3-7-2007

Cost Growth in Weapons Systems: Re-Examining Rubber Baselines and Ecomonic Factors

Philip E. Ruter II

COST GROWTH IN WEAPONS SYSTEMS:
RE-EXAMINING RUBBER BASELINES AND
ECONOMIC FACTORS

THESIS

Philip E. Ruter II, Major, USAF

AFIT/GCA/ENV/07-M9

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GCA/ENV/07-M9

COST GROWTH IN WEAPONS SYSTEMS: RE-EXAMING RUBBER BASELINES AND ECONOMIC FACTORS

THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science Cost Analysis

Philip E. Ruter II

Major, USAF

March 2007

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/GCA/ENV/07-M9

COST GROWTH IN WEAPONS SYSTEMS: RE-EXAMING RUBBER BASELINES AND ECONOMIC FACTORS

Philip E. Ruter II
Major, USAF

Approved:

Michael J. Hicks (Chairman)	7 Mar 2007 date
Jeffrey S. Smith, Lt Col, USAF (Member)	7 Mar 2007 date
William K. Stockman (Member)	7 MAR 2007 date

AFIT/GCA/ENV/07-M9

Abstract

This paper will evaluate cost overruns from a microeconomic perspective to determine their root causes. The specific variables that will be evaluated are: contract budget fluctuations, contract length, inflation, procurement budget fluctuation, research and development budget fluctuation, the technology readiness of the commodity, and industry concentration. These variables will be evaluated twice. The first evaluation will consist of a binary choice model to determine whether or not the dependent variables influence the likelihood of a cost overrun. The specific form of the evaluation will take the form of a probit regression in which an independent variable value of zero indicates the contract did not overrun its initial contract budget baseline and one indicates the contract cost more than its initial baseline. The second evaluation will regress the dependent variables against the natural logarithm of the magnitude of a cost overrun to determine whether or not they influence the amount a contract overruns its initial baseline. This study will show that budget variability, inflation, industry consolidation and immature technologies increase the likelihood that a contract will overrun its budget.

Dedication

To my children; may your love of mathematics continue to grow. Hopefully this will inspire you to great heights in future academic endeavors.

Acknowledgement

I would like to thank Dr. Michael Hicks and my committee members for their support in this endeavor. They allowed me to test my econometric limits without performing the analysis for me.

I would also like to thank my wife and children for their infinite patience and understanding.

Phil Ruter.

Table of Contents

Page

List of Figures

List of Tables

COST GROWTH IN WEAPONS SYSTEMS: RE-EXAMINING THE RUBBER BASELINE AND ECONOMIC FACTORS

I. Introduction

Issue

Defense contracts have been a part of the military establishment since the Revolutionary war. Defense contract cost overruns have most likely existed as long as defense contracts. However, prior to World War II, government agencies were not held accountable for exceeding program estimates (Calcutt, 1993). In contrast to this previous policy, Congress has required the Department of Defense (DOD) to explain virtually all cost overruns since the end of World War II.

The nature of national defense makes defense contract cost overruns a concern for all tax-paying adults. National defense is a public good. As such, citizens can neither opt out of its protection nor is there a viable alternative means of protection. Therefore, the financial costs of a defense contract cost overrun are shared by all.

Cost overruns are the result of two possible root causes. The first is simply the cost of producing the weapon system was more than anticipated. The second possible explanation for cost overruns is that recently developed technology is incorporated into existing contracts thereby expanding the contract's scope.

Hypothesis

Traditionally, a cost variance (CV) has been defined as the difference between the budgeted cost of work performed (BCWP) and the actual cost of work performed (ACWP) (Gordon, 1996). This CV is then compared to the current contract budget baseline to determine cost and schedule performance. According to this construct, a cost overrun occurs when the value of the CV is negative.

However, this is a technical definition utilized by the DOD that is overlooked by Congress and the American taxpayer. A more appropriate definition of a cost overrun should compare the current estimate at completion (EAC) to the initial contract budget base (CBBI). This result more accurately captures the cost growth of the program from inception to finish, rather than from an arbitrary point along the contract's evolution.

This study proposes a two-step method to determine the impact and magnitude of DOD contract cost overruns. This process is based on the method used by Vincent Sipple in his 2002 thesis on engineering cost risk. The first step is to determine the right-hand side (RHS) variables that influence whether or not a contract will overrun its initial budget. The second step is to determine the RHS variables that influence the magnitude of a realized cost overrun. Both steps postulate that the likelihood and magnitude of cost overruns are a function of inflation, the number of times a contract's budget changes, changes in the DOD Procurement and Research, Development, Test and Evaluation (RDT&E) budgets, the concentration of the specific segment of the defense industry, the technological maturity of the commodity being purchased, and the length of the contract.

Scope and Limitations of the Study

The data used in this study was derived from the Defense Acquisition Executive Summary database extract used by James Smirnoff in his 2006 study of the defense industry. The database contained contracts spanning 1970 to 2002. It included 14,004 progress reports from the individual services covering 1,150 contracts (Smirnoff, 2006). The data does not provide insight as to why a contract budget baseline changed. Therefore the results generated by this study can not provide any insight into which of the two causes of cost overruns is more prevalent.

Research Objectives

As stated above, the goal of this study is twofold. The first objective is to identify what causes a defense contract to overrun its initial budget. The second objective of this study is to determine what variables influence the magnitude of a contract cost overrun. This study utilized a probit regression to evaluate the causes of a cost overrun while a ordinary least squares (OLS) regression was used to determine which variables influence the magnitude of a cost overrun.

Thesis Overview

The remainder of this thesis will be organized according to the traditional thesis five chapter format. Chapter II will explore the existing literature to explain why the RHS variables were chosen to evaluate the causes and magnitudes of defense contract cost overruns. Chapter III builds the model and methods used to evaluate the cost overruns and magnitudes. Chapter IV reports the models' results. Finally, Chapter V presents a conclusion and recommends follow-on research.

II. Literature Review

Basis for Study

The public good properties of defense contracts have given rise to a great amount of research into the nature of defense contract cost overruns. However, the bulk of this research has isolated specific variables in the earned value management system rather than using economic principles to focus their analysis. Despite this lack of a theoretical underpinning, a common theme that runs through defense acquisition literature is the notion that program instability leads to contract cost overruns. Program instability can be caused by changing requirements, micro- and macro-budget instability, and immature technology.

Recent cost analysis research has explored virtually every aspect of the earned value management system and acquisition reform. Therefore, this chapter will focus on the effect of program instability on individual contracts and economic theory with specific emphasis on macroeconomic variables. The goal is to develop the theoretical basis for the model of cost overruns proposed in chapter I. The specific RHS variables that will be discussed are: inflation, the number of times a contract is rebaselined, DOD budget instability, industry concentration, contract length, and technology readiness.

Inflation

The first independent variable to be explored is national inflation. Basic economic theory holds that inflation and industry concentration both affect product price levels. According to the DOD in a, "… macroeconomic sense inflation is the change in buying power over time" (MCR, 2006). Smirnoff, in his 2006 study, evaluated the effects of unexpected inflation on all DOD contracts in a given year. He defined unexpected inflation as the difference between forecast inflation and what actually occurred. However, his analysis determined that unexpected inflation did not influence cost overruns (Smirnoff, 2006).

Rebaselines

The second RHS variable evaluated in this analysis is the instability of individual contract budgets. Contract budget instability is epitomized by the number of times a contract has been rebaselined. James Gordon, in a 1996 thesis, produced what is probably the best example of academic research into the effect of contract instability on final price. In this study, he defined a rebaseline as, "increases or decreases in the contract budget baseline (CBB) greater than 10% or adding up to greater than 10% of the CBB prior to the change" (Gordon, 1996). Unfortunately, this definition can mask a significant amount of program instability if a program encounters a multitude of small changes that do not aggregate to a large percentage of the contract, or they aggregate to only one or two 10 percent changes. Despite the rigor of his research, Gordon was unable to conclude that rebaselines influence the likelihood of a cost overrun (Gordon, 1996). These results contradicted the existing literature at the time of his study. However, a more precise definition of a rebaseline may have yielded different results.

