http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03876.html*** (Accessed 30 March 2009).

[2] T Brzustowski. *Innovation = invention + commercialization: A systems perspective*, ***Optimum Online*** **36** (2006).

[3] PM Romer. *Endogenous technological change*, ***J. Pol. Econ.*** **98**, S71–S102 (1990).

[4] MI Nadiri, TP Mamuneas. *The effects of public infrastructure and R&D capital on the cost structure and performance of us manufacturing industries*, ***Rev. Econ. Stat.*** **76**, 22–37 (1994).

[5] SustainableDevelopmentTechnology Canada. *SDTC the funding gap*, ***http://www.sdtc.ca/en/about/innovation_chain.htm*** (Accessed 12 January 2010).

[6] BA Lundvall, B Johnson, ES Andersen, B Dalum. *National systems of production, innovation and competence building*, ***Res. Pol.*** **31**, 213–231 (2002).

[7] G Banks. *Evidence-based policy-making: What is it? how do we get it?* Technical report, The Australia and New Zealand School of Government, Canberra, (February 2009).

[8] CW Churchman. *Wicked problems*, ***Manage. Sci.*** **14**, 141–142 (1967).

[9] JP Bouchaud. *Economics needs a scientific revolution*, ***Nature*** **455**, 1181 (2008).

[10] V Bush. *Science, the endless frontier: a report to the president on a program for postwar scientific research*, (1945).

[11] *OECD Science, Technology and Industry Outlook*, (2008).

[12] TJ Klette, J Moen, Z Griliches. *Do subsidies to commercial R&D reduce market failures? microeconomic evaluation studies*, ***Res. Pol.*** **29**, 471–495 (2000).

[13] Government of Canada. *Mobilizing Science and Technology to Canada's Advantage*, (2007).

[14] HA Neal, TL Smith, JB McCormick. *Beyond Sputnik, U.S. Policy in the 21st Century.* The University of Michigan Press (2008).

[15] R Voyer. *Thirty years of canadian science policy: from 1.5 to 1.5*, ***Sci. Pub. Pol.*** **26**, 277–282 (1999).

[16] T Brzustowski. *The Way Ahead.* University of Ottawa Press (2008).

[17] Council of Canadian Academies. *Innovation & Business Strategy: Why Canada Falls Short*, (15 April 2009).

[18] Government of Canada. *Speech from the throne*, ***http://www.sft-ddt.gc.ca/eng/media.asp?id=1384*** (Accessed 06 January 2010).

[19] Aerospace Industries Association of Canada. *AIAC*, ***http://www.aiac.ca/cai.asp*** (Accessed 15 March 2009).

[20] J Niosi, M Zhegu. *Aerospace clusters: Local or global knowledge spillovers?*, ***Indus. Innov.*** **12**, 5–29 (2005).

[21] AE Lublinski. *Does geographic proximity matter? evidence from clustered and non-clustered aeronautic firms in Germany*, ***Reg. Stud.*** **37**, 453–467 (2003).

[22] M Porter. *Clusters and the new economics of competition*, ***Harvard Bus. Rev.*** **November-December**, 77–90 (1998).

[23] S Breschi, F Lissoni. *Knowledge spillovers and local innovation systems: A critical survey*, ***Indus. Corp. Chan.*** (2001).

[24] DA Wolfe. *Cluster policies and cluster strategies: Lessons from the ISRN national study*, ***Ontario Ministry of Research and Innovation*** (2008).

[25] A Bramwell, DA Wolfe. *Universities and regional economic development: the entrepreneurial University of Waterloo*, ***Res. Pol.*** **37**, 1175–1187 (2008).

[26] KPMG. *Export Development Canada – Supply Chain Analysis: Aerospace*, (16 April 2009).

[27] Industrial and Regional Benefits (IRB) Policy. *Canadian aerospace and defence industry – industrial and regional benefits (irb) policy*, ***http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03657.html*** (Accessed 11 March 2009).

[28] LMJ Michaels. *The making of a lean aerospace supply chain*, ***Sup. Chain Manage.*** **4**, 135–144 (1999).

[29] Deloitte Consulting LLP. *Can we afford our own future? Why A&D Programs are late and over-budget – and what can be done to fix the problem*, (1 December 2008).

[30] TB Hassen, JL Klein, DG Tremblay. *Entreprises intermédianres à Montréal : vers une gouvernance métropolitaine de la grappe de l'aéronautique*, ***Congrès annuel de l'ASRDLF*** (2008).

[31] DA Wolfe. *From industrial policy to innovation strategies: The global and the local.* (13 March 2009).

[32] Treasury Board of Canada Secretariat. *Procurement review policy*, ***http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=12074*** .

[33] Industrial and Regional Benefits Directorate, Industry Canada. *Canada's Industrial and Regional Benefits: Essential Information for Small and Medium Enterprises*, (2009).

[34] GA Moore. *Dealing With Darwin – How Great Companies Innovate at Every Phase of Their Evolution.* Portfolio (2005).

[35] Wikipedia. *F-35 Lightning II*, ***http://en.wikipedia.org/wiki/F-35_Lightning_II*** (Accessed 15 March 2009).

[36] DG Dugay, S Casault. *Informal discussion on government procurement.* (6 March 2009).

[37] World Trade Organization. *Agreement on government procurement*, ***http://www.wto.org/english/res_e/booksp_e/analytic_index_e/gpa_02_e.htm#article16*** (Accessed 15 March 2009).

[38] Ottawa Citizen. *Air force chief defends $3B plan for new aircraft*, ***http://www.ottawacitizen.com/news/force+chief+defends+plan+aircraft/1437937/story.html*** (Accessed 29 March 2009).

[39] F Black, M Scholes. *The pricing of options and corporate liabilities*, ***J. Pol. Econ.*** **81**, 637–654 (1973).

[40] D Furbush. *"program trading." the concise encyclopedia of economics*, ***http://www.econlib.org/library/Enc1/ProgramTrading.html*** (Accessed 13 February 2010).

[41] Wikipedia. *Hedge (finance)*, ***http://en.wikipedia.org/wiki/Hedge_(finance)*** (Accessed 06 January 2010).

[42] JC Hull. *Options, Futures, and Other Derivatives.* Prentice Hall third edition, (1997).

[43] AK Dixit, RS Pindyck. *Investment under Uncertainty.* Princeton University Press (1994).

[44] JP Bouchaud, M Potters. *Theory of Financial Risk and Derivative Pricing.* Cambridge University Press second edition, (2003).

[45] S Myers. *Determinants of corporate borrowing*, ***J. Fin. Econ.*** **5**, 147–175 (1977).

[46] DP Newton, AW Pearson. *Application of option pricing theory to R&D*, ***R&D Manage.*** **24**, 83–89 (1994).

[47] PD Childs, SH Ott, AJ Triantis. *Capital budgeting for interrelated projects: A real options approach*, ***J. Fin. Quant. Anal.*** **33**, 305–334 (1998).

[48] EH Bowman, GT Moskowitz. *Real options analysis and strategic decision making*, ***Org. Sci.*** **12**, 772–777 (2001).

[49] D Goldenberg, J Linton. *Valuing research with option – nuclear fusion, an examplar case study*, ***Energy Risk*** **1**, 5–8 (2006).

[50] J Wang, WL Hwang. *A fuzzy set approach for R&D portfolio selection using a real options valuation model*, ***Omega*** **35**, 247–257 (2007).

[51] DP Newton, DA Paxson, M Widdicks. *Real R&D options*, ***Int. J. Manage. Rev.*** **5/6**, 113–130 (2004).

[52] BJA Willigers, TL Hansen. *Project valuation in the pharmaceutical industry: a comparison of least-squares monte carlo real option valuation and conventional approaches*, ***R&D Manage.*** **38**, 520–537 (2008).

[53] F D'Souza. *Putting real options to work to improve project planning*, ***Harvard Manage. Up.*** **7**, 1 (2002).

[54] JP Bouchaud, D Sornette, M Potters. *Option pricing in the presence of extreme fluctuations*, ***Math. Der. Sec.*** pages 1–14 (1997).

[55] A Matacz. *Financial modeling and option theory with the truncated Levy process*, ***Int. J. Theor. Appl. Fin.*** **3**, 143–160 (2000).

[56] JD Farmer, L Gillemot, F Lillo, S Mike, A Sen. *What really causes large price changes?*, ***Quant. Fin.*** **4**, 383–397 (2004).

[57] HE Stanley, LAN Amaral, D Canning, P Gopikrishnan, Y Lee, Y Liu. *Econophysics: Can physicists contribute to the science of economics?*, ***Physica A*** **269**, 156–169 (1999).

[58] D Chowdhury, D Stauffer. *A generalized spin model of financial markets*, ***Europ. Phys. J. B*** **8**, 477–482 (1999).

[59] D Stauffer, TJP Pennas. *Crossover in the Cont-Bouchaud percolation model for market fluctuations*, ***Physica A*** **256**, 284–290 (1998).

[60] V Plerou, P Gopikrishnan, B Rosenow, LAN Amaral, HE. *Econophysics: financial time series from a statistical physics point of view*, ***Physica A*** **279**, 443–456 (2000).

[61] L Bachelier. *Théorie de la spéculation*, ***Ann. Sci École Norm. Sup.*** **17**, 21–86 (1900).

[62] F Lillo, JD Farmer, RN Mantegna. *Master curve for price-impact function*, ***Nature*** **421**, 129 (2003).

[63] RC Merton. *Option pricing when underlying stock returns are discontinuous*, ***J. Fin. Econ.*** **3**, 125–144 (1976).

[64] P Carr, A Mayo. *On the numerical evaluation of option prices in jump diffusion processes*, ***Europ. J. Fin.*** **13**, 353–372 (2007).

[65] Wikipedia. *Volatility smile*, ***http://en.wikipedia.org/wiki/Volatility_smile*** (Accessed 12 January 2010).

[66] I Koponen. *Analytic approach to the problem of convergence of truncated Lévy flights towards the Gaussian stochastic process*, ***Phys. Rev. B*** **52**, 1197–1199 (1995).

[67] B Dubrulle, JP Laval. *Truncated levy laws and 2D turbulence*, ***Eur. Phys. J. B*** **4**, 143–146 (1998).

[68] P Repetowicz, P Richmond. In: A Chatterjee, BR Chakrabarti, eds. *Econophysics of Markets and Business Networks*, chapter Option pricing with log-stable Levy processes, pages 77–97. Springer, (2007).

[69] RN Foster. *Innovation: The Attacker's Advantage*. Simon & Schuster (1988).

[70] PG Hough. *Pitafalls in calculating cost growth from SAR*. RAND, (1992).

[71] SA Arnold, BR Harmon, KW Tyson, KG Fasana, CS Wait. *Defense Department Profit and Contract Finance Policies and Their Effects on Contract and Contractor Performance*. Institute for Defense Analyses, (2009).

[72] E Mansfield. *Academic research and industrial innovation*, ***Res. Pol.*** **20**, 1–12 (1991).

[73] C Farrukh, M Dissel, K Jackson, R Phaal, DR Probert. *Valuing technology along a timeline of technological maturity*, ***Technovation*** **47**, 42–55 (2009).

[74] A Middleton, S Bowns, K Hartley, J Reid. *The effect of defence R&D on military equipment quality*, ***Defence Peace Econ.*** **17**, 117–139 (2006).

[75] M Matsumoto, T Nishimura. *Mersenne twister: a 623-dimensionally equidistributed uniform pseudo-random number generator*, ***ACM Trans. Model. Comp. Sim.*** **8**, 3–30 (1998).

