

COST GROWTH IN WEAPON SYSTEM ACQUISITION

by

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Abstract

This paper offers a review of the literature on cost growth in the acquisition of weapon systems. A brief history of cost growth analysis is presented, followed by quantitative considerations in measuring cost growth. An examination of the empirical literature on cost growth reveals that costs of major weapon systems have consistently been underestimated. The paper also looks at the literature on incentive models and transaction cost economics for root causes of cost growth.

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1. Introduction

On July 16, 2010, the Canadian federal government announced its decision to acquire a fleet of sixty-five F-35 Lightning II Joint Strike Fighter aircrafts for an estimated \$9 billion. Subsequent maintenance and support costs would bring total program costs to an estimated \$16 billion. On March 10, 2011, the Parliamentary Budget Office questioned the government's cost estimate. In a published report, the PBO placed estimated total program costs at a significantly higher \$29 billion. On April 5, 2011, the Globe and Mail reported an expert with the Washington-based Center for Defense Information calling the PBO's estimate "hogwash". The newspaper quoted: 'It's going to be significantly more. It's not going to be \$1 billion more; it's going to be significantly more.'

A cost estimate is a forecast or prediction of actual cost. The difference between estimated cost and actual cost is called cost growth. As the above anecdote demonstrated, cost growth in the acquisition of technologically advanced weapon systems has gradually percolated into public consciousness over the past few decades. The defence acquisition process is shrouded in layers of management, regulations and approvals. Popular perception attributes cost growth in weapons systems to inefficiencies in, and mismanagement of, the acquisition process.

Contrary to public perception, cost growth in weapon systems is a legitimate economics phenomenon that is well-documented in academic and government research literature. The purpose of this paper is to survey the existing literature on cost growth. While this paper is not

intended to be American-centric, the body of literature presented relies heavily on observations and documentations of cost growth within the American acquisition system. According to Rogerson (1995), the cost growth problem in weapon acquisitions as well as procurement systems for weapons are very similar across most Western countries. Therefore, it is presumed that the conclusions drawn from the American experience have more general applications beyond the confines of the American system.

The remainder of the paper is organized into six sections. The second section provides the context for subsequent sections by discussing the importance of cost estimation to proper financial planning in defence. The third section presents a brief history of cost growth analysis. The focus is on developments in acquisition policy that allowed cost growth analysis to emerge as a field of study. A reliable source of data is critical to empirical analysis. The studies surveyed for this paper unanimously used the Department of Defense's Selected Acquisition Reports as the data source. The fourth section introduces the elements of Selected Acquisition Reports that are crucial to cost growth analysis. While the focus of this paper is not on policy, such discussions cannot be avoided as policy ultimately governs the acquisition process. Calculating cost growth is conceptually straightforward, but determining what it measures is more complex. Researchers often adjust cost estimates depending on the objective of the analysis. The fifth section discusses the nuances of cost growth measurement and reviews methodologies for cost growth calculations. The sixth section presents findings of empirical studies on weapons cost growth. These findings show that cost growth in weapons acquisition has persisted for decades despite efforts to measure, characterize and understand its causes. This section also presents factors that have been found to have strong correlations with cost growth.

The seventh section presents proposed explanations for weapons cost growth. The theoretical foundations of the explanations draw from literature on both incentive models and transaction cost economics. Since this paper is being presented to a Canadian academic institution, the inclusion of Canadian content would have been ideal. However, an attempt to examine the Canadian experience with weapons cost growth proved futile. This paper concludes with remarks on possible reasons why the existing literature on cost growth lacks Canadian content and on the need for such analysis in Canada.

2. Background

The fundamental tenet of economics is that resources are scarce. Defence budgets are likewise limited. Defence departments engage in extensive procurement activities to satisfy the capability requirements of their armed forces. It is their responsibility to ensure that limited resources are efficiently allocated amongst competing demands for the defence budget.

Weapon systems provide the armed forces with capability and enable them to conduct operations. Acquiring them requires significant time and resources. Investment decisions in weapon systems are made many years in advance of delivery of the product. These decisions require cost-benefit analysis, of which reliable cost forecasts are a vital part. A cost estimate is a forecast of future cost. Cost growth reflects the accuracy of the estimate and, by extension, the quality of the estimation system as well as the performance of the estimator in executing that system.

Consistent overestimation or underestimation of cost indicates that a bias exists in the system. Drezner et al. (1993) suggested that it is unrealistic to expect precise accuracy in a cost estimate for a technologically advanced weapon system, especially early in planning and development stages where capability requirements are still evolving. Instead, the desired objective of an estimation system is to have an unbiased estimate with expected cost growth of zero and narrowing band of error over time. Arena et al. (2006) suggested that a sound estimation system should be neutral with respect to cost growth, in which case cost growth across many programs should be dispersed around zero.

A systemic estimation bias exacerbates cost overruns and underruns, which, in turn, lead to poor financial planning and undermine the credibility of cost estimates. Arena et al. (2006) noted that overestimating costs may cause the elimination of lower-priority programs that otherwise could have been included in a given budget. In addition, overestimation often leads to a practice called “gold plating”, where excess funds are expended on capability that is neither planned nor required. Underestimating cost, on the other hand, creates unanticipated budget pressures in the future. Melese et al. (2007) noted that two often used solutions for mitigating such pressures are either to reduce quantity delivered or to reprogram funds from other programs. Both solutions, however, ultimately undermine the overall readiness of the armed forces.