A second more recent study into the effect of rebaselines on contract cost and schedule was conducted by Steven Cross in 2006. This study was primarily focused on validating the quality of the data contained in the selected acquisition reports on major defense acquisition programs (MDAP). A subsidiary goal of this study was to add new variables to recent cost research. Two of these new variables were the number of times a MDAP was rebaselined and whether an MDAP was rebaselined two or more times. Cross concluded that the number of rebaselines for MDAP does predict schedule growth and two or more rebaselines predicts cost growth (Cross, 2006). However, this study analyzed MDAPs as a whole and not as individual contracts. Each MDAP is comprised of multiple contracts; therefore program managers can move money between the contracts without changing the overall program budget. As such, analyzing changes in the MDAP budget may hide the effects on individual contracts.

Finally, the Government Accountability Office (GAO) and the U.S. Congress have also been interested in the effect of program rebaselines on the final cost of MDAPs. In 2005, a GAO audit determined that rebaselining MDAPs can mask the real per unit cost of new weapon systems. This phenomenon occurs because the number of units purchased is decreased to prevent the need to increase the contract budget. Further, once a program is rebaselined all earned value management information is reset and price and schedule increases are erased. Therefore, cost overruns based on the original estimate are no longer reported (Levin, 2005).

DOD Budgets

Since defense is a public good, there is only a fixed amount of national treasure to finance the DOD. Therefore, the funding of all DOD contracts and operations is a classic budget constraint problem. Axel Gautier studied a procurement environment where the provider is paid before the project commences. This situation exemplifies DOD acquisition programs. He stated that a significant consequence of this practice is that the procurer will obtain less of the good than desired (Gautier, 2004). Therefore, in order to obtain what is required in the initial contract, the procuring agency must pay more than originally negotiated.

Smirnoff also explored the effects of fluctuations in the total DOD procurement and RDT&E budgets. He determined that as the DOD procurement budget increases, the volume of cost overruns decreases, while changes in the RDT&E budget have no effect on the likelihood of cost overruns (Smirnoff, 2006).

Industry Concentration

A cornerstone of economic thought is that competition lowers price. According to Michael Baye, monopolies tend to, "restrict output and charge a price above marginal cost" (Baye, 2003). According to this proposition, the optimal pricing situation exists in a loosely concentrated market. Therefore, as the defense industry becomes more concentrated, both negotiated contract price and final contract price should increase, thereby increasing the likelihood for a contract to exceed its CBBI.

There are two main measures of industry consolidation that are used in the economic literature, the four-firm concentration ratio, otherwise known as the CR4, and the Herfindahl-Hirschman Index (HHI) (Baye, 2003). The CR4 is merely the percentage of industry sales comprised by the four largest producers in the industry. The CR8, which is reported by the U.S. Census Bureau, is an extension of the CR4. It is the percentage of industry sales of the eight largest producers. The HHI squares the market shares of all firms in an industry and then multiplies this value by10,000 (Baye, 2003).

Judy Davis conducted an analysis of the defense industry consolidation. One of the areas of her research was the impact of consolidation on cost overruns. She stated that the DOD hoped to achieve more than $2B in contract cost savings as the defense industry consolidated in the 1980s and 1990s (Davis, 2006). She found that despite this ambitious goal, the DOD cannot verify that these cost savings were achieved. On the other hand, Davis concluded that the defense industry has become more concentrated than in the past. Similarly, she determined that profits to the remaining defense contractors have increased. Specifically, she calculated profit margins, returns on assets, and returns on equity have all increased by 2.0 percent, 1.5 percent, and 5.9 percent respectively (Davis, 2006). Unfortunately she was unable to tie these improvements in financial fundamentals to the change in industry concentration.

The increased industry concentration found by Davis leads to less competition in the defense marketplace. Juan-Jose Ganuza explored the effect of decreased competition in the Spanish defense market. He explored the effect of information asymmetry and how they relate to contract price and the likelihood of a contract cost overrun. His procurement model for markets with less than perfect competition encouraged the buyer to provide very little product specification and to invest less than warranted in the product at the time of contract award (Ganuza, 2003). This strategy requires ongoing negotiations to refine the product specification throughout the acquisition process. This strategy virtually guarantees contract cost overruns in the highly technical defense market (Ganuza, 2003). He concluded that information asymmetry is a significant component of cost overruns and perfect competition leads to disclosure of all pertinent contract information (Ganuza, 2003).

Technology Readiness

Technology readiness (TR) refers to the measurement of, "maturity of a particular technology and the consistent comparison of maturity between different types of technology" (Mankins, 1995). The Aerospace Systems Design Laboratory used TR levels (TRL) to classify emerging technologies and determine if an aircraft development project is economically viable as a function of cost per revenue mile (Mavris, 1995). This goal is accomplished by conducting an initial feasibility study which answers the basic questions of:

- Why is the technology needed?
- Can off the shelf technology be used?
- What is the risk associated with the technology of the project? (Mavris, 1995)

A. Lee Battershell used this notion of technology risk to compare Boeing and the DOD's views on risk for the development of the C-17. Boeing typically approached technology skeptically, requiring new technology to "earn its way" on a new aircraft, while the DOD appeared to be preoccupied with new technology regardless of the cost (Battershell, 1995). Maria Hedvall stated that engineering changes are relatively inexpensive early in a system's production but become increasingly more expensive as production continues (Hedvall, 2004).

Contract Length

TR and contract length are linked in the literature. According to Battershell, the DOD approach to acquiring immature technology unnecessarily lengthens the acquisition process. New DOD acquisition programs now take 11 to 21 years to complete because of the institutional preoccupation with new technology (Battershell, 1995). This finding is corroborated by Hedvall in her study of the Swedish defense industry. She argued that defense systems are composed of several components that must be synchronized to produce the final product. However, each component is fabricated at a different rate; therefore, old technology must be incorporated into new technology. The process of incorporating different technologies raised the price of the final, integrated system (Hedvall, 2004).

Since the DOD acquisition model requires the government and defense contractors to enter into acquisition programs without full knowledge of the end product, ongoing contract negotiations are necessary. Jean Tirol advocates a two-stage procurement model where contractor's "buy into" a project. In the first stage, the contractor subsidizes additional costs and enters into negotiations with the government to recoup the additional costs in the second stage (Tirol, 1986). Hedvall agrees with the need for ongoing contract negotiation, although for a different reason. She proposes what she calls the "Culture of Change." She asserted that this culture incorporates new technology into ongoing programs as it becomes available. (Hedvall, 2004).

III. Methodology

Introduction of Model

This study utilized a two-stage model to evaluate cost growth in DOD weapon systems. The notion of using a two-step regression model to identify the drivers of cost and schedule growth and then quantify their impact on the magnitude of a cost or schedule overrun is not novel. A series of theses at the Air Force Institute of Technology beginning with Sipple and culminating with Cross used this approach to determine the impact of specific earned value management (EVM) system variables on the growth of DOD acquisition programs (Cross, 2006).

This series of theses coded individual programs or contracts as having cost or schedule growth (1) or not having growth (0). These theses used a logistic regression (logit) to determine which variables caused cost or schedule growth. The second step utilized those variables found to be statistically significant by the logit as the RHS variables in an ordinary least squares regression to quantify their impact on cost or schedule growth (Cross, 2006).

Binary Choice Models

The logistic regression used by Sipple is a binary choice model. A binary choice model is simply a model with only two possible outcomes (Long, 1997). Mathematically it is expressed by the relationship

$$P_i = \Pr(Y_i = 1) \tag{1}$$

(Escudero, 2002). According to Long, there are four potential models for phenomena in which two outcomes are possible: a linear probability model (LPM)[1], a binary logit, a binary probit, and a complementary log-log model (Long, 1997). The last model is not addressed in this paper.

