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ESSAYS ON CONTRACTUAL COMPLETENESS IN DEFENSE ACQUISITION

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Chapter 1

Introduction

The procurement of major weapons systems by the US Department of Defense (DoD) involves a challenging contracting environment in which standard pricing mechanisms, contract design, and solutions to incentive problems often do not adequately accommodate all of its unique characteristics. As a result, economists have frequently aspired to model these idiosyncratic features to address concerns of efficiency and strategic manipulation, among others. My intent with this collection of essays is to continue this endeavor. Specifically, I will apply economic analysis to the US defense acquisition process in order to enhance current understanding of the defense procurement environment, the tools available to DoD officials in addressing unique procurement issues, and the potential usefulness of these tools in other procurement scenarios. My analysis includes the investigation of multiple policies and institutions within the DoD contracting environment and focuses primarily on the DoD's employment of an incomplete contracting approach.

The next chapter examines the determinants of contractual completeness in major weapons procurement. The focus of this chapter is the DoD acquisition official's selection of a contract type, given project and firm characteristics. Additionally, the empirical research in this chapter aids in describing the role of repeat interactions in the defense contracting environment. The third chapter addresses the relevance of describability in determining cost outcomes for DoD weapons contracts. Indescribable physical characteristics and unachieved states of nature are at the heart of the hold up problem, yet economists debate the optimality of an incomplete contract as a possible solution. Using contract selection guidelines from the Federal Acquisition Regulation and performance indicators from the DoD's Earned Value Management process, I analyze the impact of *ex ante* physical describability of the underlying project on subsequent cost and schedule performance of its associated contract. My intent with this chapter is to offer new empirical information pertinent to the debate regarding the relevance of describability. Finally, the fourth chapter provides a theoretical model of contract design in the presence of exogenous uncertainty regarding the common procurement cost of an item. This chapter capitalizes on similarities between DoD acquisition and post-disaster highway procurement to demonstrate the possible gains of extending some of the DoD's contract design tools to additional government agencies.

Chapter 2

Uncovering The Determinants of Contractual Completeness In The Acquisition of Major Weapons Systems

Abstract

Major weapons acquisition comprises a significant portion of the immense budget for National Defense in the United States. The role of the U.S. Department of Defense (DoD) as both sole customer and regulatory supervisor of the U.S. defense industry places it in a unique position, as it must simultaneously promote innovation in defense technology and oversee production efficiency and profit of defense firms. Given the current budgetary environment in the U.S., this latter requirement is of primary importance. As a result of its aforementioned singular role, acquisition officials for the DoD are able to select from a wide range of contract structures in order to accommodate technological complexity, uncertainty due to dynamic political and strategic environments, and the need to continuously reward significant improvements in defense technology. This paper attempts to determine whether uniform or common practices exist in the application of the Federal Acquisition Regulation to the choice of contract type. Specifically, I estimate the empirical significance of project and winning firm characteristics in the acquisition official's ultimate choice. The research contained in this paper builds upon previous work in the defense contracting literature by examining a larger sample of military programs, including contract information from all three branches of the military (Army, Navy, and Air Force) and by considering the effect of repeat interactions in the defense acquisition environment. Additionally, the theoretical approach to *ex ante* contract formalization costs and *ex post* contractor opportunism differs from prior entries in the literature.

2.1 Introduction

The United States Department of Defense (DoD) currently finds itself in a challenging budgetary environment. Due to the completion of Operation Iraqi Freedom and the pending drawdown of U.S. forces in Afghanistan, the operational requirements for the U.S. military have diminished, providing a window for Congress to drastically reduce defense expenditure. To date, Congress has ordered the Pentagon to reduce the defense budget by $450 billion over the next decade, equivalent to a reduction in the base defense budget of approximately eight percent per year (Shanker and Bumiller, 2011).

These cuts have necessitated a renewed focus on efficiency and frugality within the DoD. For example, according to officials in the Performance Assessment and Root Cause Analyses (PARCA) for the Office of the Secretary of Defense, the defense contracting process must be thoroughly reviewed to ensure that its contracts are being awarded efficiently and are incentivizing cost-minimizing behavior by defense firms.[1] Additionally, the DoD's senior acquisition official, Undersecretary of Defense Frank Kendall, clearly stated the organization's efficiency goals in an October 2011 memorandum:

> The Department (DoD) cannot continue the practice of starting programs that prove to be unaffordable. We will work with the requirements and resources communities to ensure the programs we start have firm cost goals in place, appropriate priorities set, and the necessary trade-offs made to keep our programs within affordable limits.[2]

Statistical analysis of prior and existing contracts is, of course, an obvious yet necessary first step in ensuring that DoD acquisition policy is able to support Mr.

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[1] From personal interview with the director of PARCA, 28 February 2012.

[2] Initial guidance from the Acting Undersecretary of Defense for Acquisition, Technology, and Logistics. 7 October 2011.

Kendall's affordability goals for its future contracts. In order to fully understand the various factors that lead to adverse cost outcomes in weapons procurement, it is important to account for the entire acquisition process, including idiosyncrasies in the source selection and contract design phases. This paper will focus on the latter step, specifically on the acquisition official's choice of contractual completeness for a given project.

Economic researchers have previously examined the contract type decision in defense procurement. For instance, Crocker and Reynolds (1993) use contract information from the procurement of F-15 fighter jet engines to examine the question of optimal contract completeness.[3] The authors theorize and verify that both *ex ante* environmental complexity and potential for *ex post* opportunism are significant determinants of contractual completeness.

My goal for this paper is to broaden the scope of Crocker and Reynolds (1993). Using contract data for 18 DoD aircraft programs, this paper attempts to determine the empirical significance of project and firm characteristics in the choice of contract structure by U.S. acquisition officials. In contrast to Crocker and Reynolds (1993), I hope to determine whether these relationships are robust for multiple branches of the U.S. military and to a limited amount of project heterogeneity. Furthermore, I consider the effect of repeat interaction between the DoD and defense contractors on the contract type decision, extending the work of Corts and Singh (2004) to the defense industry. Similar to their finding that repeat interaction and contract power are substitutes in the offshore drilling industry, my results indicate that previous experience and contractual completeness are substitutes in the defense acquisition environment.

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[3] Although the DoD defines procurement as a specific type of acquisition category, I follow convention in the economic literature by using the word "procurement" interchangeably with "acquisition" in this paper.

This paper proceeds as follows. Section 2.2 provides a review of the economic literature pertaining to contract design in defense procurement. Section 2.3 provides institutional background information on the acquisition of major weapons systems by the U.S. Department of Defense. Section 2.4 presents a theoretical model of the decision of contractual completeness in defense acquisition. Section 2.5 describes the data set used in empirical estimation of the underlying theoretical model. Section 2.6 proposes two different estimation techniques and includes the definitions of the dependent and explanatory variables used in the econometric model. Section 2.7 presents the results and analysis of my initial estimation procedure. In Section 2.8, I model the effect of repeat interactions on contract selection using Two-Stage Least Squares estimation. Section 2.9 provides alternative specifications of my estimation model to check the robustness of my results, and Section 2.10 concludes.

2.2 Literature Review

The microeconomic literature discussing major weapons procurement by the U.S. Department of Defense (DoD) considers many different aspects of this unique contracting environment. In this review, I will narrow my focus to three of the most relevant issues: 1) the role of the DoD as both regulator and sole customer of the U.S. Defense industry, 2) regulation of profit and appropriate scale in defense manufacturing, and 3) the optimality of incomplete contracts in defense procurement. Quite predictably, authors in this literature are concerned with the welfare implications of acquisition decisions for major weapons systems, which routinely require the expenditure of billions of dollars of taxpayer funds. The inherent tradeoff in this scenario is straightforward: if one concedes that security is a vital component of overall welfare, a welfare-maximizing society must balance its desire for security with its aspirations to provide other vital public services. If defense officials are funding national security in an inefficient manner, either the provision levels of other services are suffering as a result, or taxpayers are saddled with an unnecessarily high tax burden given their desired level of security.

2.2.1 Role of the Department of Defense in the Defense Industrial Sector

In an overarching review of the defense procurement process in the United States, Rogerson (1994) focuses on the unique role of the DoD in the U.S. defense industrial sector. His analysis emphasizes the importance of creating a procurement process that incentivizes research and development, accommodates extraordinary levels of uncertainty, and accounts for the DoD's role as the only purchaser of U.S. defense products.[4] Rogerson points out that defense procurement is partially defined by a relentless search for superior weapons capabilities (p. 66). As a result, the contracting process must be structured to reward continuous research and development that leads to innovation in weapons production and performance. The author also acknowledges the high levels of internal and external uncertainty as signature characteristics of weapons procurement. Internal uncertainty arises due to the technologically complex nature of the weapons production process, whereas external uncertainty is the result of an ever-changing strategic and political environment (p. 67).