3. The Emergence of Cost Growth Analysis

Empirical research on cost growth in weapons acquisition first emerged early during the Cold War era. According to Melese et al. (2007), the pioneering study was conducted in 1959 by A.W. Marshall and W.H. Meckling, of the RAND Corporation, for the United States Air Force. At that time, and then throughout most of the 1960s, weapon system acquisition was largely seen as a predictable event. The underlying assumption behind acquisition policies was that choices between technical alternatives can be made based on simulations and paper studies. Management of acquisition activities was centralized within the Office of the Secretary of Defense, which attempted to plan each program in detail. It was assumed that, once planning decisions are made, development and production would proceed accordingly.

In the early 1970s, a number of programs procured through long-term fixed-price contracts, referred to at the time as the total package approach, incurred significant cost overruns and contractors had to be bailed out. A different view emerged that recognized the uncertainties involved in the acquisition process. Subsequent changes to acquisition policy included using a phased process where development was to be substantially completed before a production decision was made, replacing paper tests and simulations with hardware tests and prototyping in selecting technical alternatives, and delegating management responsibilities and authorities from central management to professional managers. As the policy environment was evolving, the groundwork was being laid for future cost growth analysis. In 1968, a reporting system called Selected Acquisition Reports (SAR) was established to centralize cost, schedule and

performance data on major programs within the Department of Defense (DoD).¹ Hough (1992) noted that no previous such system existed.

A source of reliable data is crucial for empirical studies, and the integrity of data was an issue in pre-SAR studies. Marshall and Meckling (1959) implied that their data did not come from a centralized source and remarked that some of it was “particularly messy”. They noted that a considerable degree of judgment was required in preparing the data prior to calculating cost growth. Two of their biggest challenges were finding a consistent baseline estimate across all programs and determining what the estimator had included in the cost estimates.

Approximately a decade after the SAR system was established, cost growth studies began being conducted on a more frequent basis. Weapon system acquisition and policy change are both slow-moving processes. It presumably took time for an adequate amount of data to accumulate and for the system to gain recognition and acceptance as a credible source of data. The impact of SARs on cost growth analysis is palpable. Studies became progressively more comprehensive, deeper in scope, and with larger samples. Hough (1992) noted that, while a number of pitfalls exist in using SAR data for cost growth analysis, it provides nonetheless the best source of data because it is the most consistent and official record of program management available. Accordingly, most studies presented in this survey used SARs for cost data.

¹ The overhaul in acquisition policy was collectively known as the Packard Initiatives, named after David Packard who was a co-founder of Hewlett-Packard and who served as U.S. Deputy Secretary of Defense from 1969 to 1971. However, according to Tyson et al. (1989), Robert MacNamara, the outgoing Secretary of Defense, was credited with establishing the Selected Acquisition Reporting system.

4. Data Source

According to Hough (1992), SAR is a legally mandated summary report of major defence acquisition programs. It is submitted annually to Congress in conjunction with the President's Budget. Quarterly reports are required for programs experiencing unit cost increases of fifteen percent or higher or schedule delays of six months or longer.² The report consists of nineteen sections of cost, schedule and technical information, in a standardized format, for each program. Of particular relevance to cost growth analysis are the two sections titled Program Acquisition Cost and Cost Variance Analysis.

The Program Acquisition Cost section contains estimated program costs and quantity from inception to completion regardless of the stage of development. In addition to the most current estimates, the section also contains previous milestone estimates. A milestone is a point in the acquisition process at which the program requires approval in order to proceed. The five major milestones in the acquisition process are concept studies, concept demonstration, development, production, and major modification. According to Hough (1992), only the concept demonstration, development, and production milestones are relevant to cost growth analysis. These milestone estimates figure prominently into the process of adjusting cost growth to reflect changes in quantity.

The Cost Variance section records changes in program costs. Changes between current estimate milestone estimates are attributed to one of seven variance categories: economic, quantity,

² U.S. Department of Defense news release (March 30, 2012), <http://www.defense.gov/Releases/Release.aspx?ReleaseID=15146>

schedule, engineering, estimating, other, and support. Like milestone estimates, cost variance is also an important consideration in adjusting cost growth. Both of these elements are discussed in section 5.2.

5. Measuring Cost Growth

Before proceeding, it is prudent to define some terms that are fundamental to cost growth measurement. The U.S. Defense Acquisition University (DAU) defines “procurement” as “the act of buying goods and services for the government”³, and “acquisition” as “the conceptualization, initiation, design, development, test, contracting, production, deployment, logistic support, modification, and disposal of weapons and other systems, supplies, or services to satisfy DoD needs, intended for use in, or in support of, military missions”.⁴ In the body of literature surveyed for this paper, the two terms were often used in similar contexts. The distinction between these two terms represents the “make or buy” decision that defence departments must confront with respect to weapon systems. For security and political reasons, the majority of major weapon systems are “made” rather than “bought”. Acquisition, therefore, better describes the process through which weapons systems are acquired.