Appendix A

Mathematical derivations

A.1 Evolution of shifted distribution

We need to obtain a formulation that describes how the shifted price increments behave as a function of the iid variable (i.e., η). We have from the change of variable that $x \rightarrow x_0\,(1+\rho)\,\mathrm{e}^y$ meaning that

$$y = \log\left(\frac{x}{x_0(1+\rho)}\right), \tag{A.1}$$

such that the incremented interval looks like

$$\begin{aligned} y_{k+1} - y_k &= \log\left(\frac{x_{k+1}}{x_0(1+\rho)^{k+1}}\right) - \log\left(\frac{x_k}{x_0(1+\rho)^k}\right) && \text{(A.2)} \\ &= \log\left(\frac{x_{k+1}}{x_k(1+\rho)^k}\right). && \text{(A.3)} \end{aligned}$$

Taking a series expansion of the for $\log x \simeq (x-1) - \frac{1}{2}(x-1)^2 + \ldots$ gives

$$\begin{aligned} y_{k+1} - y_k &\simeq \left(\frac{x_{k+1}}{x_k(1+\rho)} - 1\right) - \frac{1}{2}\left(\frac{x_{k+1}}{x_k(1+\rho)} - 1\right)^2 + \cdots && \text{(A.4)} \\ &= \frac{1}{(1+\rho)}\left(\frac{x_{k+1} - x_k(1+\rho)}{x_k}\right) - \frac{1}{2}\left[\frac{1}{(1+\rho)}\left(\frac{x_{k+1} - x_k(1+\rho)}{x_k}\right]\right)^2. && \text{(A.5)} \end{aligned}$$

In this form, we can make use of the definition of the return, $\eta_k = \frac{\delta x_k}{x_k} = \frac{x_{k+1} - x_k - \rho x_k}{x_k}$, to further simplify the interval equation

$$y_{k+1} - y_k = \frac{\eta_k}{(1+\rho)} - \frac{\eta_k^2}{2(1+\rho^2)} \tag{A.6}$$

$$\simeq \frac{\eta_k}{(1+\rho)} - \frac{\eta_k^2}{2}\left(1 - 2(1+\rho) + 3(1+\rho)^2 + \cdots\right) , \tag{A.7}$$

using a second series expansion of the form $\frac{1}{(1+x)^2} \simeq 1 - 2x + 3x^2 + \cdots$ for small values of x. Finally, this leads to the second order approximation for the shifted price y in terms of the iid variable, η:

$$y_{k+1} - y_k \simeq \frac{\eta_k}{1+\rho} - \frac{\eta_k^2}{2} . \tag{A.8}$$

A.2 Analytical solution for Cauchy-based option price

We start with Eq 3.23

$$\mathcal{C}_{\mathrm{C}} = e^{-rT} \int_{x_S}^{\infty} \frac{TA(x - x_S)}{((TA)^2 + (x - x_0 e^{rT})^2)} \exp\left[\frac{-(x - x_0 e^{rT})^2}{x_C}\right] \mathrm{d}x , \tag{A.9}$$

and making a change of variables $y = x - x_0 \exp(rT)$ so that the integral becomes:

$$\mathcal{C}_{\mathrm{C}} = TAe^{-rT} \int_{x_S - x_0 e^{rT}}^{\infty} \frac{(y + x_o e^{rT} - x_S)}{((TA)^2 + y^2)} \exp\left[\frac{-y^2}{x_C}\right] \mathrm{d}y . \tag{A.10}$$

This integral can be broken up into two parts:

$$\mathcal{C}_{\mathrm{C}} = TAe^{-rT} \left[\int_{x_S - x_0 e^{rT}}^{\infty} \frac{y}{((TA)^2 + y^2)} \exp\left[\frac{-y^2}{x_C}\right] \mathrm{d}y + \int_{x_S - x_0 e^{rT}}^{\infty} \frac{(x_o e^{rT} - x_S)}{((TA)^2 + y^2)} \exp\left[\frac{-y^2}{x_C}\right] \mathrm{d}y\right] . \tag{A.11}$$

The first integral can be solved by parts as

$$\int_{x_S - x_0 e^{rT}}^{\infty} \frac{y}{((TA)^2 + y^2)} \exp\left[\frac{-y^2}{x_C}\right] \mathrm{d}y = \frac{1}{2} \exp\left[\frac{(TA)^2}{x_C}\right] \mathrm{Ei}\,(1, z) , \tag{A.12}$$

where

$$z = \frac{\left((TA)^2 + x_s^2 - 2x_0 e^{rT} x_s + x_0^2 e^{2rT}\right)}{x_C} , \tag{A.13}$$

and where $\mathrm{Ei}(1, z)$ is the exponential integral function:

$$\mathrm{Ei}(1, z) = \int_z^{\infty} \frac{e^{-t}}{t} \mathrm{d}t . \tag{A.14}$$

The second integral reduces to:

$$\int_{x_S - x_0 e^{rT}}^{\infty} \frac{(x_o e^{rT} - x_S)}{((TA)^2 + y^2)} \exp\left[\frac{-y^2}{x_C}\right] \mathrm{d}y = \frac{\pi}{2}\left(x_s - x_0 e^{rT}\right)\left(\mathrm{erf}\left(\frac{TA}{\sqrt{x_C}}\right) - 1\right) \exp\left[\frac{(TA)^2}{x_C}\right] , \tag{A.15}$$

where the error function is defined as

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} \mathrm{d}t \, . \tag{A.16}$$

Regrouping all of these gives us a closed-form analytical solution (albeit quite unpleasant to work with) in the form

$$\mathcal{C}_{\text{Cauchy}} = \frac{1}{2} \exp\left[\frac{(TA)^2}{x_C}\right] \left(\mathrm{Ei}\,(1, z) + \pi \left(x_s - x_0 e^{rT}\right) \left(\operatorname{erf}\left(\frac{TA}{\sqrt{x_C}}\right) - 1\right)\right) \, . \tag{A.17}$$

Mathematically inclined people may be able to further simplify this equation – I ran out of steam here.

Appendix B

Selected Acquisition Report

Included with this thesis is a sample Selected Acquisition Report for December 2007. These mandatory reports to congress describe all ongoing major military procurement contracts based on the Department of Defense's yearly estimates in conjunction with the President's budget. Any large deviations from previous years are explained and given context.

The total program cost estimates provided in the SARs include research and development, procurement, military construction, and acquisition-related operation and maintenance. This made the information contained in these reports ideal for calibrating the volatility distribution curve needed to estimate optimal investments in R&D using the Real Option Pricing method.

SELECTED ACQUISITION REPORT (SAR) SUMMARY TABLES

As of December 31, 2007

INDEX

UNCLASSIFIED

Department of Defense
OUSD (AT&L) ARA/AM
April 4, 2008

SELECTED ACQUISITION REPORTS (SARs) - HIGHLIGHTS

As of December 31, 2007

The Department of Defense (DoD) has released details on major defense acquisition program cost, schedule, and performance changes since the September 2007 reporting period. This information is based on the Selected Acquisition Reports (SARs) submitted to the Congress for the December 2007 reporting period.

SARs summarize the latest estimates of cost, schedule, and performance status. These reports are prepared annually in conjunction with the President's budget. Subsequent quarterly exception reports are required only for those programs experiencing unit cost increases of at least 15 percent or schedule delays of at least six months. Quarterly SARs are also submitted for initial reports, final reports, and for programs that are rebaselined at major milestone decisions.

The total program cost estimates provided in the SARs include research and development, procurement, military construction, and acquisition-related operation and maintenance (except for pre-Milestone B programs which are limited to development costs pursuant to 10 USC §2432). Total program costs reflect actual costs to date as well as future anticipated costs. All estimates include anticipated inflation allowances.

The current estimate of program acquisition costs for programs covered by SARs for the prior reporting period (September 2007) was $1,702,133.0 million. After subtracting the costs for two final reports for Evolved Expendable Launch Vehicle (EELV) and Warfighter Information Network-Tactical (WIN-T) and adding the costs for two new programs, WIN-T Increment 1 and WIN-T Increment 2, from the September 2007 reporting period, the adjusted current estimate of program acquisition costs is $1,657,829.4 million. For the December 2007 reporting period, Chemical Demilitarization-Chemical Materials Agency Newport (Chem Demil-CMA Newport) was consolidated into Chem Demil-CMA.

	Current Estimate ($ in Millions)
September 2007 (94 programs)	**$ 1,702,133.0**
Less final reports on two programs (EELV and WIN-T)	-52,090.3
Plus two new programs (WIN-T Increment 1 and WIN-T Increment 2)	+7,786.7
September 2007 Adjusted (94 programs)	**$ 1,657,829.4**
Less one program to reflect the consolidation of Chem Demil CMA Newport into Chem Demil CMA report	0.0

Changes Since Last Report:

Economic		$ -4,300 5
Quantity		-7,765 0
Schedule		-1,717 9
Engineering		+1,856 6
Estimating		+15,384 9[1]
Other		+765 1
Support		-19,079 1[1]
	Net Cost Change	$ -14,855 9

December 2007 (93 programs) **$1,642,973.5**

For the December 2007 reporting period, there was a net cost decrease of $14,855 9 million or -0 9 percent for the programs that have reported previously The cost decrease was due primarily to a net decrease in planned quantities (-$7,765 0 million), the application of lower escalation rates (-$4,300 5 million), and a net decrease in support requirements (-$9,928 1 million) [1] These decreases were partially offset by additional engineering changes (hardware/ software) (+$1,856 6 million) and a net increase in program cost estimates (+$6,233 9 million)[1] Further details of the most significant changes are summarized below by program

There are three programs with Nunn-McCurdy unit cost breaches to their current Acquisition Program Baseline (APB) AEHF (Advanced Extremely High Frequency Satellite), JAVELIN, and JTRS GMR (Joint Tactical Radio System Ground Mobile Radios) That is, the program acquisition or average procurement unit costs for these programs have increased by 15 percent or more to their current APB For "significant" Nunn-McCurdy breaches, notification and unit cost breach information will be provided to the Congress, but there are no certification requirements

New SARs
(As of December 2007)

The Department of Defense has submitted initial SARs for the following programs for the December 2007 reporting period These reports do not represent cost growth Baselines established on these programs will be the point from which future changes will be measured

Program		Current Estimate ($ in Millions)
LAIRCM (Large Altitude Infrared Countermeasures)		$366 0
MRAP (Mine Resistant Ambush Protected)		22,415 0
SBSS B10 (Space Based Space Surveillance Block 10)		823 9
	Total	$23,604 9

[1] *The large increase in Estimating and the large decrease in Support are due primarily to $9 151 0 million realignment of F-35 scope from support to procurement nonrecurring costs classified as estimating*

Summary Explanations of Significant SAR Cost Changes

As of December 31, 2007

Army:

ATIRCM/CMWS (Advanced Threat Infrared Countermeasure/Common Missile Warning System) – Program costs decreased $851.0 million (-15.0%) from $5,666.9 million to $4,815.9 million, due primarily to quantity decreases of 634 B-kits from 1,710 to 1,076 B-kits (-$675.4 million), reduced support costs resulting from the B-kit quantity reduction (-$186.5 million), economic savings from completing the buy of A-kits by FY 2010 (-$52.2 million), and unit cost reductions from accelerating the buy of CMWS mission kits (-$52.2 million). These savings were partially offset by increased costs of adding a fifth Electro-Optic Missile Sensor to each CMWS (+$181.6 million) and supporting integration of Inertial Navigation System data into CMWS in fixed wing aircraft applications (+$14.7 million).