Furthermore, Rogerson (1994) describes the DoD's efforts to alleviate the

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[4] Although U.S.-produced weapons systems are regularly sold to foreign countries, the DoD thoroughly regulates this process. For example, the production contracts for weapons eventually sold to foreign countries are negotiated in conjuction with the DoD and are reported to Congress in the same format as U.S. military contracts.

"hold-up problem" in defense contracting (p. 67). Firms may be reluctant to invest significant amounts of capital in defense production because they fear the DoD may abuse its bargaining power as a sole consumer, thus preventing the recovery of firm investments. In order to assuage firms' fears, the U.S. government has responded by funding a significant portion of the research and development phase and establishing "fair price" agreements with firms, whereby contracting officers may emphasize non-price factors over lowest cost in negotiating the terms of a contract (p. 68-69). Rogerson's depiction of the DoD procurement process for major weapons systems suggests that the contracting environment is both precarious and subtle, and one can easily infer from his work that standard contracting procedures may be inadequate in this complex setting.

2.2.2 Profit Regulation and Questions of Scale

Empirical studies of U.S. Department of Defense procurement appear to be few and far between. Meaningful exploration of defense contracting practices and procedures are complicated by limited access to pertinent data, inherent national security concerns, and confidentiality of the source selection process. However, several authors have used unique data sets and publicly available information to test economic theories pertaining to the procurement of major weapons systems by the DoD.

A key effort in the provision of any good whose production includes large economies of scale and of which the government is the sole purchaser , especially in the case of a private supplier, is the regulation of economic profit received by the provider. Rogerson (1989) suggests that this regulation in the defense sector is complicated by the fact that it is involved in a multi-stage process of innovation and production. However, this unique structure may allow defense officials to prevent overall positive economic profits by providing different incentives in each stage (p. 1286). Rogerson tests the hypothesis that the DoD rewards innovation, not in the research and development phase, where the merit of the innovation may be difficult to determine in an objective fashion, but during the production phase of major defense projects by allowing the winning firms to earn positive economic profits. The author considers the winning firms for 12 "major aerospace" contracts and uses firm stock prices over a five-day window surrounding the contract award date to determine the reward to each winning firm (pp. 1297-1301). On average, Rogerson estimates the "pure economic profit" of the aerospace contracts to be 3.26 to 4.68 cents for every dollar of revenue received by the winning firm. Rogerson views this result as confirmation of his hypothesis, which suggests that the DoD rewards innovation in the production phase in order to avoid difficult measurement issues in the research and development phase.

Rogerson (1990) suggests that the defense procurement process also suffers from a principal-agent problem between Congress and U.S. defense officials. This issue is the result of Congress's deferment of weapons quality decisions to the DoD, due to the Pentagon's superior expertise in defense technology. Rogerson's theoretical exposition of this problem suggests that defense officials may choose an excessive level of technology, even when the officials derive no personal utility from weapons technology (p. 88). Thus, according to Rogerson, the defense procurement process is complicated even further due to a misalignment of incentives between the quality (DoD) and quantity (Congress) decision-makers.

Rogerson (1991) empirically examines this quality-quantity decision, testing his hypothesis that the principal-agent problem leads to an inefficient scale of production in the defense sector. Using contract data for 35 military aircraft and missile programs, Rogerson estimates that production rates have no statistically significant effect on capacity utilization rates in the sample programs (production not occurring in accordance with the LRAC curve) and that the production processes exhibit excess capacity (pp. 244-246). As a result, he concludes that the production rates for the sample aircraft and missile programs are inefficiently low. While Rogerson admits that this finding could be due to the DoD's stated goal of retaining a surge capacity, he suggests that the economic losses due to inefficient choices of scale in defense production, once quantified, could have significant welfare impacts (p. 247). However, as in many economic discussions regarding defense procurement, Rogerson's argument for improved efficiency likely overlooks the DoD's larger mission, as capacity may have a strong role in foreign policy discussions.

2.2.3 Optimal Pricing Mechanisms and Contractual Completeness

Crocker and Reynolds (1993) emphasize the complex technological environment and the multiple dimensions of competition that shape the defense contracting process and attempt to model the decision of contractual completeness. According to the authors, the completeness decision is based on a fundamental tradeoff. Defense officials attempt to balance *ex ante* costs of achieving thorough contractual agreements with the *ex post* costs of allowing opportunistic behavior by the defense contractor (pp. 126-127). As previously mentioned in this review, a primary concern of defense officials is the regulation of contractor profit while supporting technological innovation, and Crocker and Reynolds are attempting to demonstrate that this goal requires contracting officials to select an optimal level of contractual completeness for each project.

The authors use contract data for the procurement of engines for F-15 and F-16 fighter jets from 1970 to 1991, including the type of contract awarded. Crocker and Reynolds order the contracts in terms of "completeness." For example, a Firm Fixed Price (FFP) contract does not allow for any *ex post* renegotiation due to fluctuations in contractor costs, whereas a Fixed Price Incentive (FPI) contract allows for the negotiation of final cost, final profit, and final price after the contract is signed (p. 130). Accordingly, a FPI contract is assigned a value of 1 (least complete), and a FFP contract is assigned a value of 8 (most complete) on the authors' "completeness" index. Crocker and Reynolds then estimate their model via OLS and Ordered Probit to examine the significance of their suggested determinants of contractual completeness. The authors find that uncertainty (environmental complexity) and contractor history of post-contract litigation with the DoD (potential for opportunism) are indeed statistically significant determinants of contractual completeness in the case of F-15 engines.

Bajari and Tadelis (2001) create a model that illustrates the important tradeoff between transaction costs, which arise due to unanticipated changes, and cost minimization incentives in contract formalization. They claim that fixed-price contracts provide the greatest cost-minimization incentives but allow for substantial costs of renegotiation if left incomplete. Conversely, cost-reimbursement contracts provide little or no incentive to minimize performance costs. However, the less restrictive structure of these contracts accommodates changes with relatively smaller transaction costs. Essentially, the authors claim that industries involving constant technological innovation (i.e., space, defense, etc.) should embrace the use of cost-plus contracts in order to better accommodate technological uncertainty.

In a related paper, Bajari, McMillan, and Tadelis (2008) -hereafter BMT- consider the decision of optimal pricing mechanisms in procurement contracting. According to BMT, the decision of whether to award a procurement contract via competitive bidding or by negotiation with the contractor is just as important as the contract specifications and payment structure (p. 373). Using contract data from construction contracts in California from 1995-2001, BMT demonstrate that project complexity (project value, size, and administrative complexity) and contractor characteristics (experience, credit history, and firm size) are statistically significant determinants of the pricing mechanism decision (p. 385). Furthermore, the authors suggest that their findings indicate a "downside" to awarding fixed priced contracts via competitive bidding, primarily due to a lack of contractor input in the design phase (p. 395). BMT assert that procurement officials should be allowed more flexibility in awarding contracts based on the characteristics of the project and potential bidders.

Further empirical contributions to the literature concerning the contract type decision include Zervos (2009) and Jensen and Stonecash (2009). Zervos uses a recursive least squares estimation technique to examine the effects of variation in NASA's procurement policies on the perceived level of competition in space procurement in the US. The author finds that consolidation of the US space industry counterintuitively led to a relatively higher proportion of non-competitive contracts awarded to space firms. Additionally, Zervos concludes that NASA did not counter this offering of fewer non-competitive awards with contract types that included "rent control mechanisms" (p. 235). Jensen and Stonecash use difference-in-difference estimation to analyze the effects of a natural experiment involving the use of two different contract types: Cost Plus and

Fixed Price. The natural experiment arises when one of two water providers in Melbourne, Australia, changes contract types while the other remains the same. In contrast to previous studies, the authors find that the change to cost plus contracts by one of the firms led to significant additional savings, using three different measures of maintenance costs (3 different dependent variables).

This paper will contribute to the aforementioned literature in several ways. First, my analysis extends the literature on contractual completeness and pricing mechanism issues to a broader class of defense acquisition programs and to the modern defense procurement environment. In comparison to Crocker and Reynolds, my sample includes contracts for multiple modern aircraft from all branches of the Department of Defense. Second, this paper perhaps sheds light on the importance of trust and reputation in the defense contracting environment by considering the impact of repeat interactions on the contract type decision. Finally, although scholars have readily identified areas of theoretical inefficiency in the awarding of defense contracts, many hypotheses regarding defense procurement remain empirically untested, tested with non-DoD data sets, or based solely on theoretical conjecture. Thus, my unique data set allows me to contribute new information to the relatively sparse empirical literature regarding defense procurement.