Binary Logit

Since the LPM is not an appropriate estimator for a binary choice, a nonlinear model is more appropriate. A binary logit is the first nonlinear model that will be evaluated. In order to derive a nonlinear model,

$$\Pr(y = 1|\vec{x}) \tag{2}$$

must be transformed into a function that ranges from $(\cdot\,\infty, \infty)$. The transformation is accomplished by setting $1 = \lim_{x\,i\,\beta} \to \infty$ and $0 = \lim_{\cdot x\,i\,\beta} \to \cdot\infty$. The first of two common cumulative distribution functions that accommodate this transformation is the standard logistic distribution where

$$\Lambda(x_i'\beta) = \frac{\exp(x_i'\beta)}{1 + \exp(x_i'\beta)} \tag{3}$$

Transforming this function into a log-likelihood equation yields the function

$$\ell(\beta|y, X) = \sum_{i=1}^{N} \left[y_i \ln \Lambda(x_i'\beta) + (1 - y_i)(\ln \Lambda(\cdot\, x_i'\beta)) \right] \tag{4}$$

(Gordon, 2003). This function is known as the logit.

[1] Addressed in Appendix B.

Binary Probit

The second cumulative distribution function that utilizes the limits $1 = \lim_{x i \beta} \to \infty$ and $0 = \lim_{\cdot x i \beta} \to \cdot\infty$, is the standard normal distribution, where

$$\Phi\left(x_i^{'}\beta\right) = \frac{1}{2\pi}\exp\left[\cdot \tfrac{1}{2}\frac{(x-\mu)}{\sigma}\right] \tag{5}$$

(Milton, 2003). Since the standard normal distribution is symmetric about the origin the log-likelihood function becomes

$$\ell(\beta|y, X) = \sum_{i=1}^{N}\left[y_i \ln\Phi\left(x_i^{'}\beta\right) + (1 - y_i)\left(\ln\Phi\left(\cdot\, x_i^{'}\beta\right)\right)\right] \tag{6}$$

(Gordon, 2003). This function is known as the probit.

Binary Choice Model Selection

The log-likelihood functions for the probit and the logit, are remarkably similar. Long and Escudero agree that both models yield consistent results. According to Escudero, the only difference between the distributions lies in the tails. This is because the coefficients of the independent variables are scaled differently (Escudero, 2003). The variance of the probit is that of the standard normal distribution, or one, while the variance of the logit is equal to $\pi^2/3$. As such, the logit has wider tails with correspondingly larger coefficients (Escudero, 2003).

Further, both the logit and probit yield globally concave results (Gordon, 2003). Since the two nonlinear models are similar, “the choice between the logit and probit models is largely one of convenience and convention, since the results are generally indistinguishable” (Long, 1997). Therefore, the probit will be utilized in this analysis.

Estimation of Independent Variable Impact on Overrun Magnitudes

The second stage of this study is to estimate the impact of the independent variables on the magnitude of a cost overrun when one occurs. Cost overruns can occur for many reasons and the range of overruns varies between a negative value, a cost underrun, and many times the original value of the contract. An OLS regression is the simplest method to estimate the independent variables effects on overrun magnitudes (Marsh, 2000). Therefore, it will be utilized to estimate the RHS variables impact on the magnitude of cost overruns.

Model Revisited

A two stage process will be used to determine if the independent variables of this study influence the likelihood of a contract experiencing a cost overrun and if encountered the magnitude of cost overrun. The first stage will utilize a binary choice probit to determine if a contract will experience a cost overrun. The second stage of this study will utilize an OLS to estimate the amount a contract will exceed its CBB.

IV. Data Reduction and Results

Road Map

This chapter will combine the theory explored in Chapter II with the methodology proposed in Chapter III to evaluate the impact of the independent variables on the likelihood of a cost overrun occurring and magnitude of a realized cost overrun. The first portion of this chapter lists the sources of data and explains how the data was manipulated into a usable format while the second portion presents the results.

Data Collection

The data used in this study has been taken from four sources. All contract execution information has been extracted from the Defense Acquisition Executive Summary (DAES). The changes in DOD procurement and RDT&E budgets were culled from the DOD Fiscal Year 2006 Budget Green Book. Industry concentration data was pulled from the US Census Bureau. Finally, inflationary data has been interpreted from the Fiscal Year 2007 President's Budget.

Contract Information

The DAES database contains progress reports from the individual services on all Acquisition Category I programs (ACAT 1) (OSD, 2006). The services provide quarterly progress reports to OSD for each active ACAT I program. The DAES database used for this analysis was originally used by Smirnoff his 2006 thesis. Has database contained 14,002 individual submissions for 1,150 contracts that were managed by the DOD between 1977 and 2002 (Smirnoff, 2006). The Smirnoff database contains a multitude of contract information. However, this analysis will only utilize six of his independent variables. The variables used in this analysis were: ACWP, BCWP, budget at completion (BAC), CBB, submission date, and contract type.

Since most of the progress reports in the database were interim reports, the first step in the analysis was to find the first and last entry for each contract. Once this was accomplished the CBBI was defined as the CBB associated with the first entry for each contract. This value was recorded for later use in the analysis. The second step was to count the number of times the CBB was changed throughout the life of the contract. This value represents the number of times the contract was rebaselined.

A contract's length was determined by reviewing the submission date of each report. The date of the first contract entry was established as the starting point. The minimum program length was set to one year. A logical formula was then inserted into Microsoft Excel to compare each subsequent submission date with the preceding value. If the year of the more recent report was greater than the previous report, then the program length was increased by one year. This method does not round to the nearest value, nor does it allow for fractional values, however, it is functionally easy to calculate.

The key step in the analysis was to determine if the contract exceeded its initial budget. This was done by calculating the EAC and comparing this value to the CBBI. If the CBBI was greater than the EAC, the contract had not experienced a cost overrun. If the CBBI was less than the EAC, the contract had overrun its initial budget. Since the DAES only reports top-level data, the most basic EAC formula was used:

$$EAC = ACWP + (BAC - BCWP) \quad (7)$$

(DAU, 2006). The magnitude of a cost overrun or underrun was determined by taking the difference between the EAC and the CBBI.

Technology Readiness

Technology readiness was the most difficult right hand side variable to calculate with the available data. The DAES database does not provide technology readiness levels similar to those used by NASA or the Air Force Research Laboratory. Therefore, the type of contract used in the acquisition process was used to proxy the technology readiness of the commodity purchased. The government utilizes cost plus contracts to minimize contractor risk for less well-defined technology and firm price contracts for less risky ventures (Sheffrin, 1976). In this case, if the contract is a fixed price contract or any of the fixed price variants, it is denoted with a zero; while a cost plus contract is represented with a one. This structure is chosen to yield a positive coefficient for technologically immature commodities.

DOD Budgets

All DOD budget information was extracted from the National Defense Budget Estimates for the Fiscal Year 2007 (FY07) Budget, more commonly referred to as the FY07 Green Book. All procurement and research & development budget information is contained in Table 6.1 (DOD, 2006). This table lists the change in real value, in constant 2007 dollars, of DOD Total Obligation Authority, for all appropriation categories, as a percentage from the previous year. The appropriation categories that are pertinent in this study are the Procurement and RDT&E appropriations.

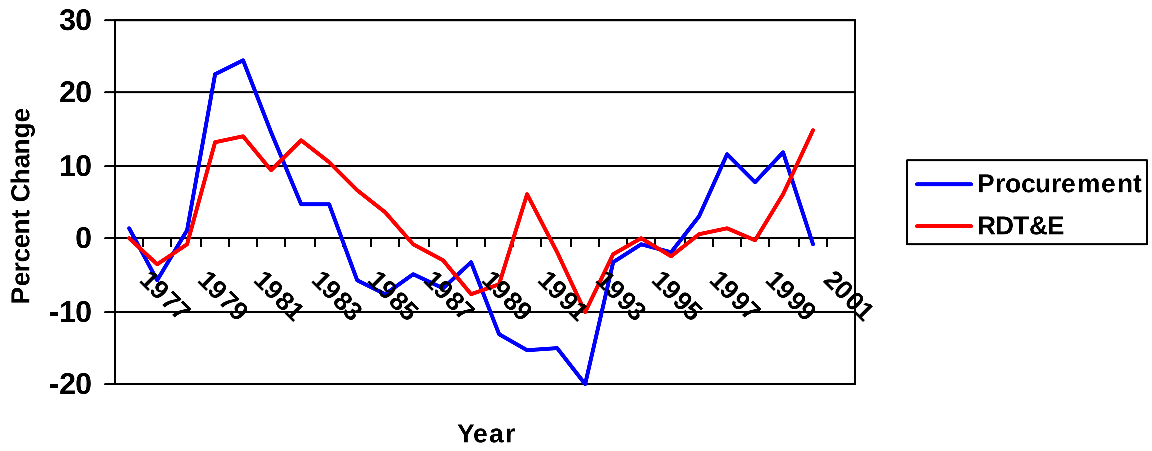

Figure 1: Percent Change of DOD Appropriations (FY77-FY02)

<u>Industry Concentration</u>

All industry concentration data was taken from surveys performed by the U.S. Census Bureau. The Census Bureau publishes a census of American industry every five years (U.S. Census, 2006). These surveys are the Economic Census, Manufacturing Surveys. An Industry Concentration Report is included in each Economic Census, Manufacturing Survey. All industry concentration data was culled from the 2002, 1997, 1992, 1987, 1982, and 1977 Industry Concentration Ratio reports.