The process to acquire a weapon system has been alternatively referred to as “projects” and “programs”. The DAU recognized that “project” is “synonymous with ‘program’ in general usage”.⁵ It defines a program as a “defined effort funded by research, development, test and evaluation and/or procurement appropriations with the express objective of providing a new or improved capability in response to a stated mission need or deficiency”.⁶ A project, meanwhile, is defined as a “planned undertaking having a finite beginning and ending, involving definition, development, production and logistics support of a major weapon or weapon support system or

³ Glossary of Defense Acquisition Acronyms & Terms (DAU, 2005), p. B-124.

⁴ Ibid., p. B-1.

⁵ Ibid., p. B-133.

⁶ Ibid., p. B-129.

systems”.⁷ The distinction between the two, therefore, is their intended objective. A program may involve multiple programs as it may require multiple weapon systems to fulfill a particular capability requirement. This survey found that most studies use “program” to refer to the weapons acquisition process. Therefore, it will be used throughout this paper in order to be consistent with the surveyed literature.

The three defining quantitative outcomes of a weapon acquisition program are cost, quantity and schedule. Quantity refers to the quantity acquired at a given cost. Like cost estimates, planned quantity may be revised numerous times over the course of a program. Schedule refers to the length of time required from development to production and then delivery of the product. Quantity and schedule are both prominent considerations in determining how cost growth is measured. It should be noted that, like cost growth, time growth in weapons acquisition has also been a topic subject to much scrutiny. While many studies surveyed in this paper examined both cost and time growth, the focus of this paper is on cost growth. Schedule-related issues are discussed only as contributing factors to cost growth.

In the most precise terms, cost growth is defined as the difference between estimated and actual costs. In cases where the program is ongoing and the actual cost is not available, the most current cost estimate is used in place of the actual cost to calculate cost growth. Hough (1992) and Drezner et al. (1993) noted that multiple measures of cost growth are possible for the same data set. For example, a program may come in on budget but acquire only half the originally-planned quantity. This program incurs zero nominal cost growth despite obvious underperformance with respect to quantity acquired. This simple example reflects the two

⁷ Ibid., p. B-133.

popular measures of cost growth: unadjusted and adjusted. The unadjusted approach measures cost growth in nominal terms without regard to the sources that caused the growth. The adjusted approach, on the other hand, removes the effects on cost growth from some factors. These adjustments are applied to the cost data before cost growth is calculated.

The two approaches serve very different purposes. Unadjusted growth is used to assess high-level budgetary impact. According to Hough (1992), it is the favoured approach by the United States Government Accountability Office and the U.S. Congressional Budget Office for illustrating the aggregate impact of cost growth, across all programs, on the defence budget regardless of the conditions responsible for the growth. Adjusted growth, on the other hand, is useful for assessing the quality of cost estimates by isolating factors that affect cost growth and normalizing those factors that cannot reasonably be attributed to cost estimation error and, therefore, beyond the estimator's control. Some of these factors can be quantified and normalized more easily than others. Drezner et al. (1993) noted that some of the more difficult factors to quantify include changes to schedule, production rate, scope, configuration, and degraded performance.

The two factors that researchers most commonly adjust for are inflation and quantity change. Several studies [Marshall and Meckling (1962), Hough (1992), Drezner et al. (1993), Bolten et al. (2008)] showed that both factors have significant impact on cost growth. While there is consensus that inflation is beyond the estimator's control, the same cannot be said for quantity change. Hough (1992) noted that conflicting views exist among researchers regarding whether its effects should be normalized in measuring cost growth. Some argue that changes in quantity

result from failure to adequately estimate requirements, which is within the estimator's control. Others feel that quantity represents capability requirements and should be exogenous to the estimation system for cost, much like the manner in which quantity produced is exogenous to the cost function. However, despite the lack of consensus, most studies surveyed in this paper adjust for quantity change.

5.1 Adjusting for Inflation

Inflation adjustment follows the standard economic practice of using inflation factors to bring cost estimates to constant-year terms. While the arithmetic is fairly simple, there are issues regarding the fidelity of inflation factors used in the calculation.

Most studies surveyed in this paper used defence-specific inflation factors to bring cost estimates to constant-year terms. Hough (1992) asserted that inflation adjustment for cost growth cannot be precise because defence-specific inflation factors are politically constrained and not program specific. As a result, they do not fully capture actual price levels changes in the economy, which is what programs must face. This, in turn, introduces an inherent element of error to cost growth calculated with constant-year cost data.

5.2 Adjusting for Quantity Change

While adjusting for inflation is relatively straightforward, adjusting for quantity change is more challenging and requires a greater degree of discretion, which is exercised while making three choices: selection of a baseline estimate, selection of a normalization quantity, and selection of a normalization method.

5.2.1 Selecting a Baseline

Cost growth, as a relative measure, requires a point of reference from which to begin counting. This point is referred to as the baseline. Hough (1992) noted that selecting the proper baseline is a crucial component of cost growth analysis regardless of whether or not one adjusts for inflation and quantity.

In general, the three phases of a weapons acquisition program are planning, development and production.⁸ Programs proceed through these phases in chronological order as listed. Acquisition policy and guidelines require that cost and quantity estimates be made for approval as the program enters each phase. The baseline estimate is often selected from these estimates.⁹

In theory, cost estimates should improve over time as requirements stabilize and better-quality data become available. The integrity of the information on which the baseline estimate is based is an important consideration in its selection. Hough (1992) noted that, while the planning estimate is widely considered to be the initial estimate of a program, the development estimate is the most frequently used baseline. Arena et al. (2006) noted that the development estimate is considered a major milestone because acquisition strategies are often determined at that point.