2.3 Institutional Background: Weapons Acquisition

The development and procurement of major weapons systems by the U.S. Department of Defense is a substantial component of the overall defense budget. Figure 2.1 depicts the development and procurement components of the U.S. National Defense budget, expressed as a percentage of total defense outlays from

1962 to 2011. Research and development expenditures remain at approximately 12-13 percent of overall defense expenditures for the majority of the period, while procurement expenses fluctuate between approximately 17 and 30 percent. This corresponds to an average of \$53.4 billion in annual outlays for procurement and \$30.3 billion for research and development during the same period.[5] While many other forms of procurement (e.g., fuel, uniforms, and a multitude of service contracts) contribute to these budget figures, the sheer magnitude of the overall costs help to emphasize the need to ensure efficiency and a feasible level of transparency in the defense contracting process.

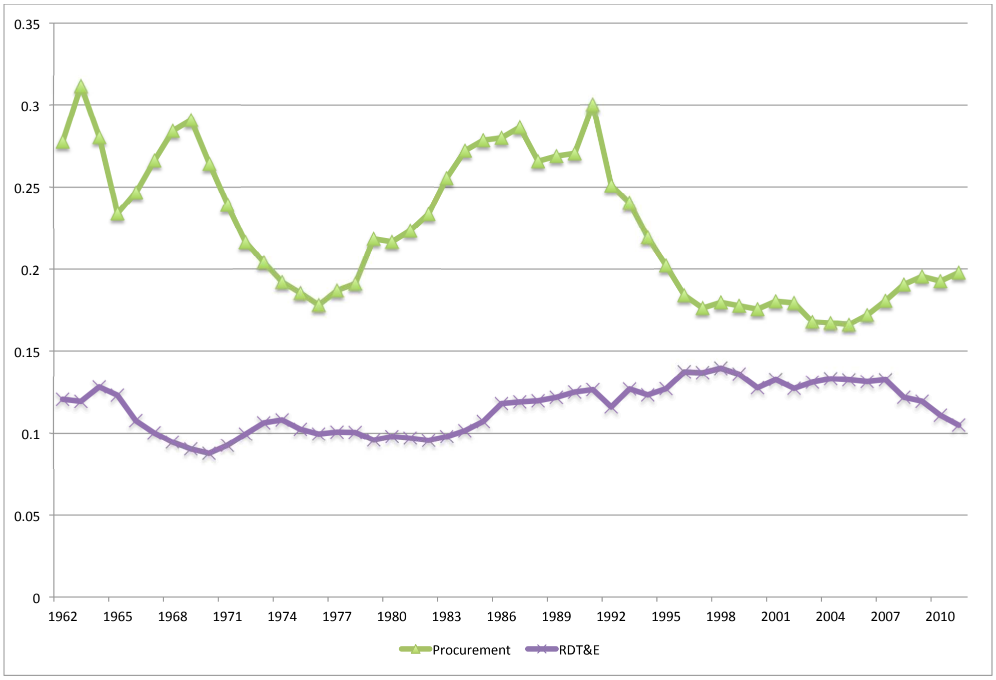

Figure 2.1: Components of US Military Spending (% of Federal Defense Outlays)

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[5] Historical Tables of the U.S. Budget, 2012

2.3.1 Federal Acquisition Regulation

The Federal Acquisition Regulation (FAR) provides guidance and direction for all forms of U.S. government expenditure, including any procurement and development by the DoD. The FAR provides guidelines and procedural requirements for all steps of the acquisition process, including but not limited to solicitation of bids, bidding procedures, contract negotiation, pricing, and payment. Despite the fact that the FAR is a 1,903-page document, its authors cannot possibly hope to account for every contingency that the contracting officer may face in his or her duties. To accommodate the diversity in acquisition projects, the FAR creates flexibility in the contracting process by providing a menu of different types of contracts that a defense official can award to a winning bidder. Specifically, the FAR gives the following statement in justification for a range of contract types:

> A wide selection of contract types is available to the Government and contractors in order to provide needed flexibility in acquiring the large variety and volume of supplies and services required by agencies....The objective is to negotiate a contract type and price (or estimated cost and fee) that will result in reasonable contractor risk and provide the contractor with the greatest incentive for efficient and economical performance. [6]

The following contract types are a selection of a larger range of types, intended to accommodate the entire acquisition process, from initial research and development to full-rate, multi-year production. Specifically, these types are represented in the data sample used for regression analysis in this paper.

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[6] FAR, 16.101a and 16.103.

- **Firm Fixed Price (FFP)**: A firm-fixed-price contract establishes a price that is not subject to revision based on unexpected cost fluctuations during the performance of the contract. The contractor is fully responsible for all costs and associated profit or loss and bears a maximum amount of risk under this type of contract. Accordingly, an FFP contract creates a maximum incentive for the contractor to account for and control cost variation, while placing a minimum oversight burden on defense acquisition program managers.[7]

- **Fixed Price Contract with Economic Price Adjustment (FPEPA)**: A FPEPA contract allows for revision of the fixed price only in the event of specified contingencies. The FAR provides guidance for three general types of economic price adjustments: 1) adjustments based on a change in prices from an agreed-upon level, which must be specified in the contract; 2) adjustments based on changes in "actual" material or labor costs experienced during performance of the contract; and 3) adjustments based on changes in agreed-upon indices of labor or material costs, which must be specifically identified in the contract.[8]

- **Fixed Price Incentive Contracts (FPI)**: A FPI contract allows the defense official to adjust profit, using a formula based on the ratio of final total cost to target total cost. The FAR specifies several types of FPI contracts.[9] However, only one of these contract types appears in the data sample that I use for this paper:

  - **Fixed Price Incentive (Firm Target) (FPIF)**: A FPIF contract

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[7] FAR, 16.202.

[8] FAR, 16.203.

[9] FAR, 16.204.

provides an agreed-upon target cost, target profit, price ceiling, and profit adjustment formula (FAR, 16.403-1). After completion of the contract, the contracting parties determine the final cost and apply the profit adjustment formula from the initial contract to determine a final price. This provides an incentive for the contractor: if final cost exceeds the target cost, final profit will be less than target profit due to the structure of the adjustment formula. However, if the contractor's final cost is lower than the target cost, the firm receives final profit that exceeds target profit. Finally, if the contractor's final costs exceed the established price ceiling, the contractor must absorb the excess cost.

- **Cost-Reimbursement Contracts**: This broad category of contracts provides for the payment of "allowable incurred costs." As part of these contracts, the contracting parties agree upon both a total cost and a price ceiling, beyond which the contractor assumes all risk.[10]
  - **Cost Plus Incentive Fee (CPIF)**: A CPIF contract allows the responsible defense official to adjust the terms of the contract, using a formula based on the ratio of final total cost to target total cost.[11]
  - **Cost Plus Award Fee (CPAF)**: A CPAF contract allows the defense official to augment the initial negotiated fee with an award, which is based on "a judgmental evaluation by the Government (FAR, 16.305)." The specified intent of this award is to "provide motivation for excellence in contract performance (FAR, 16.305)."
  - **Cost Plus Fixed Fee (CPFF)**: A CPFF contract specifies an

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[10] FAR, 16.301-1.

[11] FAR, 16.304.

agreed-upon fee, which is adjusted only in the event that the "work to be performed under the contract" changes during the contract period (FAR, 16.306). This type of contract is intended to allow risk sharing between the contractor and the U.S. government. However, the authors of the FAR admit that this type of contract provides little motivation for the contractor to minimize costs, as the contractor's profit is fixed by the terms of the initial contract.

These contract types allow the responsible acquisition official to weight both project and firm characteristics in deciding upon an appropriate form of agreement between the U.S. government and a profit-seeking private firm.

2.3.2 Selected Acquisition Reports

While acquisition officials for the DoD certainly follow the FAR and its established procedures, the aforementioned magnitude of defense research and procurement expenditure has led to significant additional regulatory classification and oversight from Congress. The DoD must designate all weapons programs that exceed $365 million in total research, development, training, and evaluation (RDT&E) or $2.19 billion in total procurement costs (FY 2000 constant $) as Major Defense Acquisition Programs (MDAPs) in accordance with 10 U.S.C. 2430.[12] Additionally, the Secretary of Defense must submit an annual Selected Acquisition Report (SAR) for every MDAP to Congress for review of each program. Each SAR must contain total cost of the program, program schedule, and a cost analysis for the projected life cycle of the program. In addition to annual SARs, the Secretary of Defense must also submit a quarterly SAR in the

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[12] Defense Acquisition University, www.acc.dau.mil.

event that the average cost of procurement exceeds the agreed-upon target by 15% in accordance with 10 U.S.C. 2432.[13] The SAR process provides Congress with a framework to make informed decisions regarding the development and procurement of major weapons systems. It is in this context that elected representatives are responsible for ensuring that DoD acquisitions are serving U.S. taxpayer interests in an efficient and welfare-maximizing manner.