The U.S. Census Bureau divides industry into sectors in order to calculate industry concentration rations. The U.S. Census Bureau used the North American Industry Classification System Codes (NAICS) to segment industry during the 1997 and

2002 censuses. Prior to 1997, the Census used the Standard Industrial Classification System (SIC) to divide American Industry. The Census Bureau published the 1997 Economic Census: Bridge Between NAIC and SIC. This document provides a crosswalk to link SIC codes to their corresponding NAICS codes. The manufacturing industry produces the products that the DOD is purchasing with the contracts contained in the DAES. The specific NAIC and SIC codes used in this analysis are:

Table 1: NAIC and SIC Crosswalk

NAIC	SIC	Description
33422	3663	Wireless Communications Equipement
33661	3732	Ship and Boat Building
332995	3489	Other Ordnance
334511	3812	Search, Detection, Navigation, Guidance
336411	3721	Aircraft Manufacturing
336412	3724	Aircraft Engine
336413	3728	Other Aircraft Manufacturing
336414	3761	Guided Missile/Space Manufacturing
336415	3764	Guided Missile/Space Propulsion
336419	3769	Other Guided Missile/Space
336992	3795	Military Armored Vehicles

Source: U.S. Bureau of the Census

The Industry Concentration Ratio reports provide the number of firms producing in that given segment of industry; the value of all shipments; the CR4, CR8, CR20, and CR50; as well as the HHI. This analysis only studies the impact of the number of firms, the CR4, and the CR8. Since the US Census Bureau only provides information once every five years, the data was extrapolated from one survey to the next.[2]

This method of extrapolation was adequate for all but two industry segments. These two industry segments were the wireless communications industry and the Search, Detection, Navigation, and Guidance industry. Additionally, this method was problematic for the HHI as well. The Census Bureau masks the HHI for highly concentrated industries to protect proprietary information. This practice generated several gaps in the data for individual industry segments making analysis difficult. Therefore, the HHI was not used as an independent variable in the analysis. The CR4 was selected as the appropriate measure to represent industry concentration.

Inflation

The Gross Domestic Product (GDP) implicit price deflator (IPD) is considered to be, “the single best measure of broad price movements in the economy” (DOD, 2007). The IPD is the ratio of “GDP in current prices to the GDP in constant prices” (DOD, 2007). Therefore the IPD will be used to calculate a proxy for inflation. It is expressed as a chain index where the base year is equal to 1.00. The GDP chain index was extracted from the FY07 Budget of the United States Government, Table 10.1. The base year for the index in this table is 2000. The growth in the GDP chain-index, over the period of analysis, is presented below:

[2] All industry concentration is provided in Appendix A.

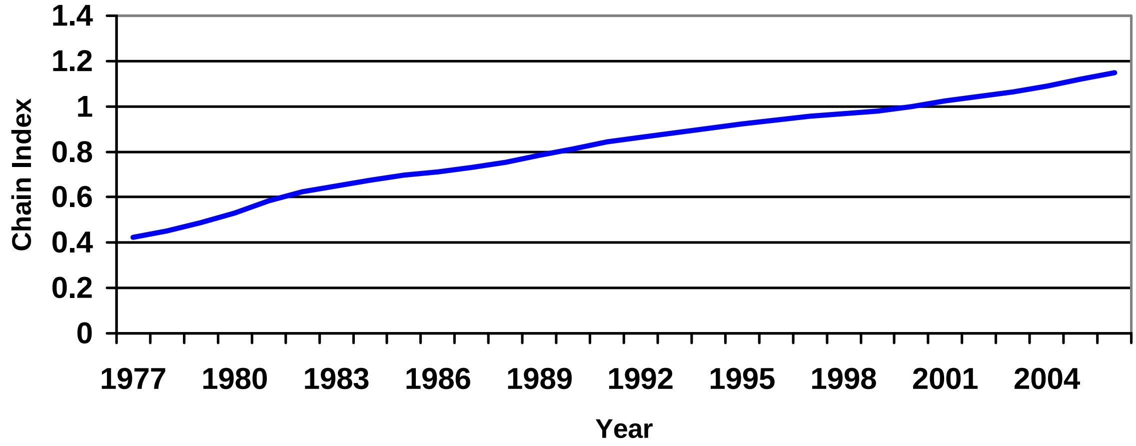

Figure 2: Growth in GDP (1977-2006)

Inflation is calculated by dividing the most current year GDP chain index by the chain index of the year in question (Davis, 2006). For example, inflation for the year 1977 was found to be 2.71 percent. This value was found by dividing the 2006 chain index value of 1.1475 by 0.4233, the 1977 chain index. Inflation, over the period of analysis is presented below.

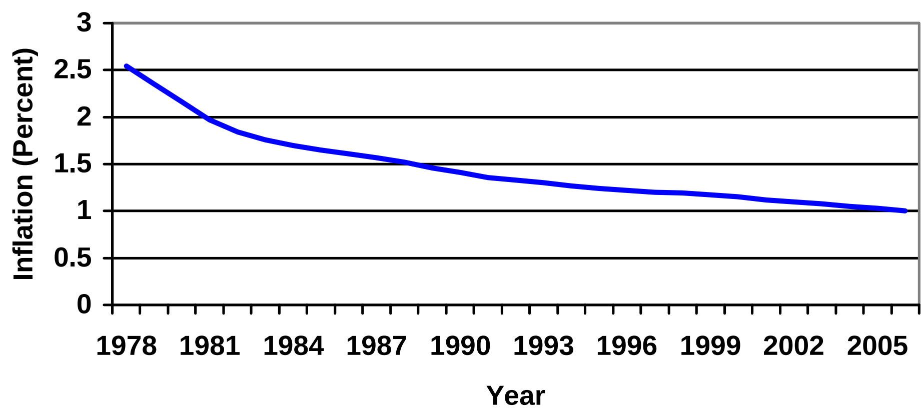

Figure 3: Inflation (1977-2006)

Results

The RHS variables discussed throughout this paper will be evaluated twice. The first evaluation will look at their influence on the likelihood of a cost overrun occurring, while the second evaluation will determine their impact on the magnitude of a realized cost overrun.

Summary Statistics

The summary statistics for the data used in this analysis are:

Table 2: Summary Statistics

Variable	obs	Mean	Std. Dev.	Min	Max
Overrun	1150	0.7095652	0.4541605	0	1
Magnitude	1150	102.1169	603.7141	-1493.6	10673.7
ln(Magnitude Cost Overrun)	818	3.283981	1.860017	-2.302585	9.275538
ln(Percent Cost Overrun)	1149	0.7274253	4.663351	-0.6804309	143.5
GDP Deflator	1150	1.522135	0.3603345	1.1	2.7108
Change Procurement Budget	1150	-0.4854783	11.31916	-19.9	24.5
Change RDT&E Budget	1150	3.278869	7.373217	-10.2	14.9
CR4	1150	61.41043	19.62887	11	96
Number Rebaselines	1150	6.733043	6.55399	0	39
Contract Length	1150	3.641739	2.049092	0	14
Technology Readiness	1150	0.4052174	0.4911477	0	1

The data indicates that nearly 71 percent of the DOD contracts encountered cost overruns with an average amount of $102 million. However, this number is influenced by four contracts for the C-17, A-12 and Trident submarine that accounted for nearly $9.7B. All contracts averaged 3.6 years with nearly seven rebaselines each. Further, inflation averaged 1.5 percent annually, with an average CR4 of 61 percent. Finally, 40 percent were fixed price contracts while 60 percent were cost-plus contracts.