⁸ To align this statement with the discussion in section 4, the planning phase includes the concept studies and concept demonstration milestones. Within the Canadian Department of National Defence, the planning phase is commonly referred to as “options analysis” while the development and production phases remain the same.

⁹ It should be noted that cost estimates can also be made prior to the planning phase and as well as over the course of each phase, not just at the beginning. The estimates made at the beginning of each phase, however, are required by policy and often require expenditure approval, which ensures a consistency of record across programs.

5.2.2 Selecting a Normalization Quantity

Cost growth measures the difference between two cost estimates. The baseline estimate is the earlier of the two estimates while the more up-to-date estimate is referred to as the current estimate. The quantities associated with both are referred to as the baseline quantity and the current quantity, respectively.

The second decision in the normalization process is whether to normalize the baseline estimate to the current quantity or to normalize the current estimate to the baseline quantity. Hough (1992) and Drezner et al. (1993) noted that this decision does have an impact on the resulting cost growth. The impact is usually not significant but becomes material if the change in quantity is large. Drezner et al. further noted that normalizing to the current quantity produces a floating baseline, which may lead to inconsistencies in future cost growth calculations. Hough demonstrated that these inconsistencies arise when a cost-quantity curve is used to adjust for quantity-induced cost variances. In such cases, normalizing to the baseline quantity is preferred over normalizing to the current quantity because it provides a constant point of reference for measuring growth.

5.2.3 Selecting a Normalization Method

Once the normalization quantity is selected, the cost data is adjusted by adding or removing the cost variance associated with the change in quantity. Hough (1992) proposed three methods for this process. The choice of method, however, has an impact on cost growth. Hough noted that, conceptually, methods two and three result in larger adjustments than method one and, therefore, should yield lower growth. He confirmed this by applying each of the three methods to a sample

of 22 weapon programs. Method one yielded a growth factor of 1.50 while methods two and three yielded 1.38 and 1.28, respectively.

The first method, which is the easiest and most straightforward, is using the quantity variance reported in the SAR. However, this method tends to understate quantity-related cost variance. Hough noted that cost variances that are the result of quantity change but are not directly related to the end item are not reported under the “quantity” category. For example, an increase in the number of aircraft delivered would lead to a corresponding increase in the number of spare parts. SAR guidelines, however, require that the increase in spares to be reported under the “support” category. Hough noted that cost variances indirectly related to quantity can also be reported under the schedule, engineering and estimating categories.

The second method is using a cost-quantity curve. Hough noted that, to properly apply this method, a curve needs to be established for each cost estimated. If the choice is to normalize the baseline estimate to the current quantity, then the appropriate curve to use is the one estimated when the baseline estimate was established. Conversely, if the choice is to normalize the current estimate to the baseline quantity, then the curve corresponding to the current estimate should be used. Establishing the shape of the cost function and estimating function parameters is a data-intensive process. Moreover, adequate data may or may not exist. Therefore, while this method more fully captures quantity-induced cost variance than the first, it is also more difficult to apply successfully and requires significantly more effort and analysis.

Dew et al. (1979) noted that, for computational purposes, the seven SAR cost variance categories fall under four basic types: quantity, recurring cost-per-unit, cost-quantity curve slope, and nonrecurring. Dew et al. demonstrated conceptually how the aggregate effect of these four types of changes can lead to the shift of the cost-quantity curve from the baseline estimate to the current estimate.

The third method is a hybrid of the first two. It first requires that quantity-induced cost variance, as reported in method one, be subtracted from total cost variance to produce a net variance. The net variance is then normalized to the baseline quantity or the current quantity using the cost-quantity curve described in method two.

5.2.4 Normalizing for Quantity Change in Practice

This survey found significant disparities in researchers' preferences for normalization quantity and normalization method. Tyson et al. (1989) chose to normalize to the initially planned quantity and used cost-quantity curves to adjust cost. Drezner et al (1993), too, chose to normalize to the initial planned quantity but used method three to adjust cost. Arena et al. (2006) chose to use a cost-quantity curve but normalized to the final quantity acquired rather than the quantity of a particular baseline estimate. They recognized that their choice to normalize to the final quantity differed from most studies but justified it using two reasons. The first is that the actual cost should be the only value that matters and, therefore, left unmodified. The second is that normalizing to the final quantity reduces the relative importance of the cost variance to cost growth. Furthermore, they also explored the impact of differences in normalization methods on final results and found that it is not substantial.

Hough (1992) noted that various segments of the research community preferred different methods for normalizing quantity change. At the time of his study, the U.S. Government Accountability Office and the Congressional Budget Office preferred the first method, the Institute for Defense Analyses the second, and RAND the third. Arena et al. (2006) noted that RAND adopted the second method in 1998.

5.3 Calculating Cost Growth

After adjusting for inflation and normalizing for quantity change, a metric for cost growth can be calculated by taking the ratio of the current cost estimate to the baseline estimate. This is a strictly positive value. Values greater than 1 represent cost overruns while values less than 1 represent cost underruns. This is commonly referred to in research literature as cost growth factor (CGF).

Alternatively, subtracting 1 from the cost growth factor yields cost growth as a percentage increase from the earlier cost estimate. In this case, positive values indicate cost overruns while negative values indicate cost underruns.