2.4 The Model

Following Crocker and Reynolds (1993) -hereafter CR- and BMT (2008), the remainder of this paper will focus on modeling the defense acquisition official's selection of contract type in component contracts for Major Defense Acquisition Programs.

In accordance with previous literature in the field, the contract type decision is based upon a tradeoff between *ex ante* contractual costs (transaction costs) and *ex post* opportunities for the contracting firm to achieve additional profit due to its information advantage. Contractual costs will arise, as in CR, due to the technological complexity of modern weaponry and the external uncertainty associated with dynamic threats to national security and the politicization of the defense acquisition process in the US. In such an ambiguous and fluid production environment, it seems virtually impossible that a defense acquisition official could account for and negotiate upon every possible contingency.[14] Meanwhile, the same defense official must also protect the interests of the U.S. taxpayer

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[13] Ibid.

[14] Interestingly, the government quantifies its administrative costs for awarding and administering eact contract under a single, fixed-price, sealed bid solicitation at $500 (FAR,14.201-8). However, the FAR also requires the contracting official to address the significant additional monitoring resources in awarding any contract type other than fixed-price (FAR, 16.306).

and adhere to Congressional mandates by regulating the profit of the defense contractor. This possibility of *ex post* seller opportunism, in CR's terminology, arises due to the defense contractor's information advantage surrounding the production process. The DoD has no organic ability to produce, nor does it often have an alternative supplier for major weapons systems, leading to a dominant bargaining position for the contractor in the full production phase of contracts.

In addition to these concerns, the DoD must be, according to Rogerson (1989), ever cognizant of its role as both regulatory supervisor and sole consumer of the U.S. defense industrial base. Therefore, defense acquisition officials must balance the requirement to promote innovation in DoD technology with its requirement to regulate profit in the defense industry. For example, the use of unmanned devices by military forces has expanded rapidly over the last decade, primarily due to the unique operational requirements of the Global War on Terror. The prevalence of urban and mountainous terrain has led to a greater need for unmanned aerial vehicles (UAVs), while the widespread use of improvised explosive devices against U.S. land vehicles and dismounted troops has necessitated the use of unmanned ground vehicles (UGVs). Due to the immediate requirement for these capabilities, the rapid fielding of UAVs and UGVs occurred in a relatively short time span (only the UAVs in my sample had a development time of less than five years), perhaps requiring more flexibility in the contracting process. Certain UAVs were distributed at the tactical level, requiring simple controls and launch procedures. Meanwhile, UAVs controlled at higher levels of command required heavier ordnance, actual runways, and experienced pilots. The diverse array of missions identified for UAVs in a relatively short time span required flexibility within the terms of the contract to adjust the product design as necessary.

At this point, I again follow CR in modeling the defense acquisition official's decision of an optimal level of contractual completeness as his or her choice of contract type. This optimal level of completeness is based on the aforementioned balance of *ex ante* contractual costs and *ex post* emphasis on profit regulation. However, I deviate from CR in their measures for *ex ante* costs and *ex post* opportunism. Instead, I choose to model the contractual completeness decision based on project characteristics (x) and winning firm characteristics (y) to accommodate the multidimensionality of the contract-type decision. Certain project characteristics - dollar amount, military branch, technological complexity - may indicate unique *ex ante* contracting costs, while other project characteristics - the presence of multiple winning firms in RDT&E contracts - may limit the opportunities for *ex post* surplus extraction by the defense firms. Likewise, certain firm characteristics, such as firm experience, firm size, or firm revenue, could have effects on both *ex ante* costs and *ex post* opportunism. An experienced firm may be familiar with the defense contracting process, leading to reduced negotiation and administrative costs, while this same measure of experience might clearly serve as an indicator of a series of profitable defense contracts for the firm. However, a profitable firm in the defense industry may have an extensive history of litigation with the U.S. government, as in Crocker and Reynolds (1993).

In order to illustrate the theoretical foundations of this model, we can consider CR's explanation of the acquisition official's decision as the selection of an optimal level of incompleteness, i^*, where $i^* \in [0, 1]$.[15] Therefore, if ($i^* = 0$), we would expect that the contract covers all potential and hypothetical outcomes from the suggested transaction. If ($i^* = 1$), the contractual arrangement does not implement any structure on the transaction. The acquisition official arrives at this decision by equilibrating the marginal cost and marginal benefit of achieving

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[15] Crocker and Reynolds (1993), p. 128

a precise contract.

From above, we assume that the acquisition official's primary costs incurred in creating a precise contract are the result of research and deliberation about possible contingencies. As the number of possible outcomes considered and covered in the contract grow, we expect the costs associated with research and negotiation efforts to also increase. Therefore, we can expect that the marginal cost of achieving contractual agreement to grow as the degree of contractual completeness increases. Similarly, the benefits associated with a more rigorous contractual agreement are due to the perceived reduction in exposure to *ex post* opportunism. If we expect that the magnitude of the possible adverse outcomes for the participants increases as the agreement covers fewer contingencies, it follows that we would assume that the marginal benefit of achieving a more precise agreement will be greatest when the completeness level is lowest. Therefore, as depicted in Figure 2.2, we expect the marginal cost of reaching a contractual agreement to be an increasing function of contractual completeness, whereas the marginal benefit should be a decreasing function.[16]

The project and firm characteristics that I am considering in this paper could have an ambiguous effect on the acquisition official's choice of i^*. In terms of Figure 2.2, this is due to their ambiguous effect on the MC and MB curves. For example, an experienced firm may assist in streamlining the negotiation procedures, which would reduce transaction costs and shift the MC curve downwards. However, the same firm's continued viability in the industry may indicate an ability to extract rents from the procurement process, shifting the marginal benefit curve for a more thorough agreement upwards. Therefore,

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[16] Figure 2.2 is a virtual reconstruction of Figure 1 from Crocker and Reynolds (1993) with minor changes due to the differences in my model.

we can expect contracts involving different project and firm characteristics to possibly require different contract type choices to achieve an optimal level of contractual completeness.

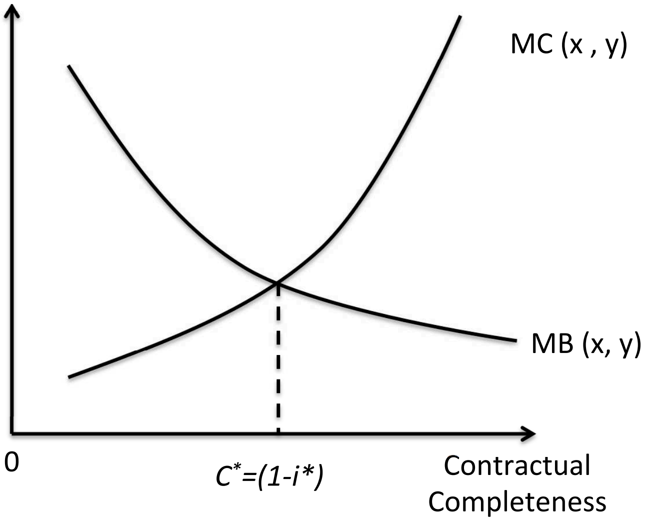

Figure 2.2: Equilibrium Concept for Contract Type Decision

In a manner comparable to CR's exposition, this series of hypotheses regarding the determinants of contractual completeness can be empirically examined using the reduced-form expression,

$$C_i^* = C(x, y) + \epsilon_i, \tag{2.1}$$

where C_i^* represents the actual level of contractual completeness, $C(\cdot)$ is a firm-invariant function used to determine contract type, and ϵ_i is a contract-specific error term. In particular, we may view the Federal Acquisition Regulation (FAR), defense acquisition history, political influence, and strategic environment as key factors in forming the function $C(\cdot)$. Using a cross-section of MDAP contracts, we can estimate the parameters of $C(\cdot)$ to determine the empirical significance of project and firm characteristics on defense officials' choice of contractual completeness.

2.5 Data

In order to estimate equation (2.1), I have constructed a cross-sectional data set of MDAP component contracts, consisting of programs from all three branches of the U.S. military (Army, Navy, and Air Force). The contract information was collected from both annual and quarterly Selected Acquisition Reports. As previously mentioned, the quarterly SARs are only generated in the event of a breach of established cost thresholds and are thus random and infrequent occurrences in the dataset.