FBCB2 (Force XXI Battle Command Brigade and Below) – Program costs increased $685.0 million (+25.5%) from $2,686.1 million to $3,371.1 million, due primarily to a quantity increase of 28,895 systems from 44,568 to 73,463 systems to support Operation Iraqi Freedom and Operation Enduring Freedom (+$683.0 million) and associated schedule, engineering, and estimating allocations* (+$99.0 million). There was an additional increase in other support for retrofit of Type I encryption for the increased quantities (+$114.1 million). These increases were partially offset by lower unit costs from beneficial contract pricing of the increased quantities (-$131.3 million) and lower estimates for the aviation A- kits (i.e., modification kits) based on current contract data (-$45.7 million).

FCS (Future Combat System) – Program costs decreased $2,609.9 million (-1.6%) from $161,930.1 million to $159,320.2 million, due primarily to the application of revised escalation indices (-$1,331.0 million) and a correction of previously reported costs that were overstated due to the use of incorrect escalation indices (-$913.2 million). There were additional decreases in other support (-$190.6 million) and Congressional statutory reductions and budget decrements (-$146.5 million).

GMLRS (Guided Multiple Launch Rocket System) – Program costs decreased $764.2 million (-11.3%) from $6,772.5 million to $6,008.3 million, due primarily to lower estimates of hardware costs for the Unitary variant at the production decision (Milestone C) (-$496.6 million) and an acceleration in the procurement buy profile (-$68.9 million). Because of the shorter buy schedule, there were lower estimates for systems engineering/program management costs (-$84.5 million), engineering services (-$44.8 million), and Government production verification testing (-$19.4 million).

LUH (Light Utility Helicopter) – Program costs increased $208.4 million (+11.1%) from $1,881.8 million to $2,090.2 million, due primarily to a quantity increase of 23 aircraft from 322 to 345 aircraft ($139.3 million). There was an additional cost increase for modifications to address issues identified during the Initial Operational Test (+$171.1 million). These modifications included ARC-231 secure radios and cabin ventilation kits for all 345 aircraft, engine inlet (air) filters for 66 aircraft, and medical evacuation kits for 84 aircraft.

STRYKER – Program costs increased by $2,560.2 million (+19.5%) from $13,130.9 million to $15,691.1 million, due primarily to a quantity increase of 640 vehicles from 2,887 to 3,527 vehicles (+$1,907.2 million) and associated schedule, engineering, and estimating allocations* (+$621.8 million), and spares and support associated with the quantity increase (+$425.1 million), There were additional increases for survivability enhancements (+$502.6 million), revised testing and management costs (+$375.7 million), and updated MILCON estimates (+$340.9 million). These increases were partially offset by a change in the mix of models procured and new cost estimates (-$797.1 million) and removal of Stryker Product Improvement Program funding (-$816.0 million).

Navy:

DDG 1000 – Program costs decreased $7,135.4 million (-19.8%) from $36,022.1 million to $28,886.7 million, due primarily to a quantity decrease of 3 ships from 10 to 7 ships (-$8,495.0 million) and revised estimates for budget reductions and inflation impacts on future ships (-$275.8 million). These decreases were partially offset by increases in FY 2009 to fully fund ships 5-7 (+$693.6 million), quantity allocations* for schedule, engineering, and estimating (+$603.7 million), additional funding for the Advanced Gun System Pallets and Sea Strike capabilities (+$308.3 million), and the application of revised escalation indices (+$291.0 million).

LCS (Littoral Combat Ship) – Program costs increased $909.7 million (+46.9%) from $1,938.9 million to $2,848.6 million, due primarily to a revised estimate in Seaframe pricing that reflects substantial cost growth and post delivery work (+$496.1 million) and a revised estimate for Mission Module development and phasing due to maturation of the definition of the Mission Modules (+$271.2 million). Costs also increased due to a lengthening of the Flight 0 schedule to incorporate additional effort (+$71.3 million), a revised estimate for program development of Flight 0 and Flight 0+ planning and execution (+$42.3 million), and additional scope for Mission Module development (+$40.7 million).

SSN 774 (Virginia Class) – Program costs decreased by $1,043.0 million (-1.1%) from $93,008.2 million to $91,965.2 million, due primarily to a lower estimate for labor and material costs (-$773.7 million) and an acceleration of the procurement buy profile that moved the FY 2020 ship up to FY 2111 (-$281.2 million).

T-AKE (Dry Cargo/Ammunition Ship) – Program costs increased by $1,086.4 million (+23.5%) from $4,628.8 million to $5,715.2 million, due primarily to the addition of one ship from 11 to 12 ships (+$471.0 million), associated outfitting and post delivery costs (+$84.5 million), and cost growth on previous ships (+$520.6 million).

Air Force:

AEHF (Advanced Extremely High Frequency) – Program costs increased $940.5 million (+14.6%) from $6,421.5 million to $7,362.0 million, due primarily to a quantity increase of one satellite from three to four satellites (+$946.0 million). Congress appropriated advance procurement for Space Vehicle 4 (SV-4) in the FY 2008 Appropriations Act. The Department added SV-4 Full Procurement in FY 2010, with a launch capability targeted in FY 2014.

C-130J – Program costs increased $3,958.2 million (+49.0%) from $8,071.1 million to $12,029.3 million, due primarily to a quantity increase of 52 aircraft from 82 to 134 aircraft (+$2,937.8 million) and associated estimating and schedule allocations* (+$399.6 million). There were additional increases in initial spares (+$85.7 million) and other support costs (+$546.9 million) associated with the higher aircraft quantity. These increases were partially offset by decreases from the acceleration of the procurement buy profile (-$18.1 million) and withholds for higher Air Force priorities and programming changes (-$12.6 million).

C-5 RERP (Reliability Enhancement and Re-engining Program) – Program costs decreased $6,375.3 million (-36.4%) from $17,506.2 million to $11,130.9 million, due primarily to net reductions in the Air Force cost estimate for equipment (-$3,332.0 million), installation (-$1,602.2 million), engineering change order estimates (-$505.5 million), and Government Furnished Equipment (-$210.2 million). Additionally, program costs decreased due to the application of revised escalation indices (-$41.0 million), a decrease in Advance Procurement costs (-$192.1 million), and decreases in initial spares (-$414.2 million) and other support and training costs (-$417.6 million).

FAB-T (Family of Advanced Beyond Line-of-Sight Terminals) – Program costs increased $454.8 million (+14.4%) from $3,167.4 million to $3,622.2 million, due primarily to a revised cost estimate resulting from analysis by the OSD Cost Analysis Improvement Group (+$348.8 million). Costs also increased due to a net quantity increase of 6 terminals from 216 to 222 terminals (+$44.7 million), adjustments in real and predicated escalation (+$26.6 million), an increase in initial spares (+$25.5 million), and a net stretch-out of the procurement buy profile (+$9.2 million).

NAVSTAR GPS (Global Positioning System) User Equipment – Program costs increased $718.4 million (+52.2%) from $1,375.3 million to $2,093.7 million, due to an increase to allow for continuation of a multi-vendor strategy through delivery of prototype cards, and to facilitate transitioning the prototype program into a full development/production program focusing on integration of military code (M-Code) capable receivers into Service-nominated lead platforms.

SBIRS (Space Based Infrared Systems) High – Program costs increased $1,675.0 million (+17.0%) from $9,879.5 million to $11,554.5 million, due primarily to a quantity increase of one Geosynchronous Earth Orbit (GEO) satellite (+$821.6 million) from three to four GEO satellites and to fully fund the latest OSD Cost Analysis Improvement Group (CAIG) cost estimate (+$866.1 million), which includes increased costs for Flight Software System (FSS) schedule slips and follow-on production efforts for host support, launch support, and other Government costs.

DoD:

Chem Demil-CMA (Chemical Demilitarization–Chemical Materials Agency) – Program costs decreased $1,220.5 million (-4.3%) from $28,643.1 million to $27,422.6 million, due primarily to adjustments to disposal facility schedules to reflect the latest operational processing rates and reduced closure durations for sites where secondary wastes can be shipped offsite or destroyed during operations (-$1,138.3 million), and the application of revised escalation indices (-$127.9 million).

F-35 (Joint Strike Fighter) – Program costs decreased by $981.3 million (-0.3%) from $299,824.1 million to $298,842.8 million, due primarily to the application of revised escalation indices (-$1,955.8 million), lower material estimates because of prime contractor's material agreements (-$1,650.6 million), and incorporation of revised prime/subcontractor labor rates (-$879.4 million). There was an additional reduction for a revised estimate of support costs (-$7,445.0 million). These decreases were partially offset by higher estimates for elements of procurement nonrecurring costs (+$4,369.0 million), an adjustment to reflect manufacturing actuals for the System Demonstration and Development (SDD) flight test articles (+$3,849.9 million), and a revised propulsion estimate to include additional hardware and increased lift fan cost (+$2,769.1 million). Overall, it should be noted that the Nunn-McCurdy unit costs are stable relative to the current and original baseline estimates.

JTRS HMS (Joint Tactical Radio System Handheld, Manpack, and Small Form Fit) – Program costs decreased $8,421.7 million (-71.4%) from $11,788.6 million to $3,366.9 million, due primarily to a quantity decrease of 232,963 radios from 328,924 to 95,961 radios (-$5,444.4 million), a reduction in costs because of a change in the type of radios purchased (i.e., change in model mix) (-$2,554.7 million), and a decrease in initial spares and other support associated with the reduced quantities (-$842.2 million). These decreases were partially offset by the addition of porting efforts for the Mobile User Objective System (MUOS) waveform (+$219.3 million) and a net stretchout of the procurement buy profile (+$157.6 million).

* *Note Quantity changes are estimated based on the original SAR baseline cost-quantity relationship Cost changes since the original baseline are separately categorized as schedule, engineering, or estimating "allocations " The total impact of a quantity change is the identified "quantity" change plus all associated "allocations "*