Binary Choice

The model utilized to explore the likelihood of a cost overrun occurring is a probit where:

$$\Pr(CO) = f\left(GDP, \Delta Pcmt, \Delta R\,\&\,D, \#\,BaselineChanges, Length, TR, CR4\right) \qquad (8)$$

In this case GDP is equal to the inflation derived from the GDP IPD, ΔPcmt is the annual percent change in the DOD Procurement budget, ΔR&D is the annual percent change in the RDT&E budget, #BaselineChanges is the number of times the CBB has changed, Length is the length of contract, TR is the technology readiness proxy, and CR4 is the industry CR4 for a given contract.

The probit model[3] yielded the following results when reporting the change in probability:

Table 3: Probit Model Results

Variable	dF/dx	P(Z)
GDP Deflator	0.0621359	0.149
Change in Procurement	0.0011605	0.485
Change in R&D	0.0006480	0.782
CR4	0.0001576	0.825
Number Rebaselines***	0.0201413	0.000
Contract Length***	0.0371733	0.002
Technology Readiness	0.0356250	0.196
Obs P.	0.7095652	
Pred P.	0.7460646	at x-bar
Pseudo R2	0.1117	
P(Chi)	0.0000	
Observations	1150	

*** Significant to the 1% level
** Significant to the 5% level
* Significant to the 10% level

The marginal effects value, or DF/dx, represents the discrete change of the dependent variable from a zero to one. In this case the discrete change occurs when a contract overruns its CBBI. The pseudo-R^2 of .1117 indicates that contract management is a volatile process and the likelihood of a contact experiencing a cost overrun is highly stochastic. Despite the fact that nearly 89 percent of the causes of a cost overrun are not explained by this model the high p-score indicates that the model has tremendous statistical significance.

Only two of the independent variables used to analyze the occurrence of cost overruns proved to be statistically significant. These two variables were the number of rebaselines and the length of the contract. However, both variables were statistically

[3] The probit is presented here as it is consistent with the models used in similar studies in the economic literature. Since the logit model is more commonly found it cost research it is presented along with a linear probability model in Appendix B. All three models yielded similar results.

significant to the one percent level, indicating a very powerful positive influence on the likelihood of an overrun occurring. As such, contract budget instability and extending the length of a contract both add to the likelihood of a contract experiencing a cost overrun. Each time a contract is rebaselined it is two percent more likely to experience a cost overrun while an additional year in program length adds 3.6 percent to the likelihood of a cost overrun. The remaining variables had no influence on the likelihood of a contract overrunning its CBBI.[4]

A Hausman test was performed to determine if there are endogenous variables in the model. The Hausman test concluded that none of the RHS variables were endogenous.[5] Therefore, contract budget instability and contract length are accurate predictors of cost overruns.

Impact on Magnitude

The left-hand side variable used in OLS regression was the magnitude of the cost overrun. This number calculated by taking the difference between the most recent EAC and the CBBI. The specific model used was:

$$OverrunMagnitude = f\left(\Delta GDP, \Delta Pcmt, \Delta R\,\&\,D, InitialCR4, \#\,BaselineChanges, Length, TR, CBBI\right) \tag{9}$$

The RHS variables used in this model are largely the same as the variables used in the probit model. The CBBI was added to help scale the magnitude while the change in GDP IPD was used to measure the effects of inflation over the life of the contract. The CR4

---

[4] The model proved highly insensitive to the measure selected to represent industry concentration. All regressions provided very similar results. Additional models utilizing alternate measures of industry concentration are contained in Appendix C.

[5] Post estimation results are included in Appendix B.

encountered when the contract was signed was used to measure industry concentration with regard to the initial contract price. The regression results are:

Table 4: OLS Model Results

Variable	Coefficient	P(t)
Change in GDP Deflator	147.145700	0.2600
Change in Procurement	0.267741	0.9010
Change in R&D	2.460645	0.4200
Initial CR4**	2.281388	0.0180
Number Rebaselines***	27.198500	0.0000
Contract Length**	43.802330	0.0040
Technology Readiness	-56.120910	0.1340
CBBI**	0.043070	0.0140
Intercept***	-335.462200	0.0000
Adjusted R2	0.1539	
P(F)	0.0000	
Observations	1055	
Bruesch-Pagan Het Test		
Chi2(1)	5738.26	
P(Chi)	0.0000	
Ramsey Omitted Variable Test		
F(3, 1043)	121.3	
P(F)	0.0000	

*** Significant to 1% level
** Significant to 5% level [6]

The adjusted r-squared value indicates that this model explains nearly 16% of the factors that influence the amount a contract over run its initial budget while the p-score indicates that the model is very significant. In conjunction with the high p-score, five of the nine RHS variables are statistically significant when considering how much a contract will exceed its CBBI.

The number of rebaselines, and intercept are significant to the one percent level while the initial CR4, CBBI, and contract length are significant to the five percent level.

[6] A second OLS regression in which the cost overrun magnitude is a function of change in the GPD IPD, change in procurement budget, change in R&D budget, change in CR4, number of rebaselines, contract

Consequently, as the CR4 increases by one percent the magnitude of a cost overrun will increase by $2.3M. Likewise the magnitude of an overrun will be increased by $27.2M for each rebaseline and $43.8M for each additional year. The CBBI while statistically significant has a very small impact on the amount of a cost overrun, although it does indicate that larger contracts will experience more cost overruns. The variables that were not statistically significant to the impact the magnitude of a cost overrun were the change in the GDP IPD, changes in the procurement and RDT&E budgets, and the type of contractual vehicle used.

Summary

The probit model presented in this chapter provides significant insight into the economic factors that influence the likelihood of a contract experiencing a cost overrun. It indicates that rebaselines and contract length are prime indicators that a contract will overrun its CBBI. Additionally, the OLS model indicates that the number of times a contract is rebaselined, contract length, and initial CR4 have a significant impact on the magnitude of a cost overrun.

---

length, technology readiness, and CBBI yielded similar coefficients and magnitudes with a adjusted r-squared of 0.1521. The rebaseline coefficient was 25.5 and the contract length coefficient was 41.2.

V. Implications and Conclusion

Results Revisited

The goal of this research was to analyze DOD contracts to determine if fluctuating contract budgets and macroeconomic variables influence the likelihood of a cost overrun for DOD acquisition contracts, and if so by how much. The analysis utilized a two-step process to determine if the likelihood and magnitude of cost overruns as a function of inflation, the number of contract rebaselines, change in procurement budget, change in RDT&E budget, CR4, contract length, and TR of the purchased commodity. The analysis concluded that the likelihood of a cost overrun is influenced by both the number of times the contract is rebaselined and the program length. Each time an acquisition contract is rebaselined the likelihood of a cost overrun occurring increased by two percent. Further, each year a contract is delayed the likelihood of a cost overrun is increased by 3.6 percent.

The analysis also determined that the magnitude of a cost overrun is influenced by the number of rebaselines, initial CR4, contract length, and CBBI of the commodity. There were an average of 44 active contracts each year between 1977 and 2002 and 71% of these contracts final costs exceeded their CBBI. This translated into nearly $850M in cost overruns a year if each contract experienced a rebaseline, or $183M per contract since the average contract was rebaselined 6.7 times. Further, extending all active contracts an extra year adds $1.4B to annual procurement costs. Finally, as the defense industry becomes more concentrated the annual cost for all contracts is an additional $71M for each percentage point rise in the CR4.

Policy Implications

The implications of these results to the DOD are relatively straightforward. A major culture change should be encouraged inside the DOD. The DOD should not attempt to evolve contracts as new technology becomes available. This practice unnecessarily lengthens acquisition programs and drives up costs and encourages budget instability for individual contracts. Program managers should be encouraged to keep acquisition programs short and resist the temptation to buy the most technologically advanced systems possible. Technology should be incorporated into existing weapons systems via small upgrades utilizing the spiral acquisition model. This practice will make the goals of acquisition programs more realistic and curb the ever lengthening life span of DOD acquisition programs.