The Department of Defense adopted the SAR format in 1997. Therefore, the available SARs range in date from 1997 to 2011.[17] However, the actual contract period varies by individual contract. For example, the data set includes both one-year initial production contracts and RDT&E contracts that extend for more than five years. In order to address heterogeneity in required technology and production characteristics, I have limited the sample to aircraft MDAPs that are currently (as of 30 APR 2012) designated as "active" by the DoD. As a result, the available sample consists of 195 individual contracts from 20 MDAPs. While I have contract data from every year from 1997 to 2011, only six of the MDAPs are active over the entire time period and none of the individual contracts cover a period longer than eleven years. Although it may seem that this data structure might facilitate the construction of an unbalanced panel, the contract type for a specific contract does not change over its lifetime, despite significant variation in

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[17] The contracts covered in these SARs have initial award dates ranging from 1986 to 2012. However, I only have observations of these contracts during the 15-year peiod indicated above.

many of the contract details. As the contract type will serve as my independent variable, this characteristic of DoD contracts requires a cross-sectional approach to my specific research question.

For each contract covered in a SAR, I am able to observe contract type, contract description, military branch, appropriation category (RDT&E vs. Procurement), initial award date, initial contract price, initial contract quantity, current contract price, current contract quantity, contractor's estimated price at completion, defense program manager's estimated price at completion, and contractor identity. In addition to serving as stand-alone project characteristics in some cases, these measures also allow me to calculate the overall cost variation of the individual contract and to discern between increases due to quantity adjustment and those due to unforeseen complications. Each contract entry also includes an identification number that allows for cross-referencing with a second U.S. government database, the Federal Procurement Database System (FPDS). From this second source, I am able to view the individual transactions that occur under the main contract number from the program SAR. Although the FPDS should theoretically allow me to collect detailed information about the contracting firm, this data is not entered into the database in a uniform or reliable manner. Therefore, I have collected all pertinent firm characteristics for the defense contractors in from annual reports to investors and Form 10-K filings to the U.S. Securities and Exchange Commission.

Prior to discussing the summary statistics for the contracts used in my empirical analysis, it is important to discuss the reduction of the overall sample due to data availability. Of the original 195 contracts, I removed twenty-five observations that were "combination" contracts, indicating that the transactions under these contract numbers were covered by various contract types. Despite the additional information contained in the FPDS database, I was unable to classify these contracts under a single contract type. Additionally, one of the contracting firms in the original sample is a private firm and does not publicly report its annual financial statistics. This resulted in the loss of an additional fifteen observations. For six contracts, I was unable to observe the completion date of the contract and was therefore unable to calculate the contract's length. Due to these data issues, my estimation sample consists of 149 observations of MDAP contracts. The MDAPS included in the estimation sample are listed in Table 2.1.

Table 2.1: MDAP Program List

CH-47F Improved Cargo Helicopter
Light Utility Helicopter
UH-60M BLACK HAWK
CH-53K Heavy Lift Replacement
E-2D Advanced Hawkeye
EA-18G Growler
F/A-18E/F Super Hornet
KC-130J
MH-60R Multi-Mission Helicopter
MH-60S Fleet Combat Support Helicopter
MQ-4C Unmanned Aircraft System Broad Area Maritime Surveillance
P-8A POSEIDON
V-22 Joint Services Advanced Vertical Lift Aircraft - Osprey
Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle - Fire Scout
C-130J Hercules
F-22 Advanced Tactical Fighter
RQ-4A/B Unmanned Aircraft System Global Hawk
F-35 Joint Strike Fighter

Tables 2.2 and 2.3 list the distribution of contract types and the distribution of firms within the sample. Approximately one-third of the contracts in the sample are Firm Fixed Price (FFP), which is similar to CR's sample of Air Force engine contracts. Roughly sixty percent of the sample contracts are fixed-price variants

and the remainder of the sample consists of cost reimbursement contracts. This distribution indicates significant variation in the type of contracts administered in the acquisition of MDAPs. Given the specialized weapons technology and production expertise required to develop and supply major weapons systems to the U.S. government, the distribution of contracting firms is, perhaps unsurprisingly, quite concentrated. The five largest firms in terms of number of contracts account for roughly eighty-five percent of the overall number of contracts.[18]

Table 2.2: Distribution of Contract Types

	Total	% of Sample
FFP	54	36.24%
FPEPA	6	4.03%
FPIF	30	20.13%
CPIF	21	14.09%
CPAF	24	16.11%
CPFF	14	9.40%

Table 2.3: Distribution of Contracts By Firm

Firm	Total Contracts	% of Sample
A	1	0.67%
B	10	6.71%
C	1	0.67%
D	33	22.15%
E	23	15.44%
F	3	2.01%
G	4	2.68%
H	16	10.74%
I	34	22.82%
J	24	16.11%

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[18] Note that, while I am able to observe contractor identity in the SAR contract information, I have specifically chosen not to disclose that information in this paper.

Table 2.4 provides a more detailed description of the contracts in the estimation sample. Of note, over half of the contracts in the sample correspond to Navy MDAPs, and approximately thirty percent of the contracts are for RDT&E purposes. The contracts managed by the Department of Defense, rather than by one of the three branches of the military, are part of the F-35 Joint Strike Fighter MDAP. The unique nature of this particular program will be discussed further in the results section of the paper. Although not listed in table 2.4, two additional summary statistics warrant mention. The data sample includes twelve contracts for MDAP components provided by dual source suppliers, representing approximately eight percent of the overall sample. Additionally, over forty percent of the contracts are performed by "Non-Subdivision" firms, which are not segments of larger corporations. For instance, Sikorsky Aircraft Corporation and Pratt-Whitney are operating segments of United Technologies Corporation, whereas Raytheon is a stand-alone corporation. In assigning this category, I defined a "Subdivision" as any firm whose stock did not trade under its own symbol on a major exchange.

Table 2.4: Summary Statistics for MDAP Contracts

	Total	% of Sample
Army	21	14.09
Navy	81	54.36
Air Force	32	21.48
Dept. Of Defense	15	10.07
RDT&E	46	30.87
Procurement	100	67.11
Acquisition O&M	3	2.01

2.6 Estimation

In order to establish the relative statistical significance of project and firm characteristics in the defense acquisition official's choice of contract type, I will estimate the following equation:

$$C_i = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{l=1}^{m} \gamma_l y_l + \alpha_i + \epsilon_i, \tag{2.2}$$

where each x_j is a project characteristic and each y_l is a firm characteristic. This specification assumes that the ϵ_i are independently and identically distributed error terms, with mean zero and constant variance σ_ϵ^2. Using the information in my data set, I am also able to estimate contractor-specific intercepts, α_i's. In addition to the firm characteristics (employment, revenue, experience), these firm-specific intercepts should allow me to capture the full effect of firm heterogeneity on the acquisition official's choice of contract type. In order to proxy for external uncertainty, I include an indicator variable for the contract's award year as an additional project characteristic (x_j).

I will estimate equation (2.2) via Ordinary Least Squares and Ordered Probit. Due to the fact that the dependent variable is not a continuous variable but a set of discrete choices, the OLS estimation technique can result in inconsistent estimates of the model parameters (Maddala (1983)). The Ordered Probit estimation method accounts for the fact that the dependent variable is actually "ordered" via its relationship with an "underlying latent variable" (Crocker and Reynolds (1993), p. 141). In my model, the dependent variable (a series of discrete numbers 1 to 6) is actually determined using an underlying latent variable (the scale of contractual completeness).

2.6.1 Dependent Variable

Following Crocker and Reynolds (1993), it is possible to rank the various contract types using a “qualitative index of completeness,” where lower values in the index include less rigorous contractual agreements (p. 132). Some additional analysis, focusing on the opportunity for renegotiation by the contracting firm under each contract type, is required to construct this index. The FAR allows the contracting officer to use cost-reimbursement type contracts only in the event that 1) project circumstances do not allow the contractor to define requirements to a degree that will facilitate a fixed-price type contract; or 2) uncertainties pertaining to contract performance do not allow for a “sufficient” level of accuracy in the estimation of costs (FAR, 16.301-2). Therefore, all cost-reimbursement contracts should be ranked lower than fixed-price contracts in terms of completeness. Furthermore, contracts with award and incentive fees should be ranked lower than those with fixed fees in the index. This is due to the fact that the contracting firm controls its profit levels to a much greater degree in these contracts. Moreover, an incentive fee contract, which is based on a profit adjustment formula that the firm can control, should be ranked lower than the award fee, which is based on a “judgmental” performance assessment from the U.S. government (FAR, 16.305). The relative completeness rankings of the FPEPA and FFP contracts are straightforward.

Table 2.5 lists the completeness index that this paper will incorporate as the dependent variable in regression analysis. The underlying assumption required for the use of this index to address the determinants of contractual completeness is that the agreed-upon contract type represents an optimal level of completeness, given the firm and project characteristics under consideration. In other words, we assume that the contract type decision represents the contracting official's equilibrium choice of C^* from Figure 2.2. Based on the contracts in the estimation sample, the mean completeness level is 3.93 with a standard deviation of 1.87.