Program Acquisition Cost Summary (Dollars in Millions)
As Of December 31, 2007

Program	Base Year	Baseline Type	Baseline Estimate			Changes To Date			Current Estimate			% Change To Date Adjusted for Qty	
			Base Year $	Then Year $	Quantity	Base Year $	Then Year $	Quantity	Base Year $	Then Year $	Quantity	Base Year $	Then Year $
Army:													
APACHE BLOCK III (AB3)	2006	DE	6,553.0	8,093.9	602	605.4	902.5	37	7,158.4	8,996.4	639	4.9	6.0
ARH	2005	DE	3,149.1	3,568.7	368	2,110.6	2,768.0	144	5,259.7	6,336.7	512	36.3	41.8
ATIRCM/CMWS	2003	PdE	2,795.7	3,240.6	2,668	1,374.1	1,575.3	921	4,169.8	4,815.9	3,589	1.8	-4.5
BLACK HAWK UPGRADE (UH-60M)	2005	PdE	16,801.7	20,847.1	1,235	2,133.5	3,195.6	-	18,935.2	24,042.7	1,235	12.7	15.3
BRADLEY UPGRADE	2001	PdE	3,724.2	3,859.8	926	4,845.6	5,835.4	1,642	8,569.8	9,695.2	2,568	5.2	2.5
CH-47F	2005	PdE	10,614.8	12,147.4	512	900.8	1,202.9	1	11,515.6	13,350.3	513	8.3	9.7
EXCALIBUR	2007	PdE	2,264.6	2,518.7	30,388	-32.1	-53.6	-	2,232.5	2,465.1	30,388	-1.4	-2.1
FBCB2	2005	PdE	1,579.9	1,556.7	22,248	1,640.9	1,814.4	51,215	3,220.8	3,371.1	73,463	20.2	21.4
FCS	2003	DE	77,800.0	92,200.0	15	34,624.5	67,120.2	-	112,424.5	159,320.2	15	44.5	72.8
FMTV	1996	PdE	11,594.2	18,921.3	85,488	4,922.4	1,755.1	-2,303	16,516.6	20,676.4	83,185	43.7	12.8
GMLRS	2003	PdE	9,780.2	11,848.9	140,239	-5,062.5	-5,840.6	-96,444	4,717.7	6,008.3	43,795	22.5	105.3
HIMARS	2003	PdE	3,711.6	4,388.4	894	-1,914.4	-2,339.4	-513	1,797.2	2,049.0	381	-11.1	-0.3
JAVELIN	1997	PdE	3,791.1	3,926.0	28,453	903.2	998.0	-2,990	4,694.3	4,924.0	25,463	10.2	10.6
JLENS	2005	DE	5,850.0	7,151.0	16	238.6	349.3	-	6,088.6	7,500.3	16	4.1	4.9
LONGBOW APACHE	1996	PdE	5,690.6	7,027.8	758	4,135.4	4,155.2	-87	9,826.0	11,183.0	671	67.4	55.3
LUH	2006	PdE	1,638.3	1,883.0	322	181.5	207.2	23	1,819.8	2,090.2	345	4.1	3.4
PATRIOT PAC-3	2002	PdE	9,084.0	9,205.8	1,159	-697.3	-680.9	-190	8,386.7	8,524.9	969	-2.7	-1.4
PATRIOT/MEADS CAP - FIRE UNIT	2004	DE	16,530.5	21,839.4	48	-722.3	-59.7	-	15,808.2	21,779.7	48	-4.4	-0.3
PATRIOT/MEADS CAP - MISSLE	2004	DE	6,220.9	8,056.0	1,528	-193.6	59.5	-	6,027.3	8,115.5	1,528	-3.1	0.7
STRYKER	2004	PdE	8,276.9	8,534.7	2,096	5,977.6	7,156.4	1,441	14,254.5	15,691.1	3,537	18.5	21.5
WIN-T INCREMENT 1	2007	PdE	3,798.0	3,879.7	1,677	-	-20.0	-	3,798.0	3,859.7	1,677	0.0	-0.5
WIN-T INCREMENT 2	2007	DE	3,445.8	3,907.0	1,893	-	-36.2	-	3,445.8	3,870.8	1,893	0.0	-0.9
Subtotal			**214,695.1**	**258,601.9**		**55,971.9**	**90,064.6**		**270,667.0**	**348,666.5**		**23.7**	**33.4**
Navy:													
ADS (AN/WQR-3)	2005	DE	1,337.0	1,431.7	15	784.9	-902.9	-15	552.1	528.8	-	-36.7	-38.9
AGM-88E AARGM	2003	DE	1,339.8	1,510.9	1,790	86.0	199.2	121	1,425.8	1,710.1	1,911	3.2	9.1
AIM-9X	1997	PdE	2,464.0	3,232.9	10,049	200.1	162.6	93	2,664.1	3,395.5	10,142	7.6	4.4
CEC	2002	PdE	4,123.3	4,310.7	272	83.7	219.8	34	4,207.0	4,530.5	306	1.5	4.6
CH-53K	2006	DE	14,980.9	18,766.3	156	44.0	-58.0	-	15,024.9	18,708.3	156	0.3	-0.3
COBRA JUDY REPLACEMENT	2003	DE	1,365.0	1,464.0	1	88.3	165.5	-	1,453.3	1,629.5	1	6.5	11.3
CVN 21	2000	DE	28,701.2	36,082.1	3	-3,714.1	-963.0	-	24,987.1	35,119.1	3	-12.9	2.7
CVN 68	1995	PdE	4,557.1	5,540.8	1	721.7	718.0	-	5,278.8	6,258.8	1	15.8	13.0
DDG 1000	2005	DE	31,547.9	36,296.3	10	-6,457.5	-7,409.6	-3	25,090.4	28,886.7	7	-0.5	3.9
DDG 51	1987	PdE	16,953.7	20,117.5	23	29,464.4	42,638.8	39	46,418.1	62,756.3	62	11.5	10.0
E-2D AHE	2002	DE	12,225.0	14,982.0	75	1,168.9	2,449.1	-	13,393.9	17,431.1	75	9.6	16.3
EA-18G	2004	PdE	7,530.8	8,636.4	84	47.5	12.7	1	7,578.3	8,649.1	85	-0.2	-0.7
EFV	2007	DE	8,493.2	8,725.2	1,025	4,671.1	7,135.0	-432	13,164.3	15,860.2	593	114.8	174.6
ERM	2005	DE	1,242.7	1,478.0	15,100	44.8	43.4	-	1,287.5	1,521.4	15,100	3.6	2.9
F/A-18E/F	2000	PdE	38,884.7	41,637.3	458	4,372.9	4,707.5	35	43,257.6	46,344.8	493	7.1	6.5
H-1 UPGRADES (4BW/4BN)	1996	DE	2,792.5	3,547.5	284	3,957.8	5,180.0	-	6,750.3	8,727.5	284	141.7	146.0
JSOW - BASELINE/BLU-108	1990	PdE	3,566.3	4,898.7	16,124	-2,090.4	-3,037.1	-12,790	1,475.9	1,861.6	3,334	-2.1	9.9
JSOW - UNITARY	1990	PdE	1,977.8	2,974.8	7,000	-200.7	-249.7	-	1,777.1	2,725.1	7,000	-10.1	-8.4
LCS	2004	PE	1,172.7	1,211.7	2	1,422.5	1,636.9	-	2,595.2	2,848.6	2	121.3	135.1
LHA REPLACEMENT	2006	DE	2,877.4	3,093.5	1	201.5	274.4	-	3,078.9	3,367.9	1	7.0	8.9
LPD 17	1996	DE	9,018.1	10,761.8	12	2,489.9	3,479.9	-3	11,508.0	14,241.7	9	92.0	111.8
MH-60R	2006	PdE	10,627.0	11,424.7	254	652.3	714.7	-	11,279.3	12,139.4	254	6.1	6.3
MH 60S	1998	PdE	5,270.1	6,093.8	237	1,234.1	1,749.2	34	6,504.2	7,843.0	271	12.4	15.6
MUOS	2004	DE/PdE	5,738.0	6,481.1	6	-71.0	200.6	-	5,667.0	6,681.7	6	-1.2	3.1
NMT	2002	DE	1,923.4	2,321.1	333	-246.6	-217.8	-28	1,676.8	2,103.3	305	-12.8	-9.2
P-8A (MMA)	2004	DE	26,494.0	31,428.6	115	311.2	1,424.3	-2	26,182.8	32,852.9	113	-0.5	5.2
RMS	2006	PdE	1,304.6	1,399.4	108	74.9	150.3	-	1,379.5	1,549.7	108	6.0	9.9
SM-6	2004	DE	4,866.3	5,983.3	1,200	-173.8	-28.9	-	4,692.5	5,954.4	1,200	-3.6	-0.5

-

Program Acquisition Cost Summary (Dollars in Millions)
As Of December 31, 2007

Program	Base Year	Baseline Type	Baseline Estimate			Changes To Date			Current Estimate			% Change To Date Adjusted for Qty	
			Base Year $	Then Year $	Quantity	Base Year $	Then Year $	Quantity	Base Year $	Then Year $	Quantity	Base Year $	Then Year $
SSDS	2004	PdE	510 1	550 3	18	46 5	118 6	24	556 6	668 9	42	-36 1	-33 1
SSGN	2002	PdE	3,869 1	4 051 9	4	-1 7	56 6	-	3,867 4	4 108 5	4	0 0	1 4
SSN 774 (VIRGINIA CLASS)	1995	DE	45,633 1	71,080 8	30	18 118 7	20 884 4	-	63,751 8	91,965 2	30	39 7	29 4
T-45TS	1995	PdE	5,528 1	5 599 5	176	1,207 3	1 228 7	47	6,735 4	6,828 2	223	5 7	4 7
TACTICAL TOMAHAWK	1999	PdE	2,977 3	3 290 3	2,790	728 3	1,085 0	502	3,705 6	4,375 3	3,292	15 3	20 8
T-AKE	2000	PdE	4,262 6	4 890 2	12	355 6	825 0	-	4,618 2	5,715 2	12	7 9	15 2
TRIDENT II MISSILE	1983	PdE	26,556 3	35 518 5	845	-174 5	3,298 9	-284	26,381 8	38,817 4	561	16 8	34 8
V-22	2005	PdE	50,250 4	53,253 4	458	222 4	973 5	-	50,472 8	54,226 9	458	0 4	1 8
VH-71	2003	DE	5,653 6	6,547 3	23	77 9	202 9	5	5,731 5	6,750 2	28	-3 3	-2 2
VTUAV	2006	DE/PdE	2 366 4	2 787 1	177	-491 6	-628 8	-	1,874 8	2,158 3	177	-20 8	-22 6
Subtotal			**400,981.5**	**483,401.4**		**57,065.1**	**88,439.7**		**458,046 6**	**571,841.1**		**11.4**	**14.6**
Air Force:													
AEHF	2002	DE/PdE	5 279 2	5 645 3	5	1 459 1	1 716 7	-1	6,738 3	7 362 0	4	29 2	30 9
AMRAAM	1992	PdE	12,278 2	13 112 4	15,450	878 1	1,768 2	-1,497	13,156 3	14 880 6	13,953	17 3	30 9
B-2 EHF INCREMENT 1	2007	DE	659 7	706 1	21	-23 3	-25 1	-	636 4	681 0	21	-3 5	-3 6
B-2 RMP	2004	DE	1,148 4	1 220 0	21	-54 7	5 4	-	1,093 7	1,225 4	21	-4 8	0 4
C-130 AMP	2000	DE	3,333 9	3,965 4	519	1,187 1	1,834 8	-297	4,521 0	5,800 2	222	76 9	102 8
C-130J	1996	PdE	730 7	839 7	11	9,074 0	11,189 6	123	9,804 7	12,029 3	134	31 4	30 3
C-17A	1996	PdE	41,250 9	41,811 9	210	17,413 9	20,494 8	-20	58,664 8	62 306 7	190	45 1	55 1
C-5 AMP	2006	PdE	888 4	856 3	61	488 6	549 0	51	1,377 0	1,405 3	112	20 1	22 4
C-5 RERP	2000	DE	8 798 0	11,093 9	126	-320 0	37 0	-15	8,478 0	11,130 9	111	2 4	6 8
F-22	2005	PdE	64,281 7	61,323 7	181	2,710 1	3,216 2	3	66,991 8	64,539 9	184	3 7	4 6
FAB-T	2002	DE	2,642 3	3,167 4	216	320 4	454 8	6	2,962 7	3,622 2	222	10 7	12 8
GBS	1997	DE	451 4	497 1	346	275 6	308 4	775	727 0	805 5	1,121	6 5	5 6
GLOBAL HAWK (RQ-4A/B)	2000	DE	4,350 3	5 394 0	63	3,751 6	4 346 7	-9	8,101 9	9,740 7	54	101 1	98 5
JASSM	1995	PdE	4,016 4	4 981 1	5,447	449 7	1 084 7	-441	4,466 1	6 065 8	5,006	18 0	30 2
JDAM	1995	PdE	2,300 3	2,606 7	89,065	2,221 8	2,653 4	112,928	4,522 1	5 260 1	201,993	28 3	29 6
JPATS	2002	PdE	4,529 0	5,041 1	783	385 5	493 2	-15	4,914 5	5,534 3	768	9 9	11 5
MINUTEMAN III GRP	1993	PdE	2,012 5	2,400 1	652	82 9	27 6	-	2,095 4	2,427 7	652	5 9	2 8
MINUTEMAN III PRP	1994	PdE	2,086 8	2,600 8	607	103 0	1 0	-6	2,189 8	2,601 8	601	5 5	0 5
MP RTIP	2000	DE	1,449 3	1 568 4	-	-334 6	-343 4	-	1 114 7	1 225 0	-	-23 1	-21 9
MPS	2004	DE	1 545 8	1 690 7	1	-152 2	-108 2	-	1 393 6	1 582 5	1	-9 8	-6 4
NAS	2005	PdE	1 373 2	1 421 1	93	50 3	69 6	-2	1,423 5	1 490 7	91	4 8	6 3
NAVSTAR GPS SPACE & CONTROL	2000	PdE	5,015 6	5,120 9	33	947 5	1 185 2	-	5 963 1	6 306 1	33	18 4	23 2
NAVSTAR GPS - USER EQUIPMENT	2000	PdE	797 8	874 4	-	992 8	1,219 3	-	1,790 6	2 093 7	-	124 4	139 4
NPOESS	2002	PdE	5,538 0	6 117 6	6	3 825 0	5 022 6	-2	9,363 0	11 140 2	4	83 4	101 7
SBIRS HIGH	1995	DE	3,679 5	4 147 3	5	5,879 2	7,407 2	-1	9,558 7	11 554 5	4	178 2	200 2
SDB I	2001	PdE	1,526 0	1,786 3	24 070	-274 0	-309 4	-	1,252 0	1,476 9	24,070	-18 0	-17 3
WGS	2001	PdE	980 4	1 042 5	3	784 0	908 0	2	1,764 4	1,950 5	5	14 5	16 3
Subtotal			**182,943 7**	**191,032.2**		**52,121.4**	**65,207.3**		**235,065 1**	**256,239 5**		**25 2**	**31.1**
DoD:													
BMDS	2002	PE	44,740 1	47,217 1	-	44,658 2	55 695 3	-	89,398 3	102,912 4	-	99 8	118 0
CHEM DEMIL-ACWA	1994	PdE	1,957 4	2 430 4	3,134	3,541 4	5,561 5	2	5,498 8	7,991 9	3,136	180 9	228 8
CHEM DEMIL-CMA	1994	PdE	11,513 7	12 879 9	29,060	10,945 6	14 542 7	-	22,459 3	27 422 6	29,060	95 1	112 9
DIMHRS	2007	DE	947 5	922 3	-	-97 3	-103 4	1	850 2	818 9	1	-10 3	-11 2
F-35 (JSF)	2002	DE	177,100 0	233 000 0	2,866	32,914 5	65,842 8	-410	210,014 5	298 842 8	2,456	30 6	44 0
JTRS GMR	2002	DE	14,437 2	19,112 9	108,388	-194 1	1,423 5	-21,736	14,243 1	20,536 4	86,652	13 3	27 6
JTRS HMS	2004	DE	8 569 0	10 717 0	328,674	-5,897 2	-7,350 1	-232 713	2,671 8	3 366 9	95 961	-42 7	-36 1
JTRS NED	2002	DE	812 9	914 4	-	930 3	1,047 4	-	1,743 2	1,961 8	-	114 4	114 5
MIDS	2003	PdE	1 824 8	1,818 9	2,964	464 3	553 8	843	2,289 1	2,372 7	3,807	11 7	14 0
Subtotal			**261,902 6**	**329,012.9**		**87,265.7**	**137,213.5**		**349,168 3**	**466,226.4**		**45.4**	**57.8**
Grand Total			**1,060,522 9**	**1,262,048.4**		**252,424 1**	**380,925.1**		**1,312,947 0**	**1,642,973.5**		**24.1**	**31.3**