The majority of the studies surveyed in this paper present cost growth as CGF rather than percentage increase. The difference between CGF and percentage increase is merely a matter of presentation as they are mathematically equivalent. For consistency, the results of all empirical studies discussed in the next section will be presented as adjusted CGF.

CGFs, rather than dollar values, are used when comparing or aggregating cost growth over several programs. When doing so, the baseline has to be aligned across all programs for the comparison or aggregation to be meaningful.

6. Empirical Evidence of Cost Growth

Overall, the studies surveyed found that costs of weapon systems are generally underestimated. As previously stated, all CGFs presented in this section have been adjusted for inflation and quantity change.

In their pioneering study, Marshall and Meckling (1959) reported an average CGF of 1.8, with a minimum of 0.6 and a maximum of 14.7, for a sample of 22 air force programs. An unpublished RAND study, also conducted in 1959, reported average CGF of 3.23 for a sample of 24 air force programs.¹⁰ Peck and Scherer (1962) reported an average CGF of 3.2, with a minimum of 0.7 and a maximum of 7.0, for a sample of 12 aircraft and missile programs.

Moving into the SAR era, Dews et al. (1979) computed cost growth for a sample of 31 army, navy and air force programs. The authors used the development estimate as the baseline and normalized to the development quantity using the third method described in section four. The reported average CGF for the sample was 1.20, with a minimum 0.78 and a maximum of 2.12.

Tyson et al. (1989) examined cost and schedule growth trends in a sample of 89 army, navy and air force programs. The authors also used the development estimate as the baseline but normalized to the development quantity using the second method. The reported average CGF for the sample was 1.51, ranging from a minimum of 0.76 to a maximum of 5.19.

¹⁰ Arena et al. (2006), p. 9.

Hough (1992) conducted a comparative analysis of accepted quantity normalization methods using a sample of 22 weapon programs and reported average CGFs of 1.28, 1.38 and 1.50 depending on the method used.

Drezner et al. (1993) sought to identify the magnitude of cost growth and search for trends and patterns in a sample of army, navy and air forces programs. The authors used the development estimate as the baseline and normalized to the development quantity using the third method. The reported average cost growth was 1.20.

Tyson et al. (1994) sought to quantify cost growth and identify trends and patterns in growth in tactical aircrafts and tactical missiles. The authors used the development estimate as the baseline and normalized to the development quantity using the second method. The reported average CGFs were of 1.20 for a sample of 7 aircraft programs and 1.54 for a sample of 20 missile programs.

Arena et al. (2006) examined cost growth from development and production for a sample of 46 completed programs. By necessity, the authors used development and production estimates as baselines but for both cases normalized to the final quantity using the second method. They reported an average CGF of 1.46 from development estimate and 1.16 from production estimate. This study is one of the few that deviated from the pattern of normalizing to the baseline quantity. Arena et al. justified their approach by arguing that the final realized cost is more important than estimated cost and, therefore, should be left unmodified.

The impact of the SAR system on empirical work is significant. A readily available pool of data led to larger and more varied samples, which enabled researchers to examine differences in cost growth across various sample characteristics. The most commonly examined characteristics are time period, equipment type, program size, and program phase. The expected results and reported findings are discussed below.

6.1 Time Period

Several studies sought to determine whether cost estimates have improved over time. The expectation is that changes in policy and lessons learned from previous experiences would have led to improvements in cost estimation. The empirical evidence, however, does not conclusively support that expectation.

Dews et al. (1979) compared acquisition experiences in the 1960s and the 1970s and found that programs initiated in the 1970s generally exhibited lower cost growth than those initiated in the 1960s. While the authors contend that policy change is the main contributor, they also acknowledge effects from other factors such as differences between the two samples in program maturity and technical content.

Tyson et al. (1989) calculated average development growth, average production growth, and average total program growth for the 1960s, early 1970s, late 1970s, and the 1980s based on the start of the development phase. The results are summarized in Table 1 below. They found that all three measures were highest in the 1960s, decreased significantly in the early 1970s, but rebounded in the late 1970s. Programs in the 1980s showed lower development growth than

earlier programs but were too recent for production growth and total program growth to be conclusive.

Table 1: Cost Growth by Time Period, Tyson et al. (1989)

	Development Growth	Production Growth	Total Program Growth
1960s	1.36	1.89	1.66
Early 1970s	1.25	1.42	1.37
Late 1970s	1.28	1.73	1.58
1980s	1.16	0.91	0.92

Tyson et al. also cited the stage of program completion as a factor, arguing that it may take time for cost estimates to be revised as problems arise in development and production. Additional factors cited to explain the time trend include broad policy changes in the early 1970s, high inflation and declining budgets in the late 1970s, and low inflation and expanding budgets in the 1980s.

Drezner et al. (1993) compiled average cost growth for each five-year interval, based on development start, from 1965 to the late 1980s and found that cost growth has remained fairly constant over time around 1.20. Like the two studies mentioned above, Drezner et al. also cited evidence that cost growth tends to accumulate as programs mature.

6.2 Weapon Type

Several studies reported that cost growths differ across weapon types. Marshall and Meckling (1959) found that missiles are more likely to record higher cost growth than fighters, bombers and cargoes and tankers. Tyson et al. (1989) found that tactical munitions programs recorded higher cost growth than aircrafts, satellites and strategic missiles. Drezner et al (1993) found that

vehicles recorded the highest average cost growth, followed by aircrafts, electronics, munitions and missiles. Tyson et al. (1994) found that the maximum CGF for tactical missiles was significantly higher than that for tactical aircrafts. At the other end of the scale, Marshall and Meckling and Drezner et al. both found that ships exhibit the least cost growth.