Table 2.5: Dependent Variable for Estimation (Completeness Rank)

C (Completeness) =	1 if type =	CPIF (Cost-Plus Incentive Fee)
	2 if type =	CPAF (Cost-Plus Award Fee)
	3 if type =	CPFF (Cost-Plus Fixed Fee)
	4 if type =	FPIF(Fixed-Price Incentive Fee)
	5 if type =	FPEPA (Fixed-Price, Economic Price Adj.)
	6 if type =	FFP (Firm Fixed Price)

2.6.2 Explanatory Variables

The project characteristics (x) and firm characteristics (y) for each contract serve as the covariates in equation (2.2). Table 2.6 provides a list of my proposed explanatory variables and their definitions, while Table 2.7 lists the summary statistics for these variables from the sample of contracts used for estimation. Prior to estimation, it is important to justify my selection of these variables and to elaborate briefly on their definitions.

Project Characteristics

In accordance with the cost-benefit analysis mentioned earlier in this paper, it may be reasonable to expect that contracting officials will be more thorough in constructing more expensive contracts. Leaving room for negotiation or surplus extraction in these contracts could expose the government to a relatively greater risk of surplus extraction. Therefore, we might anticipate that a contract's size (in dollar amount) could affect the acquisition official's choice of contractual completeness. To control for project size, I included the initial price ($ADJIP$) for each contract. In order to compare prices across all contracts, I used the Official 2013 Escalation Index used to account for inflation in December 2011 SARs. This calculation converted all contract prices to 2005 U.S. dollars.

To further control for project heterogeneity in the contract type decision, I included indicator variables for controlling military component (Army, Navy, or Air Force) and for the acquisition phase during which the contract was awarded (RDT&E or Procurement) In the case of military component, contracts controlled by the Department of Defense are in the excluded category, and O&M (Operations and Maintenance) contracts are the excluded acquisition phase category.

The presence of internal and external uncertainty in defense procurement is one of its defining characteristics. Constantly advancing the technological frontier in defense weaponry will require the Department of Defense to display both patience and encouragement to the defense industry as they strive to maintain technological superiority. However, the DoD's ability to fund and promote the efforts of its contractors is directly affected by external threat, political pressures, and economic conditions within the United States. In order to capture the effects of uncertainty on the acquisition official's choice of contract type, I use a combination of several control variables.

I use the variable $LENGTH$ to proxy for the effects of external uncertainty. If a longer contracted time period is more likely to expose the parties to unanticipated changes in the security and political environments, the acquisition official may select a more complete contract type for agreements covering longer periods. I use the variable $WINAGE$ to control for internal uncertainty. It is reasonable to expect that contracts earlier in the life of an MDAP will involve more unproven technology. Due to the fact that an acquisition program progresses from development to low-rate initial production to multi-year production, one would expect that earlier contracts in the program would involve the most complicated technological issues. Therefore, it is likely that a contracting official might choose less complete contract types in the early phases of a MDAP. In order to calculate *WINAGE*, I determined the number of years between a contract's award date and the initial award date for any contract within the same MDAP.

The next variable that I use to control for internal and external uncertainty, *LVAR*, requires further explanation. In Crocker and Reynolds (1993), the authors capture the effect of technological uncertainty by including a variable for "Unexpected Engine Removals," which occur when an aircraft engine fails and must be removed prior to scheduled maintenance (p. 138). The authors assume that the acquisition official would anticipate these removals and assign a contract type accordingly, thereby assuming that the engine removals are realizations of the official's *ex ante* perception of technological uncertainty. In a similar manner, I now assume that any cost variation or quantity changes, which result in price variation in my sample, are the realizations of anticipated environmental uncertainty by contracting officials. In other words, the officials would have chosen specific contract types that would allow these cost fluctuations or quantity changes to occur within the terms of the agreement. This variable is calculated using a contract's initial price and repeat observations of a contract's current price from multiple SARs.

The presence of a secondary source for a particular component may inhibit a firm's ability to extract contractual surplus at subsequent stages of renegotiation. For example, a contractor is unlikely to attempt to take advantage of the government in subsequent negotiations if the government has the option to purchase solely from a secondary source. As a result, it may be the case that the acquisition official can issue less complete contracts in these cases due to the passive enforcement mechanism provided by the alternate contractor. In order to control for this competitive effect, I include the indicator variable $DUALS$ for contracts that provide an item that is also provided to the DoD in a separate contract by another firm.

Firm Characteristics

As mentioned in the Model section of this paper, the characteristics of a firm that signal its profitability or success within the defense industry may have confounding effects on the acquisition official's choice of contract type. Although a successful firm may have a demonstrated ability to work within the regulatory structure of the defense procurement environment, it is also possible that this success may be an indicator of the firm's innate ability to extract contractual rents from the government. Therefore, the hypotheses for the effects of the firm characteristics on the acquisition official's contract type decision may not be as straightforward as the effects of the project characteristics. One of the empirical goals of this paper, therefore, is to attempt to determine whether firm characteristics affect acquisition officials' decisions in a uniform manner.

In order to shed light on this issue, I include measures of firm size: annual revenue ($LREV$) and annual employment ($LEMP$). The revenue figures are from the annual investor reports or Securities and Exchange Commission filings for the year in which the contract in question was awarded. In the case that the contractor is part of a larger firm, I use the operating segment revenues (i.e., the segment revenues for Sikorsky Aircraft Corporation rather than the revenue for the entire United Technologies Corporation). In order to compare firm revenue *(LREV)* across contracts, I first converted foreign currencies to U.S. dollars using the appropriate exchange rate for firms whose parent companies traded on foreign stock exchanges.[19] I then used the aforementioned Escalation Index to convert all revenue figures into 2005 U.S. dollars. I collected the firm employment figures from the same investor reports and Form 10-K filings. However, I was unable to collect employment data at the operating segment level. Therefore, the employment figures reflect the overall annual corporate employment levels. In order to better understand the effect that this measurement issue may have on my results, I will interact the non-subdivision indicator (*NSD*) with the continuous firm characteristics during estimation.

Another factor that may affect the acquisition official's contract type choice is the firm's reputation or past business history with the Department of Defense. One might expect that defense officials would be more apt to allow firms with more experience in weapons production to operate under less restrictive contractual conditions. On the other hand it may be more feasible to negotiate a fixed price contract with an experienced firm, which might be more adept at forecasting supply chain issues, production requirements, etc. This effect would tend to lead to a more complete contractual agreement, on average. Therefore, this is another instance in which the firm characteristic has an ambiguous theoretical effect on the acquisition official's choice of contract type. To capture the effect of a firm's business history with the Department of Defense, I include the variable *PREVCONT*. This variable is calculated using only the contracts that appear within my estimation sample. While this is certainly not an ideal measure of contractor experience, it is similar to the method used by BMT (2008).

Finally, it is likely that the government is cognizant of its business partners' financial viability. In other words, it is unlikely that the DoD will agree to

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[19] I gathered all exchange rate information from xe.com.

terms with an inherently risky company without requiring certain contractual concessions to ensure that its interests are protected in the event that the firm becomes insolvent. Due to the fact that many of the firms in my empirical sample are operating segments of larger corporations, this concern is even more appropriate. Although the DoD may interact only with representatives from the defense segment, one would expect that the DoD would also be aware that the larger corporation's overall financial status could affect all of its divisions. To proxy for short- and long-term indebtedness, I have also included the firm's current ratio (current liabilities / current assets) and its leverage ratio (long term debt / total assets), which I collected from annual investor reports and Form 10-K Filings.