Distribution of Cost Changes (Then Year Dollars in Millions)
As Of December 31, 2007

Program	Cost Changes Between the Baseline and Current Estimates															
	Economic		Quantity		Schedule		Engineering		Estimating		Other		Support		Total	
	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date
Army:																
APACHE BLOCK III (AB3)	-57 0	-75 0	-	395 5	15 4	145 6	-	-	56 1	394 2	-	-	-8 5	42 2	6 0	902 5
ARH	-39 3	26 8	-	901 6	104 4	306 2	-194 8	81 1	31 5	827 5	-	-	35 6	624 8	-62 6	2,768 0
ATIRCM/CMWS	-24 8	209 4	-	1,800 8	-52 2	-642 0	181 6	-483 2	-773 8	632 8	-	-	-181 8	57 5	-851 0	1,575 3
BLACK HAWK UPGRADE (UH-60M)	-143 4	85 0	-	-	-416 7	585 6	-	1,112 1	858 9	1,258 7	-	-	-86 1	154 2	212 7	3,195 6
BRADLEY UPGRADE	-33 7	4 2	831 4	5,597 3	-5 1	-293 6	-102 6	751 1	-112 5	-884 3	-	-	-167 9	660 7	409 6	5,835 4
CH-47F	-65 8	103 9	23 4	23 4	-49 7	-152 0	0 5	0 5	-21 3	1,279 4	-	-	14 4	-52 3	-98 5	1,202 9
EXCALIBUR	-22 5	-27 3	-	-	0 1	0 1	-	-	23 1	-27 0	-	-	-	0 6	0 7	-53 6
FBCB2	-5 3	29 4	683 0	1,220 8	-28 9	-41 4	18 1	114 9	-95 6	124 9	-	-	113 7	365 8	685 0	1,814 4
FCS	-1,331 0	5,552 6	-	-	-	20,101 7	-	23,940 6	-1,047 5	7,017 0	-	-	-231 4	10,508 3	-2,609 9	67,120 2
FMTV	-97 7	-2,525 5	-	-597 8	-669 2	-1,729 9	-0 3	3,030 3	1,409 4	3,451 2	-	-	-767 8	126 8	-125 6	1,755 1
GMLRS	-59 2	669 4	-	-8,922 7	-68 9	1,291 4	-	-	-633 4	1,110 3	-	-	-2 7	11 0	-764 2	-5,840 6
HIMARS	-10 9	247 3	-	-2,332 3	-	-17 3	-	39 6	-32 0	-136 3	-	-	3 2	-140 4	-39 7	-2,339 4
JAVELIN	-3 7	-55 0	341 1	524 7	-2 1	-22 8	-	7 0	22 4	519 5	-	-	67 0	24 6	424 7	998 0
JLENS	-51 2	81 8	-	-	-42 1	-43 0	-	-	-78 4	237 5	-	-	304 7	73 0	133 0	349 3
LONGBOW APACHE	-14 8	-251 1	110 6	172 3	-	22 3	-	2,530 1	69 8	1,197 5	-	-	-17 4	484 1	148 2	4,155 2
LUH	-10 8	-5 3	139 3	139 3	6 4	-2 1	84 9	84 9	-1 4	-8 0	-	-	-10 0	-1 6	208 4	207 2
PATRIOT PAC-3	-10 9	170 8	-	-558 9	-	43 4	-	-	14 1	-336 2	-	-	-	-	3 2	-680 9
PATRIOT/MEADS CAP - FIRE UNIT	-212 6	875 6	-	-	-	-	-	-	-10 4	-813 2	-	-	-2 9	-122 1	-225 9	-59 7
PATRIOT/MEADS CAP - MISSLE	-82 2	314 8	-	-	-	13 0	-	-	30 5	-268 4	-	-	-4 8	0 1	-56 5	59 5
STRYKER	-82 9	171 6	1,907 2	4,381 7	-94 5	-176 4	1,099 8	1,862 6	-62 4	-253 1	-	-	-207 0	1 170 0	2 560 2	7,156 4
WIN-T INCREMENT 1	-19 8	-19 8	-	-	-0 6	-0 6	-	-	-3 0	-3 0	-	-	3 4	3 4	-20 0	-20 0
WIN-T INCREMENT 2	-35 8	-35 8	-	-	-	-	-	-	86 0	86 0	-	-	-86 4	-86 4	-36 2	-36 2
Subtotal	-2,415 3	5,547 8	4,036 0	2,745 7	-1,303 7	19,388 2	1,087 2	33,071 6	-269 9	15,407 0	-	-	-1,232 7	13,904 3	-98 4	90,064 6
Navy:																
ADS (AN/WQR-3)	22 8	-2 1	-	-566 5	-	7 7	-	-	-22 8	-186 5	-	-	-	-155 5	-	-902 9
AGM-88E AARGM	-9 6	69 4	-3 5	55 9	27 8	26 0	-	0 8	48 4	80 5	-	-	-44 3	-33 4	18 8	199 2
AIM-9X	-19 7	-209 5	-	19 5	21 4	216 8	-	249 9	1 3	202 0	-	-	4 5	-316 1	7 5	162 6
CEC	-0 3	70 0	185 9	20 3	10 1	109 6	-33 4	213 0	-283 5	-255 8	-	-	203 0	62 7	81 8	219 8
CH-53K	-132 3	-59 2	-	-	-	-	-	-	-52 5	-25 5	-	-	2 7	26 7	-182 1	-58 0
COBRA JUDY REPLACEMENT	-2 4	56 7	-	-	-	-	-	-	111 4	108 8	-	-	-	-	109 0	165 5
CVN 21	325 3	3,881 4	-	-	-	265 8	-	-963 6	-234 9	-4,146 6	-	-	-	-	90 4	-963 0
CVN 68	25 3	-176 4	-	-	-	-54 5	-	-65 7	-6 7	887 6	-	127 0	-	-	18 6	718 0
DDG 1000	291 0	1 022 0	-8,495 0	-8 495 0	-64 2	85 8	591 1	-249 7	541 7	227 3	-	-	-	-	-7,135 4	-7 409 6
DDG 51	53 5	-3,833 3	-	36,929 9	-	985 1	-	2,250 7	-50 1	6,306 4	-	-	-	-	3 4	42,638 8
E-2D AHE	-107 6	785 6	-	-	-	652 5	-	480 3	39 9	420 5	-	-	11 8	110 2	-55 9	2,449 1
EA-18G	-31 3	-31 2	-	72 4	-	-9 7	-	-	30 8	4 9	-	-	-39 9	-23 7	-40 4	12 7
EFV	-88 9	248 9	-	-2,950 4	-	1,700 4	-	414 6	-22 5	7,159 8	-	-	-0 5	561 7	-111 9	7,135 0
ERM	-10 1	-10 1	-	-	-	-	-	-	53 5	53 5	-	-	-	-	43 4	43 4
F/A-18E/F	142 9	-246 3	-64 8	1,864 0	-12 6	1 061 9	-	223 1	-46 2	5 1	-	-	-63 3	1,799 7	-44 0	4,707 5
H-1 UPGRADES (4BW/4BN)	-56 0	-138 6	-	-	-5 0	542 6	75 2	638 3	100 2	3,110 7	-	-	-93 4	1,027 0	21 0	5,180 0
JSOW - BASELINE/BLU-108	-2 1	-30 5	-	-3,204 5	-0 6	379 8	-	104 0	-12 1	-265 7	-	-	-2 6	-20 2	-17 4	-3,037 1
JSOW - UNITARY	-16 9	133 5	-	-	2 1	0 4	23 7	78 6	-9 8	-449 5	-	-	-6 9	-12 7	-7 8	-249 7
LCS	-0 3	39 9	-	-	71 3	147 4	43 7	116 7	795 0	1,332 9	-	-	-	-	909 7	1,636 9
LHA REPLACEMENT	39 9	55 8	-	-	-	-	-	-	-224 9	-53 4	272 0	272 0	-	-	87 0	274 4
LPD 17	98 9	460 6	-	-4,037 8	6 1	774 2	-	-	49 6	4,696 4	493 1	1,586 5	-	-	647 7	3,479 9
MH-60R	-52 9	-20 6	-	-	14 4	68 5	15 6	207 3	789 8	803 1	-	-	-329 2	-343 6	437 7	714 7
MH-60S	-28 5	215 4	83 5	690 3	1 3	242 6	-0 3	-46 0	-176 0	303 5	-	-	53 4	343 4	-66 6	1,749 2
MUOS	-31 2	264 2	-	-	-	-	-	-	340 0	-63 6	-	-	-	-	308 8	200 6
NMT	22 6	75 0	-4 5	-4 5	5 3	5 3	-	-	-51 9	-212 5	-	-	-2 0	-81 1	-30 5	-217 8
P-8A (MMA)	-214 1	1 282 3	-201 0	-201 0	13 0	831 5	165 4	165 4	404 5	-672 6	-	-	12 5	18 7	180 3	1 424 3
RMS	-2 9	-2 9	-	11 3	148 6	148 6	-	-	4 6	5 6	-	-	-12 3	-12 3	138 0	150 3
SM-6	-46 5	258 4	-	-	-0 9	-75 7	-	-	47 5	-76 6	-	-	-3 4	-135 0	-3 3	-28 9
SSDS	-1 5	10 5	-	450 2	-	17 3	-	-	-4 0	-351 2	-	-	-	-8 2	-5 5	118 6
SSGN	2 0	52 3	-	-	-	-	-	7 0	11 5	-2 1	-	-	-0 2	-0 6	13 3	56 6
SSN 774 (VIRGINIA CLASS)	806 5	-5,063 8	-	-	-833 9	7,689 6	-	1,272 3	-887 7	15,951 0	-	280 0	-127 9	755 3	-1,043 0	20,884 4