Even though there is heterogeneity across the three studies in the classification of weapon types, their results appear largely consistent with the exception of vehicles in the study by Drezner et al. The authors, however, acknowledged that small samples sizes could have skewed the results. Their findings are summarized in Table 2 below. Drezner et al. also noted that significant variations in sample sizes across weapon types make the results difficult to generalize.

Table 2: Cost Growth by Weapon Type, Drezner et al. (1993)

Weapon Type	Cost Growth Factor	Number of Observations
Vehicle	1.71	3
Aircraft	1.28	14
Electronic	1.24	27
Munition	1.22	7
Missile	1.17	44
Space	1.16	3
Helicopter	1.13	5
Ship	1.10	14
Other	0.99	3

The authors of the three studies all suggested that cost growth is a function of technological content. Weapons that are required to be at the cutting edge of technological innovation tend to exhibit high cost growth. These weapons, such as aircrafts and missiles, are most common amongst air force systems.

Tyson et al. proposed management attention as another factor for differences in cost growth. Less glamorous weapon systems such as munitions exhibit higher cost growth because they don't receive as much high-level management attention as needed.

6.3 Program Size

Drezner et al. (1993) examined cost growth across program sizes, where program size is measured by total constant baseline cost, and found that cost growth tends to be higher in smaller programs. They proposed that, because cost growth in a smaller program leads to a lower cost increase in dollar terms than the same growth would in a larger program, smaller programs are likely to receive less management and oversight attention because of their size. However, by the same token, cost growth in a smaller program is also more visible because of their size.

6.4 Program Phase

Dews et al. (1979) found that cost growth tends to increase as programs mature. In their sample of 31 programs, the 14 that have been in development for three years or less had yet to exhibit noticeable cost growth. The average CGF for the 14 programs is 1.03, compared to 1.34 for the 17 mature programs. Tyson et al. (1989) examined cost growth in development and production separately and found that development cost growth is lower than production cost growth. These are generally consistent with earlier findings that cost growth tends to accumulate as a program matures.

Tyson et al. cited schedule growth as a possible contributing factor to cost growth in both development and production. Another factor is that production requires a significantly longer

period of time than development, which makes it more susceptible to unanticipated events that drive up cost.

6.5 Other Characteristics

Drezner et al. (1993) examined cost growth across service lines. The three services of the armed forces are the army, the navy, and the air forces. Drezner et al. found that mean cost growth for army programs is the highest of the three services, followed by the air forces and then the navy. McNicol (2004) also found that army programs exhibit statistically significant higher cost growth than did air force and navy programs. Drezner et al. suggested that variations in cost growth across service line may be attributed to differences in weapon type and program size.

Tyson et al. (1989) compared cost growth in new start programs with modification programs. A modification program modifies an existing program in order to enhance existing capabilities or add new capabilities. They found that modification programs are more likely to exhibit lower cost growth. This result generally holds across, time period, weapon type and program phase. The only exceptions were modification programs for air-launched tactical munitions, which exhibited the highest average development CGF out of all types of systems examined. Modification of such weapons usually involves a new guidance and control system. While the sample size was small, Tyson et al. noted that the technical difficulties in system integration for such modifications are often underestimated.

Wolf (1990) examined the relationship between cost growth and the political and economic climates during the period of system development. The author found that economic conditions

had no statistically significant impact on growth and that Democratic congressional majorities are associated with increased cost growth. Both of these findings were contrary to expectations. Gross national product was used to measure economic growth. Wolf noted that the annual percentage change in GNP may not be of sufficient duration to capture aspects of the economy that would influence cost growth. With respect to the political factors examined, Wolf suggested that when Democrats hold congressional majorities, they are more likely to reduce appropriations for ongoing programs, leading to program stretch. Program stretch is the practice of acquiring the same quantity but over an extended period of time. Tyson et al. (1989) noted that program stretch is directly related to cost growth.

7. Economic Explanations for Cost Growth

The studies presented in the previous section quantified cost growth, explored basic differences in cost growth, and identified factors that influence cost growth. These findings, however, are more descriptive than explanatory. They provide little in the way of answers for the question: why does cost growth occur? Given that cost growth reflects challenges in estimating cost, the more fundamental question is: why are costs of weapon systems difficult to estimate?

As previously mentioned, a cost estimate is a forecast of actual cost. Uncertainty makes forecasting difficult. The weapons acquisition process is defined as the conceptualization, development, and production of weapon systems, by the government, for the armed forces. From the government's perspective, there are massive uncertainties in the weapons acquisition process. These uncertainties lead to a unique relationship between government and firms in which government funds private firms in carrying out most of the effort. This relationship is the focal point of the theoretical foundation of cost growth.

7.1 The Nonmarket Nature of Weapons

The market economy is the hallmark of post-war economic growth in Western countries but particularly in the United States. While it has been established that the market system has its limitations and that it does not exist in its purest form, it nonetheless provides an effective system for governing production decisions and for determining price. By setting the market price, a market system provides a measure of predictability with respect to costs.