Table 2.6: Explanatory Variables

Project Characteristics (x)	Definition
ladjip	Log of Inflation-Adjusted Initial Contract Price ($Millions)
army, navy, af	Separate Intercepts for Army, Navy, AF (DoD excluded)
rd, proc	Separate Intercepts for RDT&E and Procurement (O&M excluded)
length	Number of Months between Contract Award Date and Scheduled Completion
lvar	Log of (1+Variance) of Contract's Target Price
winage	Within Program Age (in Years): Contract Award Date - Initial Award Date
duals	Indicator Variable for Presence of Multiple Sources (=1 if Multiple)
Firm Characteristics (y)	**Definition**
lemp	Log of Annual Employment
lrev	Log of Inflation- and Exchange Rate- Adjusted Annual Revenue (Segment Level)
prevcont	Number of Existing Contracts for Firm Prior to Award Date
nsd	Indicator Variable for Firms that are not a Subdivision of a Larger Corporation
cratio	Firm's Current Ratio (Current Liabilities/Current Assets)
lev	Firm's Leverage Ratio (Long-Term Debt/Total Assets)

Table 2.7: Summary Statistics for Explanatory Variables

	Mean	Std. Dev.	Min	Max
adjip ($M)	846.22	2081.46	0.33	20128.73
length	40.47	27.64	2.00	138.00
var (Thousands)	235.77	130.20	0.00	15374.20
winage	7.11	6.10	0.00	23.00
emp (Thousands)	145.01	62.77	32.00	31.90
rev ($M)	11243.05	8247.74	2275.76	30894.20
prevcont	15.11	11.48	0.00	46.00
cratio	0.90	0.22	0.48	2.15
leverage	0.16	0.07	0.05	0.39

2.7 Results and Analysis

2.7.1 Ordinary Least Squares Results

Table 2.8 displays the results of estimating equation (2.2) via ordinary least squares.[20] From the baseline regression in column (1), I can make several observations. First, the indicator variable for an RDT&E contract is negative and significant at the 10% level. This result is intuitive, as one would expect contracts during the RDT&E phase of a MDAP to include more technological uncertainty as the contractor attempts to create and integrate new defense technologies. Second, although insignificant, the negative signs on the *ADJIP* and *WINAGE* variables are counterintuitive and problematic. These measures suggest that contracts with larger initial prices and contracts that occur later in a MDAP's production cycle should be less complete, on average. Third, the firm characteristics are statistically insignificant in this regression, and I certainly hesitate to draw any conclusions about their theoretically ambiguous effects based on this initial result. Finally, note that I have included only results for regressions containing the variable *CRATIO* as a measure of a firm's financial risk. I based this decision on a comparison of Schwartz Information Criteria from regressions including only the current ratio, only the leverage ratio, and both measures.

In columns (2) and (3), I add the controls for competitive contracts, *DUALS*, and internal uncertainty, *LVAR*, respectively. In both cases, the estimated coefficients are statistically insignificant, and the indicator variable for RDT&E contracts also has a statistically insignificant effect after the addition of these

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[20] I strongly rejected my initial assumption of homoskedastic error terms using the Breusch-Pagan Test. This result holds for the sample including the F-35. However, I failed to reject the null of homoskedasticity for the sample not including the F-35. Therefore, all standard errors shown for the sample including the F-35 are heteroskedasticity-robust.

two variables to the model. In Crocker and Reynolds (1993), the presence of dual source contracts was a significant determinant of contractual completeness in several (but not all) of their regressions. However, over forty percent of the contracts in their data sample were awarded in a dual source environment (p. 137), whereas less than ten percent of the contracts in my data sample are for dual source items. I assume that this relative scarcity is a factor in the difference between our results.

In column (4), I add indicator variables for contracts controlled by different branches of the military. Interestingly, the results suggest that Army, Navy and Air Force officials select more complete contracts, on average, in comparison to the DoD baseline. In subsequent regressions in columns (5), (6), and (7), the coefficients for these variables become increasingly significant. While the rankings for the Army and Air Force alternate, the results suggest that the Navy awards the least complete contract types of the three service branches. This relative ranking is perhaps due to the Navy's involvement with projects requiring the integration of relatively more complex technologies. For example, the Navy is the controlling branch for four fixed-wing aircraft and the V-22 Osprey, an aircraft with vertical takeoff capabilities. In contrast, the Army's contracts involve only three different types of helicopters, and two of these projects are modernization programs for older airframes. Therefore, it seems reasonable that the Navy would require the use of contract types that allow for more technological uncertainty in comparison to the acquisition officials for the Army.[21]

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[21] An alternative specification might include a variable that captures the project's position relative to the frontier of defense technology at the time of its inception. However, my current level of expertise on defense aircraft is not sufficient to meaningfully differentiate beyond the differing military branches. The analysis included in this paper would be greatly strengthened by consultation with aircraft engineers familiar with these projects, who might possess the expertise to rank these projects on a scale of technological heterogeneity.

The addition of the controls for military component also results in the significance of the $WINAGE$ variable. However, the sign on this variable remains negative. This is likely due to a lack of uniformity in the length of the MDAPs contained in my data set. For example, the first contract awarded for the V-22 Osprey program occurred in 1986, and its unique technological advances required a relatively long period for research and development. As a result, acquisition officials for the V-22 were writing CPIF contracts for low-rate initial production twenty-one years after the initial contract award for the program. In contrast, acquisition officials awarded the first contract for the CH-47F in 1998 and issued its last CPIF contract after only five years. Although the contracting officials are awarding contract types in the prescribed manner (i.e., more complete contracts for later phases of production), the phases of production are not timed in accordance with an industry-wide standard, thus confounding the ability of this variable to measure the effect of the contract's placement in the overall production sequence.

In column (5), I add interaction terms to precisely examine the effect of a firm's status as a "non-subdivision" on the acquisition official's contract type decision. This step results in the significance of the $PREVCONT$ variable. The coefficient on the number of previous contracts is positive, suggesting that an experienced contractor's knowledge of the defense acquisition process, its own production capabilities, and awareness of potential technological pitfalls may allow more complete specification of potential contingencies. However, it is also possible that this variable is capturing a production sequence effect due to the fact that it is left censored. If contractors are only responsible for one project in the sample, the number of previous contracts may closely follow the number of production steps that have elapsed. If I possessed the number of previous contracts for each contractor prior to the contracts in my data sample, I would perhaps be able to separate these effects.

The coefficient on the firm's current ratio, *CRATIO*, is negative and significant in column (5), suggesting that a higher current ratio results in a less complete contract. It is possible that this result reflects the significant amount of contract-specific investment that firms must undertake during the initial phase of a MDAP. If the firms are incurring large amounts of short-term debt in order to produce a prototype or demonstrate the feasibility of the new technology, this activity would be reflected in the firms' current ratios and would likely be accompanied by a less complete contract type as a result of a large amount of technological uncertainty.

In adding the interaction terms, I sought to explore the possibility that DoD acquisition officials would have a fundamentally different approach to contracting with firms that were solely defense contractors. In column (5), we see that the coefficient on the interaction between the "non-subdivision" indicator variable and the leverage ratio is positive and significant. This suggests that defense acquisition officials perhaps approach "non-subdivision" firms that possess risky long term debt positions in a more cautious fashion than when dealing with operating segments of larger corporations with the same risk profile.

In columns (6) and (7), I sequentially introduce firm effects and then year effects as additional covariates. Unfortunately, the introduction of these additional controls for firm heterogeneity and external uncertainty result in a high degree of collinearity and questionable standard errors. Although the results in columns (6) and (7) are qualitatively very similar to column (5), I hesitate to draw any further conclusions from these additional regressions as the introduction of these additional covariates results in multicollinearity problems with the *NSD* indicator variable.

2.7.2 Ordered Probit Results

As mentioned in the Estimation Section of this paper, OLS estimation of equation (2.2) may result in inconsistent estimates of the model parameters. In order to account for the discrete nature of my dependent variable, I can estimate equation (2.2) via ordered probit.[22] Table 2.9 displays the results of this estimation procedure.

In Table 2.9, I progress from the baseline regression to the regression with firm and year effects in the same sequence as in Table 2.8. Of note, the coefficient of the RDT&E indicator variable is of smaller magnitude and is never statistically significant in the ordered probit results. Additionally, the results of column (7) should be interpreted with caution, as the model completely determines three observations once the firm and year effects are added as covariates.

The coefficient for *WINAGE* is again negative and significant. However, the coefficient is smaller in magnitude and remains significant in column (6) of the ordered probit results, after the addition of the firm intercepts. The measure of *ex ante* rational expectations of technological uncertainty, *LVAR*, is also significant following the addition of the interaction terms in column (5). However, the coefficient indicates a positive relationship with contractual completeness, which is contrary to my theoretical prediction. One would expect that a contract involving more technological uncertainty would be less rigorous in terms of describing possible outcomes, leading to a less complete contract. It is possible that the positive coefficient for this contract is due to the fact that the

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[22] Note that the regression coefficients and threshold values are determined via log likelihood maximization. See Cameron and Trivedi (2010) for a full explanation of ordered probit estimation.

measured variation in the contract price also involves price fluctuations due to quantity changes. Therefore, it is quite possible that my results are confounded by the fact that the DoD regularly modifies fixed-price variant contracts to purchase more units than initially specified, leading to large price increases.

The magnitude, significance, and sign of the ordered probit coefficients for the different firm characteristics are very similar to those from OLS estimation. Previous contracts, current ratio, and leverage ratios for NSD firms appear to be significant factors in the acquisition official's choice of contract type. Additionally, the effect of the interaction between the *NSD* indicator and revenue is positive and significant after controlling for firm effects. In other words, this suggests that NSD firms with larger annual revenues receive more complete contracts, on average. It is possible this finding is due to the aforementioned streamlining effect, where a company specializing in defense acquisition is adept at forecasting supply chain difficulties, technological hurdles, and pertinent external uncertainty.