Distribution of Cost Changes (Then Year Dollars in Millions)
As Of December 31, 2007

Program	Cost Changes Between the Baseline and Current Estimates															
	Economic		Quantity		Schedule		Engineering		Estimating		Other		Support		Total	
	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date
T-45TS	-0 7	42 5	-25 6	920 6	9 5	-158 3	-13 1	77 5	33 8	322 9	-	-	-1 3	23 5	2 6	1,228 7
TACTICAL TOMAHAWK	-18 1	88 1	-228 0	330 2	-7 6	233 0	-2 2	24 7	91 8	353 0	-	-	-	56 0	-164 1	1,085 0
T-AKE	38 7	265 2	471 0	72 2	9 3	33 5	-	-	567 4	454 1	-	-	-	-	1,086 4	825 0
TRIDENT II MISSILE	-84 0	-236 4	-	-6,719 1	-	1,816 5	-374 1	92 3	-320 9	5,710 4	-	-	694 5	2,635 2	-84 5	3,298 9
V-22	-231 4	66 3	-	-	-11 2	746 0	-	213 2	-29 5	36 2	-	-	-137 8	-88 2	-409 9	973 5
VH-71	-21 9	33 8	-98 2	352 4	203 0	203 0	-	-	492 1	-381 9	-	-	30 4	-4 4	605 4	202 9
VTUAV	40 9	40 9	-	-	2 5	2 5	40 2	40 2	-15 2	-701 7	-	-	-10 7	-10 7	57 7	-628 8
Subtotal	699 1	-542 2	-8,380 2	15,610 4	-390 3	18,695 7	531 8	5,544 9	2 103 6	40,691 0	765 1	2,265 5	137 1	6,174 4	-4,533 8	88 439 7
Air Force:																
AEHF	-10 7	14 5	946 0	-23 3	-	1,092 5	-7 2	43 1	5 2	583 9	-	-	7 2	6 0	940 5	1,716 7
AMRAAM	-26 8	-311 2	-156 7	-1,746 1	-50 1	1,829 4	-6 5	1,126 1	254 4	681 6	-	-	74 4	188 4	88 7	1,768 2
B-2 EHF INCREMENT 1	-2 0	-2 0	-	-	0 7	0 7	-	-	-19 1	-19 1	-	-	-4 7	-4 7	-25 1	-25 1
B-2 RMP	0 5	48 1	-	-	116 5	116 9	-	-	-11 0	-140 9	-	-	-10 1	-18 7	95 9	5 4
C-130 AMP	-15 9	-190 9	-232 6	-1,105 6	-19 4	240 3	-	77 6	469 7	2,397 7	-	-	-382 6	415 7	-180 8	1,834 8
C-130J	-1 8	122 8	2,937 8	8,390 1	224 6	-398 6	-	169 1	165 5	129 9	-	-	632 1	2,776 3	3,958 2	11,189 6
C-17A	-0 7	-819 3	-	-1,631 8	-	4,828 1	-	382 5	-48 6	13,897 1	-	412 0	-106 6	3,426 2	-155 9	20,494 8
C-5 AMP	-0 7	-3 3	-	291 4	-	2 9	-	14 4	-25 4	-7 6	-	-	20 9	251 2	-5 2	549 0
C-5 RERP	-41 0	33 0	-	-672 1	-	564 9	-	-54 9	-5,502 5	-347 0	-	-	-831 8	513 1	-6,375 3	37 0
F-22	-15 9	67 7	-	374 9	-	65 0	-	-	-721 6	1,838 4	-	-	-15 3	870 2	-752 8	3 216 2
FAB-T	26 6	26 6	44 7	44 7	9 2	9 2	-	-	316 0	316 0	-	-	58 3	58 3	454 8	454 8
GBS	-0 5	-10 2	10 1	266 0	10 3	43 3	10 2	101 9	-80 0	-101 9	-	-	0 1	9 3	-49 8	308 4
GLOBAL HAWK (RQ-4A/B)	-15 3	38 0	-	-486 9	-	-772 9	82 8	3,584 2	-151 7	1 263 9	-	-	26 9	720 4	-57 3	4,346 7
JASSM	-23 5	178 5	-	-323 2	13 5	213 0	-129 2	14 7	384 0	993 5	-	-	24 7	8 2	269 5	1,084 7
JDAM	-3 6	68 7	-62 8	1,452 1	0 9	-38 6	-	15 5	36 0	932 9	-	-	-11 9	222 8	-41 4	2,653 4
JPATS	-13 8	36 5	-	-76 0	-0 1	57 8	226 8	441 0	-247 6	110 1	-	-	32 5	-76 2	-2 2	493 2
MINUTEMAN III GRP	13 8	25 1	-	-37 6	-	0 1	-	-	-20 2	40 5	-	-	-1 5	-0 5	-7 9	27 6
MINUTEMAN III PRP	17 8	13 9	-	-11.5	-	-29 8	-	25 5	-30 7	-35 2	-	-	-5 0	38 1	-17 9	1 0
MP RTIP	-0 2	43 4	-	-	-	156 1	-	-351 0	-12 8	-191 9	-	-	-	-	-13 0	-343 4
MPS	-4 3	62 2	-	-	-	-18 0	-	6 7	4 3	-156 4	-	-	-	-2 7	-	-108 2
NAS	-4 5	8 8	-	-18 5	-3 6	11 0	-	-	38 9	51 2	-	-	-3 6	17 1	27 2	69 6
NAVSTAR GPS - SPACE & CONTROL	-5 5	40 8	-	-2 3	-	8 3	-	435 4	-35 7	463 6	-	-	-2 3	239 4	-43 5	1,185 2
NAVSTAR GPS - USER EQUIPMENT	-2 7	17 7	-	-	-	-	-	277 8	722 0	918 9	-	-	-0 9	4 9	718 4	1,219 3
NPOESS	-44 9	184 8	-	-594 5	-	980 2	3 0	-859 7	21 5	5,311 8	-	-	-	-	-20 4	5,022 6
SBIRS HIGH	-15 6	41 0	821 6	-298 8	-	560 3	2 0	506 4	861 9	6,475 5	-	-	5 1	122 8	1 675 0	7,407 2
SDB I	-5 0	35 1	-	-	-1 6	-11 7	-	-	-1 3	-332 3	-	-	1 1	-0 5	-6 8	-309 4
WGS	-1 2	27 3	-	634 2	-	-	-	63 2	7 9	203 5	-	-	-	-20 2	6 7	908 0
Subtotal	-197 4	-202 4	4,308 1	4,425 2	300 9	9,510 4	181.9	6,019 5	-3,620 9	35,277 7	-	412 0	-493 0	9,764 9	479 6	65,207 3
DoD:																
BMDS	4 7	2,325 1	-	-	-	-1,684 3	-	56,455 0	-380 4	-1,400 5	-	-	-	-	-375 7	55,695 3
CHEM DEMIL-ACWA	-66 0	74 5	-	-	-	-150 2	-	-	107 6	5,637 2	-	-	-	-	41 6	5,561 5
CHEM DEMIL-CMA	-127 9	202 6	-	-	-	10,705 0	-	-	-1,092 6	3,626 4	-	8 7	-	-	-1,220 5	14,542 7
DIMHRS	-1 9	-1 9	-	-	-	-	-	-	15 5	15 5	-	-	0 2	-117 0	13 8	-103 4
F-35 (JSF)	-1,955 8	5,309 9	-	-25,434 9	-	29,614 1	-	12,789 3	17,841 8	41,528 3	-	-	-16,867 3	2 036 1	-981 3	65,842 8
JTRS GMR	-140 7	879 4	-2,420 2	-3,020 0	-480 1	1,488 4	-	12 4	2,979 4	1,817 8	-	-	269 9	245 5	208 3	1,423 5
JTRS HMS	-66 5	648 8	-5,444 4	-5,444 4	157 6	334 5	-	-	-2,195 9	-2,016 5	-	-	-872 5	-872 5	-8,421 7	-7,350 1
JTRS NED	-39 1	-42 1	-	-	-	-	-	725 3	-103 2	364 2	-	-	-	-	-142 3	1,047 4
MIDS	6 3	27 4	135 7	261 8	-2 3	-6 0	55 7	296 7	-0 1	-3 0	-	-	-20 8	-23 1	174 5	553.8
Subtotal	-2,386 9	9 423 7	-7 728 9	-33,637 5	-324 8	40,301 5	55 7	70,278 7	17,172 1	49,569 4	-	8 7	-17,490 5	1,269 0	-10 703 3	137,213 5
Grand Total	-4,300 5	14,226 9	-7 765 0	-10 856 2	-1,717 9	87,895 8	1 856 6	114 914 7	15,384 9	140,945 1	765 1	2 686 2	-19,079 1	31,112 6	-14 855 9	380,925 1

Distribution of Cost Changes (Base Year Dollars in Millions)
As Of December 31, 2007