A second major implication of this study is to the defense marketplace. The defense industry consolidation that has been encouraged over the past two decades should be halted and reversed. Although significant barriers exist to entry in the defense industry as a prime contractor, this analysis was not limited to primes. The DOD should encourage more competition in the subcontractor arena which should in turn lead to more prime contractors in the future. The combination of these two proposals, constraining the technology procurement of ongoing acquisition programs and halting the defense industry consolidation should reduce acquisition costs by several million dollars for each major acquisition program.

Suggestions for Further Research

This research can be extended in several ways. Probably the most useful extension would be to determine what proportion of contract cost overruns are caused by changing requirements and the proportion generated by poor cost estimates. A second way to extend this research would be to apply this model to the individual services and different types of systems procured by the DOD. Finally, the technology readiness proxy utilized by this study is very rudimentary. Enhancing the technology readiness level proxy may provide more powerful insight into the causes of contract cost overruns.

Appendix A: NAIC and SIC Information

This Appendix lists the industry concentration information extracted from the US Census Bureau's Survey of Industry, Industry Concentration Report. Each table contains the extrapolated data for a single NAIC/SIC segment of the manufacturing industry.

Table 5: 33422 Wireless Communications Equipment

Year	# Firms	CR4	CR8	HHI
2002	934	44	55	584
2001	966	45	56	661
2000	999	46	57	739
1999	1031	47	58	817
1998	1064	48	58	894
1997	1096	49	59	972
1996	1049	47	58	927
1995	1002	46	57	883
1994	955	44	55	838
1993	908	43	54	794
1992	861	41	53	749
1991	803	40	53	700
1990	745	39	54	650
1989	688	39	54	601
1988	630	38	55	551
1987	572	37	55	502
1986	572	37	55	502
1985	572	37	55	502
1984	572	37	55	502
1983	572	37	55	502
1982	572	37	55	502
1981	572	37	55	502
1980	572	37	55	502
1979	572	37	55	502
1978	572	37	55	502
1977	572	37	55	502

The SIC code for the wireless communications industry was established with the 1987 industry census.

Table 6: 33611 Ship and Boat Building

Year	# Firms	CR4	CR8	HHI
2002	1649	51	56	884
2001	1645	48	55	797
2000	1641	46	54	710
1999	1638	43	53	623
1998	1634	41	52	536
1997	1630	38	51	450
1996	1779	37	48	436
1995	1928	36	46	423
1994	2078	35	43	410
1993	2227	33	41	396
1992	2376	32	38	383
1991	2322	32	39	416
1990	2269	32	39	449
1989	2215	33	40	482
1988	2162	33	40	515
1987	2108	33	41	548
1986	2053	29	37	457
1985	1998	25	33	365
1984	1944	22	30	274
1983	1889	18	26	182
1982	1834	14	22	91
1981	1897	13	21	73
1980	1960	13	21	55
1979	2022	12	20	36
1978	2085	12	20	18
1977	2148	11	19	0

Table 7: 332995 Other Ordnance

Year	# Firms	CR4	CR8	HHI
2002	58	78	90	2994
2001	59	79	90	2811
2000	61	79	90	2628
1999	62	80	90	2445
1998	64	81	89	2262
1997	65	82	89	2080
1996	66	82	89	2050
1995	67	82	89	2019
1994	69	83	89	1989
1993	70	83	89	1959
1992	71	83	89	1929
1991	69	82	89	1915
1990	66	81	89	1901
1989	64	79	90	1886
1988	61	78	90	1872
1987	59	77	90	1858
1986	60	73	88	1699
1985	61	70	87	1539
1984	63	66	85	1380
1983	64	63	84	1220
1982	65	59	82	1061
1981	70	57	80	849
1980	75	55	78	637
1979	79	52	76	424
1978	84	50	74	212
1977	89	48	72	0

Table 8: 334511 Search, Detection, Navigation, Guidance

Year	# Firms	CR4	CR8	HHI
2002	504	59	77	1196
2001	519	59	77	1203
2000	534	59	77	1211
1999	549	59	77	1219
1998	564	59	77	1227
1997	579	59	77	1235
1996	590	53	71	1065
1995	601	46	65	895
1994	613	40	60	725
1993	624	33	54	555
1992	635	27	48	385
1991	692	27	48	388
1990	748	28	48	391
1989	805	28	49	395
1988	861	29	49	398
1987	918	29	49	401
1986	918	29	49	401
1985	918	29	49	401
1984	918	29	49	401
1983	918	29	49	401
1982	918	29	49	401
1981	918	29	49	401
1980	918	29	49	401
1979	918	29	49	401
1978	918	29	49	401
1977	918	29	49	401

The SIC code for the search, detection, navigation and guidance industry was established with the 1987 industry census.

Table 9: 336411 Aircraft Manufacturing

Year	# Firms	CR4	CR8	HHI
2002	184	81	94	2948
2001	182	81	94	2863
2000	179	81	94	2779
1999	177	81	94	2695
1998	174	81	94	2610
1997	172	81	95	2526
1996	168	81	94	2564
1995	164	80	94	2603
1994	159	80	94	2641
1993	155	79	93	2679
1992	151	79	93	2717
1991	148	78	93	2547
1990	145	76	93	2377
1989	143	75	92	2208
1988	140	73	92	2038
1987	137	72	92	1868
1986	137	70	90	1766
1985	138	69	88	1664
1984	138	67	85	1562
1983	139	66	83	1460
1982	139	64	81	1358
1981	141	63	81	1086
1980	144	62	81	815
1979	146	61	81	543
1978	149	60	81	272
1977	151	59	81	0

Table 10: 336412 Aircraft Engine

Year	# Firms	CR4	CR8	HHI
2002	296	77	82	2102
2001	293	76	82	2033
2000	290	76	81	1963
1999	287	75	81	1893
1998	284	75	80	1823
1997	281	74	80	1754
1996	293	75	81	1879
1995	305	75	82	2003
1994	316	76	82	2128
1993	328	76	83	2253
1992	340	77	84	2378
1991	346	77	84	2343
1990	353	77	84	2307
1989	359	77	83	2272
1988	366	77	83	2236
1987	372	77	83	2201
1986	354	76	83	2116
1985	336	75	83	2032
1984	317	74	83	1947
1983	299	73	83	1863
1982	281	72	83	1778
1981	270	72	84	1422
1980	259	73	84	1067
1979	248	73	85	711
1978	237	74	85	356
1977	226	74	86	0

Table 11: 336413 Other Aircraft Manufacturing

Year	# Firms	CR4	CR8	HHI
2002	760	54	69	950
2001	818	54	69	985
2000	876	54	69	1020
1999	933	55	69	1056
1998	991	55	69	1091
1997	1049	55	69	1126
1996	1045	53	67	1055
1995	1041	51	66	985
1994	1036	48	65	914
1993	1032	46	63	843
1992	1028	44	62	772
1991	1007	44	61	748
1990	987	43	60	724
1989	966	43	59	700
1988	946	42	58	676
1987	925	42	57	652
1986	922	41	56	641
1985	920	40	56	630
1984	917	40	55	620
1983	915	39	55	609
1982	912	38	54	598
1981	866	39	54	478
1980	820	41	55	359
1979	773	42	55	239
1978	727	44	56	120
1977	681	45	56	0

Table 12: 336414 Guided Missile/Space Manufacturing

Year	# Firms	CR4	CR8	HHI
2002	13	96.0	99.0	D
2001	13	95.1	99.1	D
2000	14	94.2	99.2	D
1999	14	93.4	99.4	D
1998	15	92.5	99.5	D
1997	15	91.6	99.6	D
1996	17	87	98	D
1995	19	83	97	D
1994	20	79	96	D
1993	22	75	94	D
1992	24	71	93	1570
1991	23	68	93	1500
1990	22	66	93	1430
1989	21	63	92	1360
1988	20	61	92	1290
1987	19	58	92	1220
1986	18	61	93	1292
1985	18	63	94	1363
1984	17	66	94	1435
1983	17	68	95	1506
1982	16	71	96	1578
1981	17	70	96	1262
1980	18	68	95	947
1979	18	67	95	631
1978	19	65	94	316
1977	20	64	94	0