Prices of weapon systems, however, are not determined by a market system. They are determined, instead, by the government's reimbursement of costs incurred by the firm, plus a negotiated fee. Peck and Scherer (1962) argued that a market system for weapons cannot exist for four reasons. First, a high level of uncertainty permeates the acquisition process. Private investments are subject to changes in policy and risks of technological obsolescence. Peck and Scherer classified uncertainties into two broad categories: internal and external. Internal uncertainty relates to unanticipated difficulties in design, development and production. External uncertainty relates to changes in demand for the weapon systems such as external threats, operational requirements, and availability of substitute weapons systems.

Second, sunk cost in the development phase of a weapon program is prohibitively high. It can be argued that internal and external uncertainties are not unique to weapon systems. Any product with a high technological quotient is subject to internal uncertainties in research and development, and most products are subject to external uncertainties with respect to changes in market demand and changes in availability of substitutes. What is unique to weapon systems, however, is the combination of both high uncertainty and high sunk costs in development. Firms are reluctant to bear the risks posed by the uncertainty while knowing that investments made in research and development are unlikely to be recouped through profits.

Third, an important characteristic of a market system is the firm's ability to take the initiative regarding product decisions. While, there are numerous operational and technical decisions that have to be made in weapons development, the firm has the final say in none of them. The government makes these decisions unilaterally for obvious security and political reasons.

Finally, while the government is the only buyer of weapons, the unique requirements of weapons gives the firm a measure of bargaining power as well. This essentially creates a monopoly-monopsony relationship between government and firm, which does not correspond to a market system.

A reasonable question to ask is, given the nonmarket nature of weapons, why does government not take development and production in-house? Rogerson (1995) proposed that the reasons are both organizational and ideological. Organizationally, firms allocate resources more efficiently than government, which has cumbersome personnel systems and lacks flexibility for decision-making. Ideologically, governments have a preference for private enterprise. According to Rogerson, state ownership of defence firm, which is common in Europe, indicates that ideological preference may be more important than organizational infeasibility.

7.2 Incentive Models

Despite the fact that Peck and Scherer conducted their analysis fifty years ago, their characterizations of the nonmarket nature of the weapons acquisition process remains relevant today. What has evolved in the intervening years is insight into the government-firm relationship. Both Peck and Scherer (1962) and Scherer (1964) noted that government and firm may not have the same information about cost. In addition, Peck and Scherer noted that the firm's objectives may not be aligned with the government's interests. These observations came to be known, in incentive model literature, as information asymmetry and the principal-agent problem.

Incentive models emerged from information economics and game theory. Under this school of thought, economic problems are analyzed by focusing on the strategic behaviour of economic agents acting on limited information. Economists have devoted considerable time and effort to analyzing the incentive problem in public procurement. Incentive contracts have the government reimburse a fraction of the firm's costs. The fraction reimbursed represents the power of the incentive scheme. Incentive contracts range from high-powered fixed-price contracts, under which the firm claims the residuals of its cost savings, to low-powered cost-plus-fixed-fee contracts, under which the firm does not bear any of the cost. While it would appear that government achieves maximum cost efficiency under a fixed-price contract, high-powered contracts are not optimal. Laffont and Tirole (1993) showed that, under information asymmetry, moral hazard and adverse selection force the government to give up higher rent to the firm under high-powered contracts. The optimal response by the government is to manage the trade-off between cost efficiency and rent extraction by using a lower-powered, cost-sharing incentive scheme.

Rogerson (1995) derived a simple incentive model to illustrate incentive considerations in weapons acquisition. Rogerson showed that, in addition to the trade-off between cost efficiency and rent extraction, the government also has to consider the trade-off between cost efficiency and risk allocation for the firm and that the optimal response is also a cost-sharing scheme. The power of the contract, however, is dependent on the functional forms of the firm's utility and the distribution function of symmetric uncertainty about costs.

According to Rogerson, while this symmetric uncertainty is intended to reflect both internal and external uncertainties, the most crucial element of uncertainty in weapons acquisition revolves around research and development (R&D). An important feature of weapons acquisition is the constant pursuit of technical innovation in order to improve the performance and capability of weapons. Rogerson argued that, rather than being just a phase in the acquisition process, government pays for R&D as a product as much as it does for the physical weapons acquired through the process. R&D as a product, however, is inherently difficult to purchase, which creates the need to provide incentives for innovation.

Rogerson noted that the difficulty in inducing R&D represents a hold-up problem. Government is the sole buyer of weapons, the production of which requires R&D. In commercial markets, consumers indirectly pay for R&D because it is embodied in the final product. Weapons R&D, however, may not result in a final product due to high uncertainty. Firms, therefore, see investing their own funds in R&D as a risk venture because they may never recover the sunk expenses.

Rogerson noted that government has responded to this hold-up problem by directly funding all defence-related R&D, including intermediate R&D that may not lead to a final deliverable product. In addition, government also funds many specialized physical assets used for testing and production that are not easily adapted for uses in other weapon programs or beyond weapons acquisition. This is reflected by the government's need to manage the trade-off between cost efficiency and risk allocation.