Program	Base Year	Cost Changes Between the Baseline and Current Estimates													
		Quantity		Schedule		Engineering		Estimating		Other		Support		Total	
		This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date
Army:															
APACHE BLOCK III (AB3)	2006	-	269 2	-	-	-	-	43 9	307 4	-	-	-3 3	28 8	40 6	605 4
ARH	2005	-	709 8	74 8	161 8	-155 7	71 5	26 3	696 9	-	-	20 8	470 6	-33 8	2 110 6
ATIRCM/CMWS	2003		1,299 3		-153 9	159 6	-301 6	-544 0	465 9	-	-	128 3	64 4	-512 7	1,374 1
BLACK HAWK UPGRADE (UH-60M)	2005	-	-	-	112 1	-	893 8	662 1	1,011 5	-	-	-56 0	116 1	606 1	2,133 5
BRADLEY UPGRADE	2001	622 5	4,418 9	62 4	62 4	-76 8	625 5	-99 3	-741 1	-	-	-147 7	479 9	361 1	4,845 6
CH-47F	2005	17 3	17 3	-0 1	-0 1	0 5	0 5	-37 8	920 5	-	-	9 8	-37 4	10 3	900 8
EXCALIBUR	2007	-	-	-	-	-	-	20 1	-32 6	-	-	-	0 5	20 1	-32 1
FBCB2	2005	606 4	1 099 3	-4 1	3 3	16 1	112 7	-94 0	102 3	-	-	100 1	323 3	624 5	1,640 9
FCS	2003	-	-	-	7 739 7	-	17 079 5	-673 9	4,410 2	-	-	-134 4	5 395 1	-808 3	34,624 5
FMTV	1996	-	-97 2	-	42 8	-0 5	2 216 3	1 051 2	2,558 6	-	-	-549 2	201 9	501 5	4,922 4
GMLRS	2003	-	-5 929 7	-	224 1	-		-466 9	633 0	-	-	-2 3	10 1	-469 2	-5 062 5
HIMARS	2003	-	-1,689 8	-	-16 6	-	35 5	-27 8	-157 3	-	-	2 6	-86 2	-25 2	-1,914 4
JAVELIN	1997	269 5	469 0	-0 7	-4 5	-	7 3	17 9	406 6	-	-	52 1	24 8	338 8	903 2
JLENS	2005	-	-	-	-	-	-	-73 0	189 0	-	-	231 8	49 6	158 8	238 6
LONGBOW APACHE	1996	87 7	178 5		-	-	2,083 8	58 3	1,422 3	-	-	-13 2	450 8	132 8	4 135 4
LUH	2006	110 5	110 5	-0 6	6 9	74 4	74 4	3 1	-9 6	-	-	-9 3	-0 7	171 9	181 5
PATRIOT PAC-3	2002	-	-463 5	-	46 8	-	-	12 1	-280 6	-	-	-	-	12 1	-697 3
PATRIOT/MEADS CAP - FIRE UNIT	2004	-	-	-	-	-		-8 2	-635 2	-	-	-2 7	-87 1	10 9	-722 3
PATRIOT/MEADS CAP MISSLE	2004	-	-	-	-	-		26 1	-195 8	-	-	-4 0	2 2	22 1	-193 6
STRYKER	2004	1 579 2	3 753 4	-50 2	-50 2	919 2	1 594 1	-53 5	-472 5	-	-	-135 0	1 152 8	2,259 7	5 977 6
WIN-T INCREMENT 1	2007	-	-	-	-	-	-	-3 1	-3 1	-	-	3 1	3 1	-	-
WIN-T INCREMENT 2	2007		-	-	-	-	-	74 6	74 6	-	-	-74 6	-74 6		-
Subtotal		3 293 1	4 145 0	81 5	8 174 6	936 8	24 493 3	-92 0	10,671 0	-	-	-839 7	8 488 0	3 379 7	55,971 9
Navy:															
ADS (AN/WQR 3)	2005	-	-465 3	-	-		-	23 5	-174 7	-	-	-	-144 9	-23 5	-784 9
AGM-88E AARGM	2003	-2 6	41 4	11 3	0 6	-	0 7	35 8	68 7	-	-	-34 2	-25 4	10 3	86 0
AIM-9X	1997	-	12 9	14 6	64 3	-	200 2	1 1	150 3	-	-	3 5	-227 6	19 2	200 1
CEC	2002	139 2	21 0	6 5	13 4	-24 9	212 7	-213 1	-107 0	-	-	149 4	-56 4	57 1	83 7
CH-53K	2006	-	-	-	-	-	-	-52 7	21 4	-	-	2 3	22 6	-50 4	44 0
COBRA JUDY REPLACEMENT	2003	-	-	-	-	-	-	92 7	88 3	-	-	-	-	92 7	88 3
CVN 21	2000	-		-	88 0	-	-688 9	-273 5	-3,113 2	-	-	-	-	-273 5	-3 714 1
CVN 68	1995	-		-	-72 8	-	-5 3	-7 9	685 1	-	114 7	-	-	-7 9	721 7
DDG 1000	2005	-6 319 2	-6 319 2	-47 7	85 9	449 2	-233 5	441 7	9 3	-	-	-	-	-5,476 0	-6 457 5
DDG 51	1987	-	24,694 7		89 1		1,480 1	-77 8	3 200 5		-	-	-	-77 8	29,464 4
E-2D AHE	2002	-		-	208 1	-	374 3	20 9	517 6	-	-	6 8	68 9	27 7	1 168 9
EA-18G	2004	-	59 4	-		-	-	26 2	8 2	-	-	-33 7	-20 1	-7 5	47 5
EFV	2007	-	-2,365 8	-	364 7	-	363 9	-23 8	5 884 8	-	-	-0 3	423 5	24 1	4 671 1
ERM	2005	-		-		-	-	44 8	44 8	-	-	-	-	44 8	44 8
F/A-18E/F	2000	-49 7	1,502 5	-	868 8	-	200 1	-44 0	134 7	-	-	-45 3	1 666 8	-139 0	4 372 9
H-1 UPGRADES (4BW/4BN)	1996	-	-	-11 7	166 3	60 9	529 7	71 1	2,516 8	-	-	-64 5	745 0	55 8	3,957 8
JSOW - BASELINE/BLU-108	1990	-	-2,059 3	-	2 4	-	76 6	-5 5	-97 3	-	-	-1 4	-12 8	-6 9	-2,090 4
JSOW - UNITARY	1990	-	-	-	5 9	16 0	49 2	-5 1	-247 0	-	-	-4 1	-8 8	6 8	-200 7
LCS	2004	-	-	60 9	127 5	38.5	102 8	704 0	1,192 2	-	-	-	-	803 4	1 422 5
LHA REPLACEMENT	2006	-	-	-		-	-	-211 9	-48 2	249 7	249 7	-	-	37 8	201 5
LPD 17	1996	-	-3 024 6	4 8	320 5	-	-	28 9	3,993 0	370 9	1,201 0	-	-	404 6	2,489 9
MH-60R	2006	-	-	6 4	35 0	14 2	187 3	690 4	735 7	-	-	-284 3	-305 7	426 7	652 3
MH-60S	1998	59 0	514 0	0 9	128 2	-0 2	-36 6	-138 2	385 2	-	-	44 7	243 3	-33 8	1,234 1
MUOS	2004	-	-	-	-	-	-	281 1	-71 0	-	-	-	-	281 1	-71 0
NMT	2002	0 6	0 6	-	-	-	-	-40 3	-181 8	-	-	-1 5	-65 4	-41 2	-246 6
P-8A (MMA)	2004	-175 4	-175 4	11 1	270 5	137 8	137 8	343 5	-553 1	-	-	1 2	9 0	318 2	-311 2
RMS	2006	-	-3 7	88 5	88 5	-	-	3 7	1 0	-	-	-10 9	-10 9	81 3	74 9
SM-6	2004	-	-	-	-	-	-	34 9	-73 5	-	-	-2 9	-100 3	32 0	-173 8

Distribution of Cost Changes (Base Year Dollars in Millions)
As Of December 31, 2007

Program	Base Year	Cost Changes Between the Baseline and Current Estimates													
		Quantity		Schedule		Engineering		Estimating		Other		Support		Total	
		This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date	This Qtr	To Date
SSDS	2004	-	361.6	-	7.7		-	2.7	-316.4		-	-	-6.4	2.7	46.5
SSGN	2002	-	-		-		6.8	10.3	-8.1	-		-0.2	-0.4	10.1	-1.7
SSN 774 (VIRGINIA CLASS)	1995	-		-168.3	1 708.0	-	956.0	-571.6	14 737.4	-	216.3	-95.0	501.0	-834.9	18 118.7
T-45TS	1995	-20.3	841.9	7.5	71.7	-10.4	77.3	27.2	320.1		-	-1.5	39.7	2.5	1,207.3
TACTICAL TOMAHAWK	1999	-168.7	235.4	-14.4	151.3	-1.6	19.7	71.3	275.5	-	-	-	46.4	-113.4	728.3
T AKE	2000	343.5	16.8	-	-		-	418.2	338.8	-			-	761.7	355.6
TRIDENT II MISSILE	1983	-	3,970.8	-		-193.7	51.7	-162.4	2 629.6		-	312.5	1 115.0	-43.6	-174.5
V-22	2005	-		-	398.9	-	157.1	-22.3	-264.9	-	-	-115.4	-68.7	-137.7	222.4
VH-71	2003	-75.0	272.0	130.4	130.4		-	418.7	-302.6	-	-	4.7	-21.9	478.8	77.9
VTUAV	2006	-	-	-	-	35.7	35.7	11.8	518.6		-	-9.1	-8.7	14.8	-491.6
Subtotal		-6,268.6	10,190.1	100.8	5 179.5	521.5	4 255.4	1 878.4	31 861.6	620.6	1 781.7	-179.2	3 796.8	-3 326.5	57 065.1
Air Force:															
AEHF	2002	784.9	-64.1	-	1 037.3	-6.2	37.7	4.6	442.0	-	-	6.2	6.2	789.5	1 459.1
AMRAAM	1992	-103.5	-1 065.5	-8.6	775.2	-4.5	867.9	176.2	207.7	-	-	51.6	92.8	111.2	878.1
B-2 EHF INCREMENT 1	2007	-	-		-		-	-18.7	-18.7	-	-	-4.6	-4.6	23.3	-23.3
B-2 RMP	2004	-	-	86.6	86.6	-	-	-2.5	-124.5	-	-	-8.4	-16.8	75.7	-54.7
C-130 AMP	2000	-157.9	-777.6	-36.4	63.0	-	69.2	370.8	1,528.6	-	-	-290.1	303.9	-113.6	1,187.1
C-130J	1996	2,129.1	6 730.5	175.5	-264.1	-	126.2	145.7	259.8	-	-	435.7	2 221.6	2 886.0	9,074.0
C-17A	1996	-	-824.7	-	1,418.4	-	371.9	-38.3	13,640.0	-	411.0	-85.7	2,397.3	-124.0	17,413.9
C-5 AMP	2006	-	257.9	-	3.0	-	13.9	-23.9	-9.8	-	-	19.0	223.6	-4.9	488.6
C-5 RERP	2000	-	-521.0	-	166.8	-	-52.3	-3,906.4	-274.2	-	-	-599.3	360.7	-4,505.7	-320.0
F-22	2005	-	348.2	-	-	-	-	-645.6	1,587.3	-	-	-10.2	774.6	-655.8	2,710.1
FAB-T	2002	33.6	33.6	-	-	-	-	243.9	243.9	-	-	42.9	42.9	320.4	320.4
GBS	1997	7.8	231.2	8.0	35.8	7.9	85.8	-63.8	-84.7	-	-	0.1	7.5	-40.0	275.6
GLOBAL HAWK (RQ-4A/B)	2000	-	-321.6	-1.2	-528.9	62.9	3 052.4	-136.5	971.0	-	-	21.7	578.7	-53.1	3 751.6
JASSM	1995	-	-230.9	-	-20.8	-97.5	10.8	249.5	686.5		-	17.0	4.1	169.0	449.7
JDAM	1995	-46.5	1,225.2	-	-	-	12.5	27.7	801.1	-	-	-8.5	183.0	-27.3	2 221.8
JPATS	2002	-	-58.5	-	10.4	178.2	344.5	-200.6	141.5	-	-	24.8	-52.4	2.4	385.5
MINUTEMAN III GRP	1993	-	-34.1	-	0.4	-	-	-15.8	116.5	-	-	-1.4	0.1	-17.2	82.9
MINUTEMAN III PRP	1994	-	-10.4	-	-26.9	-	21.3	-25.4	93.1	-	-	-4.1	25.9	-29.5	103.0
MP RTIP	2000	-	-	-	129.4	-	-289.7	-11.2	-174.3	-	-	-	-	-11.2	-334.6
MPS	2004	-	-	-	-15.5	-	6.0	3.4	-139.1	-	-	-	-3.6	3.4	-152.2
NAS	2005	-	-15.1	-	11.6	-	-	30.4	39.3	-	-	-3.5	14.5	26.9	50.3
NAVSTAR GPS - SPACE & CONTROL	2000	-	20.0	-	-	-	391.9	-30.0	330.2	-	-	-1.6	205.4	-31.6	947.5
NAVSTAR GPS - USER EQUIPMENT	2000	-	-	-	-	-	251.6	562.7	739.4	-	-	-1.1	1.8	561.6	992.8
NPOESS	2002	-	-432.2	-	682.2	2.8	-677.1	15.4	4,252.1	-	-	-	-	18.2	3,825.0
SBIRS HIGH	1995	604.4	-244.2	-	301.5	1.6	453.8	625.4	5 265.4	-	-	4.4	102.7	1 235.8	5,879.2
SDB I	2001	-	-	-	-	-	-	1.9	-273.8	-	-	0.8	-0.2	-1.1	-274.0
WGS	2001	-	560.5	-	-	-	59.7	6.4	182.1	-	-	-	-18.3	6.4	784.0
Subtotal		3 251.9	4,807.2	223.9	3 865.4	145.2	5 158.0	-2 658.5	30 428.4	-	411.0	-394.3	7 451.4	568.2	52 121.4
DoD:															
BMDS	2002	-	-	-	-1 417.0	-	47,553.5	-337.9	-1 478.3	-	-	-	-	-337.9	44 658.2
CHEM DEMIL-ACWA	1994	-	-	-	-175.1	-	-	81.3	3 716.5	-	-	-	-	81.3	3 541.4
CHEM DEMIL-CMA	1994	-	-	-	8 011.5	-	-	-695.3	2 926.5		7.6	-	-	-695.3	10 945.6
DIMHRS	2007	-	-	-	-	-	-	15.6	15.6	-	-	0.2	-112.9	15.8	-97.3
F-35 (JSF)	2002	-	-16,249.1	-	8 797.1	-	9 686.7	11 888.9	30,737.5	-	-	-11,276.0	-57.7	612.9	32,914.5
JTRS GMR	2002	-1,468.6	-1,865.7	0.1	364.4	-	-72.7	1,955.7	1 306.0	-	-	244.8	73.9	732.0	-194.1
JTRS HMS	2004	-3 902.6	-3,902.6	-	-	-	-	-1 520.6	-1,367.0	-	-	-627.6	-627.6	-6,050.8	-5,897.2
JTRS NED	2002	-	-	-	-	-	648.1	-91.3	282.2	-	-	-	-	-91.3	930.3
MIDS	2003	112.2	224.1	-0.2	-0.2	48.5	267.0	-2.5	-5.3	-	-	-18.7	-21.3	139.3	464.3
Subtotal		-5,259.0	-21,793.3	-0.1	15,580.7	48.5	58,082.6	11 293.9	36,133.7	-	7.6	-11,677.3	-745.6	-5 594.0	87,265.7
Grand Total		-4 982.6	-2,651.0	406.1	32,800.2	1 652.0	91 989.3	10 421.8	109 094.7	620.6	2 200.3	-13,090.5	18 990.6	-4,972.6	252 424.1