Table 13: 336415 Guided Missile/Space Propulsion

Year	# Firms	CR4	CR8	HHI
2002	16	90	99	D
2001	17	88	99	D
2000	17	86	98	D
1999	18	83	98	D
1998	18	81	98	D
1997	19	79	97	2056
1996	21	77	96	1934
1995	23	76	95	1812
1994	24	74	94	1690
1993	26	73	93	1568
1992	28	71	92	1446
1991	28	71	93	1471
1990	28	72	94	1496
1989	27	72	95	1520
1988	27	73	96	1545
1987	27	73	97	1570
1986	26	72	96	1536
1985	24	71	95	1503
1984	23	70	95	1469
1983	21	69	94	1436
1982	20	68	93	1402
1981	20	68	93	1122
1980	19	68	93	841
1979	19	69	93	561
1978	18	69	93	280
1977	18	69	93	0

Table 14: 336419 Other Guided Missile/Space

Year	# Firms	CR4	CR8	HHI
2002	51	60	75	2515
2001	50	63	77	2478
2000	50	65	79	2440
1999	49	67	81	2403
1998	49	69	84	2365
1997	48	72	86	2327
1996	49	72	86	2269
1995	50	73	86	2210
1994	52	74	86	2151
1993	53	74	86	2093
1992	54	75	86	2034
1991	55	72	84	1897
1990	57	70	83	1760
1989	58	67	81	1624
1988	60	65	80	1487
1987	61	62	78	1350
1986	58	50	62	1080
1985	55	37	47	810
1984	51	25	31	540
1983	48	12	16	270
1982	45	0	0	0
1981	44	15	17	0
1980	43	30	34	0
1979	43	46	52	0
1978	42	61	69	0
1977	41	76	86	0

Table 15: 336992 Military Armored Vehicles

Year	# Firms	CR4	CR8	HHI
2002	31	88	93	D
2001	32	88	93	D
2000	33	87	93	D
1999	35	87	93	D
1998	36	87	93	D
1997	37	86	93	D
1996	37	86	93	D
1995	37	87	93	D
1994	37	87	93	D
1993	37	88	94	D
1992	37	88	94	2320
1991	40	89	94	1856
1990	42	90	94	1392
1989	45	90	95	928
1988	47	91	95	464
1987	50	92	95	0
1986	48	91	93	503
1985	45	89	91	1006
1984	43	88	89	1509
1983	40	86	87	2012
1982	38	85	85	2515
1981	34	85	87	2012
1980	31	86	90	1509
1979	27	86	92	1006
1978	24	87	95	503
1977	20	87	97	0

Appendix B: Probit Post Estimation Results and Alternate Models

This appendix presents the Hausman test post estimation results and additional models with utilizing the CR4 as to measure industry concentration. The first model presented is the initial probit model contained in Chapter IV, including residuals as an independent variable. The results indicate that the only variable that is statistically significant is the residual variable. This model is then compared to the initial model via the Hausman test. The Hausman test revealed that the initial model provided efficient coefficient estimators while the second model with residuals does not provide efficient estimators. This indicates that endogeneity is not contained in the model.

Table 16: Probit with Residuals

Variable	dF/dx	P(Z)
GDP Deflator	0.0141148	0.783
Change in Procurement	0.0001945	0.912
Change in R&D	0.0002687	0.910
CR4	0.0000218	0.976
Number Rebaselines	0.0089044	0.229
Contract Length	0.0094943	0.632
Technology Readiness	0.0118328	0.703
Residuals*	0.7124867	0.075
Obs P.	0.7095652	
Pred P.	0.7401252	at x-bar
Pseudo R2	0.1138000	
Log Likelihood	-614.08974	
P(Chi)	0.0000	
Observations	1150	

Table 17: Hausman Results

	Coefficients			
	b (Before)	B (after)	b-B	sqrt(diag(v_b-v_B))
GDP Deflator	0.1939282	0.0435259	0.1504023	-
Change in Procurement	0.0036219	0.0005998	0.0030221	-
Change in R&D	0.0020226	0.0008286	0.001194	-
CR4	0.000492	0.0000671	0.0004249	-
Number Rebaselines	0.0628618	0.0274585	0.0354033	-
Program Length	0.1160192	0.0292778	0.0867414	-
Technology Readiness	0.1120096	0.0365718	0.0754378	-

The next two models present alternate methods to estimate the likelihood of a cost overrun occurring on a DOD procurement contract. The first competing model is the logit while the second is a simple ordinary least squares (OLS) estimation.

Table 18: Logit Model

Variable	Odds Ratio	P(Z)
GDP Deflator	1.3335890	0.190
Change in Procurement	1.0058870	0.500
Change in R&D	1.0015870	0.897
CR4	0.9999807	0.856
Number Rebaselines***	1.1275950	0.000
Contract Length***	1.1994520	0.005
Technology Readiness	1.2083360	0.193
Pseudo R2	0.1133	
Log Likelihood	-614.3977	
P(Chi)	0.0000	
Observations	1150	
Pearson Goodness of Fit		
Number Covariate Patterns	996	
Pearson Chi2 (988)	1030.08	
P(Chi)	0.1714	

A LPM is merely an OLS regression to fit binary choice phenomena. As such, the LPM provides the worst results of the three models that will be evaluated. It does this because the observed phenomena produce an S-shaped curve that relates the probability of an event occurring to the studied independent variables, yet it linear relationship is produced (Long, 1997).

This linear relationship is problematic for several reasons. The first is that the data is heteroskedastic. The S-shaped nature of the curve indicates that the data does not have a constant variance, therefore a key assumption of the OLS is violated and the resulting coefficients are inefficient estimators of probability (Long, 1997). The second assumption violated when a LPM is used to estimate a binary choice model is that of normality of the error terms. The error terms must result from either

$$\varepsilon_1 = 1 - E(y|x_i) \tag{13}$$

or

$$\varepsilon_0 = 0 - E(y|x_i). \tag{14}$$

Hence, the error terms can not be normally distributed. Although normally distributed error terms are preferred, they are not required (Long, 1997).

Finally, a LPM can produce results that simply do not make sense. In this construct the expected value of y given a vector of independent variables is

$$E(y|\vec{x}) = \Pr(y = 1|\vec{x}) \tag{15}$$

(Long, 1997). Since a binary choice model is bounded (0,1), and it is possible for a LPM to yield a result outside this range, the LPM can produce results that do not fit the underlying data (Gordon, 2003).

The LPM yields an inefficient estimator of $\Pr(Y_i = 1)$ in binary response situations. It is inefficient for the reasons stated above: it does not have a common variance and it yields answers outside the possible range. Despite these shortcomings, it can provide a rough estimate before more rigorous analysis is conducted.

Table 19: OLS Model

Variable	Coefficient	P(t)
GDP Deflator	0.059648	0.146
Change in Procurement	0.001278	0.415
Change in R&D	0.000085	0.969
CR4	-0.000064	0.925
Number Rebaselines***	0.013196	0.000
Contract Length***	0.034892	0.001
Technology Readiness	0.030369	0.252
Intercept***	0.394804	0.000
Adjusted R2	0.1028	
P(F)	0.0000	
Observations	1150	
Bruesch-Pagan Het Test		
Chi2(1)	69.01	
P(Chi)	0.0000	
Ramsey Omitted Variable Test		
F(3, 1139)	7.22	
P(F)	0.0001	

The results of these two models are consistent with the probit presented in the main text. All three models yield the same significant variables and very similar pseudo- and adjusted r-squared results. This indicates the model is highly insensitive to functional form. Further, the OLS model passed the Bruesch-Pagan heteroskedasticity test and the Ramsey Omitted Variable test at the one percent level.

Appendix C: Alternate Measures of Industry Concentration

This appendix presents the two additional probit models that utilize alternate measures of industry concentration to determine the likelihood of a cost overrun occurring. The first model utilizes the number of firms in a given segment of the defense industry while the second utilizes the CR8.