7.3 Transaction Costs

Cost estimation in weapons acquisition traditionally relies on a Work Breakdown Structure (WBS).¹¹ Similar to a production function, a WBS identifies the inputs and activities required to produce a weapon system. Cost estimates developed for each WBS component are rolled up into an estimate for the overall program. The cost estimate for each WBS component may be based on a previous, similar program or they can be developed with the input from industry.¹²

Cost estimates developed from WBS focus primarily on economic production costs such as input costs, learning curves, economies of scale, and economies of scope. Melese et al. (2007) argued that forecasting economic production costs is necessary but not sufficient in developing proper cost estimates for weapon systems. They contend that costs of weapon systems are consistently underestimated because transaction costs, such as search and information costs, decision, contracting, and incentive costs, and measurement, monitoring and enforcement costs, are not properly captured in cost estimates based on WBS.

Transaction costs revolve around the concept that markets are not “frictionless”. For every economic transaction that takes place, there exist costs other than the price directly paid. The emergence of transaction cost economics in the 1970s have been attributed to the works of Oliver Williamson [Melese et al. (2007), Hardt (2009)]. The concept of transaction costs, however, has existed in economic literature for far longer. Coase (1937) proposed that firms exist because they allow certain transaction costs to be saved.

¹¹ Melese et al. (2007). It should be noted that both the U.S. Department of Defense and the Canadian Department of National Defence rely on Work Breakdown Structures in costings of major projects.

¹² Costing Handbook, Department of National Defence.

In the context of weapons acquisition, the transaction that takes place between government and the firm is complex and multi-faceted. Transaction costs can be expected from several sources. First, the trade-offs between cost efficiency and rent extraction and between cost efficiency and risk allocation can be characterized as transaction costs.

Second, the principal-agent problem may exist between government and firm as well as within government itself. Rogerson (1995) noted that government is not a single rational actor as assumed in incentive models but is instead a complex hierarchical institution. Incentive problems that exist between actors within government impact the way in which government interacts with the firm.

Finally, Rogerson (1995) noted that government typically funds more than one design of a weapon system before sole-sourcing production because R&D costs are relatively low compared to production costs. It is, therefore, sensible to pursue more than one design strategy since it is not clear what works best. Hence the acquisition process consists of a competitive development phase and a monopoly-monopsony production phase. Melese et al. noted that the firm with the winning design and the production contract would take advantage of its stronger bargaining position to engage in unproductive renegotiation of terms.

8. Conclusion

Cost growth in weapons acquisition has for decades been a topic of scrutiny among researchers from both academia and government. This paper offered a survey of the body of literature that has been compiled. These studies showed that cost growth is a legitimate economic phenomenon, the root causes of which are grounded in theories relating to both information economics and transaction cost economics. These studies also showed that cost estimates have not noticeably improved over time despite the efforts of researchers to better understand the nature of the cost growth problem.

While these conclusions were drawn primarily from American literature on cost growth, research has shown that these conclusions have implications beyond the American system due to similarities in the acquisition systems of most Western countries. These implications should be particularly relevant for Canada given the economic integration and military co-operation between the two countries. The Canadian Department of National Defence (DND) follows a very similar approach to the U.S. DoD in developing cost estimates. It is conceivable that its cost estimates, too, are subject to the underestimation bias found in the American system.

It is clear that the Americans have more at stake with respect to the negative consequences of cost growth due to the staggering disparity in military spending between the two countries. From 1990 to 2011, American military spending more than doubled from approximately US\$300 billion per annum to over US\$730 billion annum. Over the same period, Canadian military

spending more than doubled, too, from approximately US\$11 billion to US\$ 23 billion.¹³ The U.S. has consistently devoted a quarter of its military expenditures to equipment. Canada, meanwhile, has decreased from 18 percent in the early 1990s to around 13 percent throughout the 2000s. When these two pieces of information are put together, it is obvious that cost growth has a far greater impact on the U.S.

The pattern of Canadian military acquisitions may explain why cost growth has not received much attention. According to Stone (2009), DND has alternated between periods of high and low levels of expenditure on major weapon systems rather than replacing aging assets in a gradual and consistent manner. This pattern is reflected in Table 3.

Table 3: Canadian Major Weapon Acquisitions, 1960s to 2000s¹⁴

1960s	Protecteur Class auxiliary replenishment ships
	Labrador helicopters
	Sea King helicopters
	Hercules transport aircraft
1970s	Iroquois Class destroyers
1980s	CF-18 Hornet fighter aircraft
1990s	Halifax Class frigates
	Kingston Class maritime coastal defence vessels
	Griffon helicopters
	Polaris transport aircraft
2000s	Victoria Class submarines
	Globemaster transport aircraft

There was a flurry of acquisition activity in the 1960s, followed by a lull over the next two decades. The cycle was repeated over the 1990s and 2000s.

¹³ Financial and Economic Data Relating to NATO Defence, p. 4.

¹⁴ This table is compiled from information extracted from the websites of the Royal Canadian Air Force (<http://www.rcaf-arc.forces.gc.ca/v2/equip/index-eng.asp>) and the Royal Canadian Navy (http://www.navy.gc.ca/cms/1/1-a_eng.asp). The Canadian Army does not disclose equipment information on its website.

DND currently is on an upswing in the acquisition cycle. At the strategic level, Defence acquisition is driven by the Canada First Defence Strategy. One of its primary objectives is to modernize the CF's asset base by replacing core equipment fleets. Over the next twenty years, the government plans to invest close to \$490 billion in defence. In order to ensure that the investment is allocated efficiently, cost growth analysis should be made a priority.

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