Program Funding Status (Then Year Dollars in Millions)

As Of December 31, 2007

Program	Prior Years	FY 2008	FY 2009	Balance of Program	Total
Grand Total	**625,118.8**	**76,919.9**	**74,210.1**	**866,724.7**	**1,642,973.5**
Army Subtotal:	**76,035.6**	**16,259.6**	**12,712.3**	**243,659.0**	**348,666.5**
APACHE BLOCK III (AB3)	280 0	192 5	209 5	8,314 4	8,996 4
ARH	355 7	365 2	583 6	5,032 2	6,336 7
ATIRCM/CMWS	2,063 0	479 9	454 8	1,818 2	4,815 9
BLACK HAWK UPGRADE	2,310 4	1,444 5	1,095 3	19,192 5	24,042 7
BRADLEY UPGRADE	6,788 2	831 0	195 1	1,880 9	9,695 2
CH-47F	3,599 7	1,025 4	972 9	7,752 3	13,350 3
EXCALIBUR	819 8	92 8	112 4	1,440 1	2,465 1
FBCB2	2,278 2	303 3	295 6	494 0	3,371 1
FCS	11,391 6	3,374 6	3,316 2	141,237 8	159,320 2
FMTV	9,579 3	1,992 6	946 6	8,157 9	20,676 4
GMLRS	1,063 2	246 4	299 1	4,399 6	6,008 3
HIMARS	1,010 7	241 0	261 8	535 5	2,049 0
JAVELIN	4,356 9	166 8	259 3	141 0	4,924 0
JLENS	337 7	478 2	356 4	6,328 0	7,500 3
LONGBOW APACHE	9,343 1	813 9	653 8	372 2	11,183 0
LUH	242 2	228 9	224 5	1,394 6	2,090 2
PATRIOT PAC-3	7,538 1	469 7	496 1	21 0	8,524 9
PATRIOT/MEADS CAP	1,085 4	369 8	462 3	27,977 7	29,895 2
FIRE UNIT	694 9	316 3	431 3	20,337 2	21,779 7
MISSILE	390 5	53 5	31 0	7,640 5	8 115 5
STRYKER	9,565 7	1,337 9	1,231 4	3,556 1	15,691 1
WIN-T INCREMENT 1	2,018 5	1,694 4	21 9	124 9	3,859 7
WIN-T INCREMENT 2	8 2	110 8	263 7	3,488 1	3,870 8
Navy Subtotal:	**270,724.5**	**29,538.5**	**30,123.2**	**241,454.9**	**571,841.1**
ADS (AN/WQR-3)	527 6	1 2	-	-	528 8
AGM-88E AARGM	536 5	78 9	58 7	1,036 0	1,710 1
AIM-9X	1,144 7	120 7	149 6	1,980 5	3,395 5
CEC	3,084 3	117 0	123 3	1,205 9	4,530 5
CH-53K	698 8	388 4	570 5	17,050 6	18,708 3
COBRA JUDY	902 1	267 8	237 2	222 4	1,629 5
CVN 21	6,143 9	3,037 5	4,188 0	21,749 7	35,119 1
CVN 68	5,820 3	369 2	69 3	-	6,258 8
DDG 1000	9,983 3	3,399 6	3,002 9	12,500 9	28 886 7
DDG 51	62,161 4	187 2	143 0	264 7	62,756 3
E-2D AHE	2,127 6	843 9	1,110 2	13,349 4	17,431 1
EA-18G	2,485 2	1,695 5	1,804 3	2,664 1	8,649 1
EFV	2,282 8	246 0	313 7	13,017 7	15,860 2
ERM	339 6	29 8	38 8	1,113 2	1,521 4
F/A-18E/F	37,170 4	2,106 4	1,920 2	5,147 8	46,344 8
H-1 UPGRADES (4BW/4BN)	2 811 4	465 5	504 7	4,945 9	8,727 5
JSOW	2,450 3	159 7	171 8	1,804 9	4,586 7
BASELINE/BLU-108	1,659 9	-	-	201 7	1,861 6
UNITARY	790 4	159 7	171 8	1,603 2	2,725 1
LCS	1,894 2	304 1	336 0	314 3	2,848 6
LHA REPLACEMENT	1,795 6	1,371 6	16 7	184 0	3,367 9
LPD 17	12,150 8	1,590 8	207 0	293 1	14,241 7
MH-60R	4,142 6	1,068 8	1,260 3	5,667 7	12,139 4
MH-60S	3,922 2	546 6	599 0	2,775 2	7,843 0
MUOS	1,720 8	812 6	1,023 3	3,125 0	6 681 7

Program Funding Status (Then Year Dollars in Millions)

As Of December 31, 2007

Program	Prior Years	FY 2008	FY 2009	Balance of Program	Total
NMT	292 8	101 6	117 3	1,591 6	2,103 3
P-8A (MMA)	2,688 5	862 3	1,290 8	28,011 3	32,852 9
RMS	482 7	23 0	54 4	989 6	1,549 7
SM-6	374 1	172 4	321 5	5,086 4	5,954 4
SSDS	104 9	42 5	69 4	452 1	668 9
SSGN	3,956 9	147 9	2 5	1 2	4,108 5
SSN 774 (VIRGINIA CLASS)	28 291 4	3,553 9	3,813 6	56,306 3	91,965 2
T-45TS	6,795 9	32 3	-	-	6,828 2
TACTICAL TOMAHAWK	2,447 5	380 5	281 1	1,266 2	4,375 3
T-AKE	4,034 0	604 7	998 7	77 8	5,715 2
TRIDENT II MISSILE	29,129 1	1,073 4	1,093 2	7,521 7	38,817 4
V-22	22,876 0	3,038 5	3,112 5	25,199 9	54,226 9
VH-71	2,434 7	225 4	1,047 8	3,042 3	6,750 2
VTUAV	519 6	71 3	71 9	1,495 5	2,158 3
Air Force Subtotal:	**179,589.4**	**12,839.3**	**12,579.3**	**51,231.5**	**256,239.5**
AEHF	5,194 2	733 3	404 6	1,029 9	7,362 0
AMRAAM	10,109 9	316 5	505 1	3,949 1	14,880 6
B-2 EHF INCREMENT 1	120 9	77 1	103 6	379 4	681 0
B-2 RMP	474 9	263 1	383 5	103 9	1,225 4
C-130 AMP	1,199 0	275 1	321 7	4,004 4	5,800 2
C-130J	6,713 9	816 2	208 4	4,290 8	12,029 3
C-17A	59,403 9	483 5	615 5	1,803 8	62,306 7
C-5 AMP	833 2	124 6	104 4	343 1	1,405 3
C-5 RERP	1,326 8	366 3	561 8	8,876 0	11,130 9
F-22	54,146 1	4,278 7	3,998 8	2,116 3	64,539 9
FAB-T	767 2	240 2	183 2	2,431 6	3,622 2
GBS	647 7	44 0	88 7	25 1	805 5
GLOBAL HAWK (RQ-4A/B)	3,789 3	882 1	1,100 7	3,968 6	9,740 7
JASSM	1,677 3	172 0	253 3	3,963 2	6,065 8
JDAM	4,561 7	150 4	115 0	433 0	5,260 1
JPATS	2,973 0	575 7	375 2	1,610 4	5,534 3
MINUTEMAN III GRP	2,424 6	1 9	1 2	-	2,427 7
MINUTEMAN III PRP	2,290 1	249 1	62 6	-	2,601 8
MP RTIP	1,144 1	38 7	42 2	-	1,225 0
MPS	543 6	168 7	161 5	708 7	1,582 5
NAS	839 1	98 9	98 3	454 4	1,490 7
NAVSTAR GPS	6,186 3	491 5	342 7	1,379 3	8,399 8
SPACE & CONTROL	5,259 2	328 6	204 9	513 4	6,306 1
USER EQUIPMENT	927 1	162 9	137 8	865 9	2,093 7
NPOESS	3,774 1	663 5	577 5	6,125 1	11,140 2
SBIRS HIGH	6,430 9	911 3	1,814 1	2,398 2	11,554 5
SDB I	563 7	94 6	133 2	685 4	1,476 9
WGS	1,453 9	322 3	22 5	151 8	1 950 5
DoD Subtotal:	**98,769.3**	**18,282.5**	**18,795.3**	**330,379.3**	**466,226.4**
BMDS	46,614 8	8,655 3	9,335 7	38,306 6	102,912 4
CHEM DEMIL-ACWA	1,414 8	407 1	397 5	5,772 5	7 991 9
CHEM DEMIL-CMA	15,810 0	1,209 8	1,222 5	9,180 3	27,422 6
DIMHRS	651 3	104 2	63 4	-	818 9
F-35 (JSF)	30,271 9	7 086 0	7,094 2	254,390 7	298,842 8
JTRS GMR	774 4	231 6	196 3	19,334 1	20,536 4
JTRS HMS	375 4	168 4	167 9	2,655 2	3 366 9
JTRS NED	906 4	248 6	242 3	564 5	1,961 8
MIDS	1,950 3	171 5	75 5	175 4	2,372 7