Table 20: Probit (Firms)

Variable	dF/dx	P(Z)
GDP Deflator	0.0589753	0.165
Change in Procurement	0.0011540	0.486
Change in R&D	0.0006637	0.776
Firms	-0.0000076	0.701
Number Rebaselines***	0.0203382	0.000
Program Length***	0.0367790	0.003
Technology Readiness	0.0349616	0.205
Obs P.	0.7095652	
Pred P.	0.7461283	at x-bar
Pseudo R2	0.1118	
Log Likelihood	-615.4402	
P(Chi)	0.0000	
Observations	1150	

Table 21: Probit (CR8)

Variable	dF/dx	P(Z)
GDP Deflator	0.0602118	0.155
Change in Procurement	0.0012157	0.462
Change in R&D	0.0006712	0.774
CR8	-0.0000634	0.922
Number Rebaselines***	0.0199631	0.000
Program Length***	0.0374885	0.002
Technology Readiness	0.0364329	0.186
Obs P.	0.7095652	
Pred P.	0.7459790	at x-bar
Pseudo R2	0.1117	
Log Likelihood	-615.5089	
P(Chi)	0.0000	
Observations	1150	

These results are consistent with the probit presented in Chapter IV. The same variables are significant to the one percent level. The only difference is the sign for the measure of industry concentration has flipped from positive to negative. However, the statistical significance on both models is low enough to make this result insignificant. Therefore, the model is not sensitive to the specific measure of industry concentration.

References

Baye, Michael R. 2003. *Managerial Economics and Business Strategy.* New York: McGraw-Hill.

Battershell, A. Lee. 1995. "Technology Approach: DoD Versus Boeing (A Comparative Study)." *Defense Acquisition Quarterly*, Summer 1995, 213-230.

Calcutt, Harry M., Jr. 1993. "Cost Growth in DoD Major Programs: A Historical Perspective." Executive Research Project. Industrial College of the Armed Forces, National Defense University, Ft McNair, Washington DC.

Cross, Steven M. 2006. Data Analysis and its Impact on Predicting Schedule & Cost Risk. MS Thesis. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH.

Davis, Judy B. 2006. The Impact of the Defense Industry Consolidation of the Aerospace Industry. MS Thesis. Graduate School of Engineering Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH.

"Earned Value Management Gold Card." 2006. Defense Acquisition University. https://acc.dau.mil/communitybrowser.aspx?id=19577.

Economic Census. 2006. http://www.census.gov/epcd/www/concentration.html (accessed multiple times September-December, 2006)

Escudero, Walter Sosa. 2002. "Chapter 9 Binary Choice Models: Logits and Probits." http://www.econ.uiuc.edu/~sosa/econ472/notas82001.pdf.

Fiscal Year 2007 President's Budget. 2006. Government Printing Office. http://www.gpoaccess.gov/usbudget/fy05/hist.html (accessed December, 2006).

Ganuza, Juan-Jose. 2003. "Competition and Cost Overruns in Procurement." UPF Economics and Business Working Paper 772.

Gautier, Axel. 2004. "Regulation Under Financial Constraints." *Annals of Public and Cooperative Economics,* 75:4, 645-656.

Gordon, James A. 1996. "Does a Rubber Baseline Guarantee Overruns" A Study of Cost Performance and Contract Changes in Major Defense Acquisition Programs. MS Thesis. School of Logistics and Acquisition Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH.

Gordon, Sanford. 2003. "Inference, Uncertainty and Binary Choice Models." http:/www.nyu.edu/gsas/dept/politics/grad/classes/quant2/binarymodels_lecture3.pdf.

Hedvall, Maria. 2003. "Change as a Cost Driver in Defence Procurement," *Defence and Peace Economics*, Vol 15(1), 101-108.

Intercooled STATA. 2006. Version 9.0, Computer Software. STATACorp.

Levin, Robert E. 2005. *Defense Acquisitions: Information for Congress on Performance of Major Programs Can Be More Complete, Timely, and Assessable.* Washington DC. Government Accountability Office: GAO-05-182.

Long, J. Scott. 1997. *Regression Models for Categorical and Limited Dependent Variables*. Thousand Oaks: SAGE Publications, Inc.

Mankins, John C. 1995. "Technology Readiness Levels." Advanced Concepts Office, Office of Space Access and Technology, NASA. A White Paper.

Marsh, Thomas L. and Ron C. Mittelhammer. 2000. "Truncated Regression in Empirical Estimation." Department of Agricultural Economics, Kansas State University direct correspondence.

Mavris, Dmitri N., Oliver Bandte, and Jason T. Brewer. 1995. "A Method for the Identification and Assessment of Critical Technologies Needed for an Economically Viable HSCT." School of Aerospace Engineering, Georgia Institute of Technology.

Milton, Susan J. and Jesse C. Arnold. 2003. *Introduction to Probability and Statistics*. New York: McGraw-Hill.

Office of the Secretary of Defense. 2006. Department of Defense. http://www.acq.osd.mil/cars/DAESFAQ.asp (accessed multiple times August 2006).

Smirnoff, James P. 2006. The Impact of Economic Factors and Acquisition Reforms on the Cost of Weapons Systems. MS Thesis. Graduate School of Engineering Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH.

Wise, Gregory A. and Charles B. Cochran. 2006. *DoD Inflation Handbook.* McLean, Virginia. MCR Federal LLC.

Vita

Major Philip E. Ruter II was born in Louisville, KY. In 1986, he graduated from Ramstein American High School, in what was then West Germany, and attended the University of Louisville under an Air Force ROTC scholarship. He graduated in May 1991 with a Bachelor of Arts in Physics and was commissioned 2 May 1991.

He entered active duty in February, 1992 as a Student Air Traffic Control officer at Tyndall AFB, FL. His first active assignment was as the Deputy Chief, Air Traffic Control Operations at Pope AFB, NC. After several assignments in airfield operations he career broadened into the financial management field. As a Financial Management officer he has served as a base budget officer, joint staff officer, and comptroller squadron commander. He has completed Squadron Officers' School by correspondence and in residence and has completed Air Command and Staff College by correspondence. He has completed a Master of Public Administration from University of Alaska. In August 2005, he entered the Cost Analysis program in the Graduate School of Engineering and Management, Air Force Institute of Technology. After graduation he will be assigned to the Air Force Flight Standards Agency, Resources and Requirements division.

REPORT DOCUMENTATION PAGE				*Form Approved* *OMB No. 074-0188*
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to an penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**				
1. REPORT DATE *(DD-MM-YYYY)* 22-03-2007	**2. REPORT TYPE** Master's Thesis			**3. DATES COVERED** *(From – To)* October 2005 – March 2007
4. TITLE AND SUBTITLE Cost Growth in Weapons Systems: Re-examining Rubber Baselines and Economic Factors				**5a. CONTRACT NUMBER**
				5b. GRANT NUMBER
				5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Ruter, Philip E. II., Major, USAF				**5d. PROJECT NUMBER**
				5e. TASK NUMBER
				5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765				**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GCA/ENV/07-M9
9. N/A				**10. SPONSOR/MONITOR'S ACRONYM(S)** N/A
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) N/A
12. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT This paper will evaluate cost overruns from a microeconomic perspective to determine their root causes. The specific variables that will be evaluated are: contract budget fluctuations, contract length, inflation, procurement budget fluctuation, research and development budget fluctuation, the technology readiness of the commodity, and industry concentration. These variables will be evaluated twice. The first evaluation will consist of a binary choice model to determine whether or not the dependent variables influence the likelihood of a cost overrun. The specific form of the evaluation will take the form of a probit regression in which an independent variable value of zero indicates the contract did not overrun its initial contract budget baseline and one indicates the contract cost more than its initial baseline. The second evaluation will regress the dependent variables against the natural logarithm of the magnitude of a cost overrun to determine whether or not they influence the amount a contract overruns its initial baseline. This study will show that budget variability, inflation, industry consolidation and immature technologies increase the likelihood that a contract will overrun its budget.				
15. SUBJECT TERMS Cost analysis, econometric modeling, probit, Defense budget, program instability, industry concentration, technology readiness, DAES				
16. SECURITY CLASSIFICATION OF:		**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. Michael J. Hicks (ENV)
REPORT U / **ABSTRACT** U / **c. THIS PAGE** U		UU	64	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-3636, ext 4605 (michael.hicks@afit.edu)