The coefficients for the indicators of controlling military branch maintain their statistical significance from the OLS results. However, the magnitudes of these effects are much smaller when estimated via ordered probit. Furthermore, the relative ranking of the three branches in terms of average completeness of contracts is also consistent with the OLS results. The Air Force tends to award the most complete contracts, followed by the Army, with the Navy writing the least complete contracts. It's also interesting to note that the coefficients for these indicator variables are all positive when compared to the excluded category, DoD. Due to the fact that this category consists of only those from the F-35 MDAP, this finding suggests the F-35 may be inherently different from the other projects in the data sample. This possibility warrants more discussion and will be the focus of the next subsection of this paper.

Table 2.8: Ordinary Least Squares Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ladjip	-0.0392	-0.0391	-0.0535	-0.0022	0.0053	0.0428	0.0370
	(0.0948)	(0.0952)	(0.0985)	(0.1008)	(0.0923)	(0.1042)	(0.1107)
rd	-2.0097*	-2.0179	-2.0115	-1.8792	-1.6552	-1.1230	-1.4085
	(1.2459)	(1.2560)	(1.2501)	(1.3155)	(1.4015)	(1.3358)	(1.6356)
proc	0.6921	0.6860	0.6436	0.6380	0.8922	1.2486	1.0372
	(1.2591)	(1.2651)	(1.2501)	(1.3254)	(1.4067)	(1.3281)	(1.6074)
length	0.0004	0.0004	-0.0003	0.0002	-0.0009	-0.0009	-0.0001
	(0.0042)	(0.0042)	(0.0043)	(0.0044)	(0.0043)	(0.0049)	(0.0059)
winage	-0.0440	-0.0436	-0.0457	-0.0564*	-0.0628*	-0.0537	-0.0446
	(0.0339)	(0.0337)	(0.0344)	(0.0348)	(0.0364)	(0.0407)	(0.0589)
duals		0.0540	0.0568	0.4456	0.4911	0.5080	0.3409
		(0.4849)	(0.4745)	(0.5687)	(0.5836)	(0.6432)	(0.6280)
lvar			0.0262	0.0336	0.0443	0.0505*	0.0487
			(0.0314)	(0.0320)	(0.0328)	(0.0323)	(0.0380)
army				1.1039	1.5567*	1.8474**	2.0630**
				(0.8079)	(0.8094)	(0.8748)	(1.0274)
navy				0.7349	1.0320*	1.4010**	1.4230*
				(0.6091)	(0.6099)	(0.6634)	(0.7810)
af				1.3058*	1.6216**	1.9754***	1.8556**
				(0.6934)	(0.6747)	(0.7138)	(0.7924)
lemp	-0.0618	-0.0630	-0.0472	-0.2260	-0.3329	-0.6720	-1.0866
	(0.3690)	(0.3719)	(0.3727)	(0.3514)	(0.3726)	(1.1735)	(1.4656)
lrev	-0.1763	-0.1739	-0.1621	-0.1182	-0.0675	-0.0540	-0.1334
	(0.2155)	(0.2179)	(0.2177)	(0.2280)	(0.2648)	(0.3391)	(0.4128)
prevcont	0.0179	0.0178	0.0196	0.0225	0.0358**	0.0528**	0.0967**
	(0.0127)	(0.0127)	(0.0135)	(0.0150)	(0.0161)	(0.0215)	(0.0436)
nsd	0.4010	0.4029	0.3878	0.2289	-3.7534	omitted	omitted
	(0.2771)	(0.2820)	(0.2858)	(0.3657)	(10.0122)		
cratio	-0.5370	-0.5280	-0.5439	-0.8285	-1.7982*	-1.5869	-1.6410
	(0.5981)	(0.5995)	(0.6230)	(0.8999)	(0.9890)	(1.4121)	(1.6643)
nsd × lrev					0.4676	1.3120**	1.4851
					(0.7273)	(0.6533)	(1.0058)
nsd × cratio					1.1137	-0.9830	-2.3301
					(1.5213)	(1.7368)	(2.4081)
nsd × lev					7.0754**	12.9814***	14.7246***
					(2.8610)	(3.6207)	(4.9891)
nsd × lemp					-0.2228	1.1801	1.3938
					(0.8234)	(1.4391)	(2.0276)
constant	6.9632*	6.9477*	6.5977	7.4092*	8.3168*	10.9795	16.9883
	(4.1601)	(4.1670)	(4.2076)	(4.0859)	(4.2991)	(14.4671)	(18.0231)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
R-Squared	0.4184	0.4185	0.4218	0.4480	0.4764	0.5452	0.5765
F Statistic	18.37	18.42	16.74	12.05	11.92		
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000		
N	149	149	149	149	149	149	149

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.9: Ordered Probit Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	-0.0117 (0.0666)	-0.0115 (0.0667)	-0.0263 (0.0707)	0.0170 (0.0750)	0.0256 (0.0733)	0.0536 (0.0866)	0.0423 (0.0931)
rd	-1.1449 (1.0407)	-1.1639 (1.0453)	-1.1707 (1.0420)	-1.1183 (1.0756)	-0.9086 (1.1064)	-0.5509 (1.1189)	-0.8921 (1.2755)
proc	0.6103 (1.0445)	0.5970 (1.0444)	0.5556 (1.0417)	0.5528 (1.0742)	0.8689 (1.1045)	1.2260 (1.1089)	1.0276 (1.2430)
length	-0.0003 (0.0030)	-0.0003 (0.0030)	-0.0008 (0.0030)	-0.0007 (0.0031)	-0.0016 (0.0031)	-0.0013 (0.0038)	0.0001 (0.0044)
winage	-0.0401 (0.0276)	-0.0392 (0.0273)	-0.0412 (0.0280)	-0.0485* (0.0280)	-0.0621** (0.0298)	-0.0581* (0.0351)	-0.0436 (0.0496)
duals		0.1210 (0.3999)	0.1170 (0.3893)	0.4203 (0.4911)	0.4902 (0.5422)	0.5352 (0.5848)	0.4029 (0.5538)
lvar			0.0226 (0.0241)	0.0289 (0.0247)	0.0429* (0.0261)	0.0505* (0.0270)	0.0535* (0.0316)
army				0.8037 (0.5992)	1.2532* (0.6414)	1.5640** (0.7233)	1.8640** (0.8423)
navy				0.4841 (0.4510)	0.7656** (0.4853)	1.1080** (0.5473)	1.2327** (0.6405)
af				0.9702* (0.5006)	1.3504*** (0.5276)	1.8078*** (0.6047)	1.6976*** (0.6614)
lemp	-0.1292 (0.2932)	-0.1295 (0.2936)	-0.1135 (0.2945)	-0.2411 (0.2763)	-0.3831 (0.2934)	-0.4960 (0.8816)	-0.7687 (1.1063)
lrev	-0.1510 (0.1648)	-0.1481 (0.1649)	-0.1388 (0.1659)	-0.1156 (0.1733)	-0.0983 (0.2079)	-0.1203 (0.2676)	-0.2023 (0.3209)
prevcont	0.0164 (0.0108)	0.0162 (0.0107)	0.0179 (0.0114)	0.0193 (0.0124)	0.0318** (0.0141)	0.0498*** (0.0194)	0.0888** (0.0377)
nsd	0.2834 (0.2119)	0.2884 (0.2166)	0.2709 (0.2224)	0.1539 (0.2901)	-6.7072 (8.9785)	-26.2766 (15.7126)	-30.8976 (19.7908)
cratio	-0.4285 (0.4381)	-0.4054 (0.4369)	-0.4124 (0.4572)	-0.6077 (0.6601)	-1.4676** (0.7363)	-1.5686 (1.0639)	-1.3806 (1.2459)
nsd × lrev					0.5788 (0.5538)	1.2713** (0.5828)	1.2087 (0.8771)
nsd × cratio					0.9093 (1.0931)	-1.4503 (1.3964)	-2.4193 (2.0764)
nsd × lev					6.2724*** (2.3508)	11.7382*** (3.5143)	12.4292*** (4.3422)
nsd × lemp					-0.3534 (0.6994)	1.5192 (1.3391)	2.1090 (1.7398)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
Likelihood Ratio	62.07	67.41	68.33	86.7	100.22	513.95	1049.5
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N	149	149	149	149	149	149	149

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2.7.3 Estimation without the F-35 MDAP

With a price of \$81.4 million per aircraft and a total program cost exceeding \$1 trillion, the F-35 Lightning Joint Strike Fighter is the most expensive single weapon program in the history of the United States Department of Defense.[23] Given its unique objectives and reliance on foreign government support, it is natural that the procurement of this aircraft is controlled by the Department of Defense rather than by one of its component branches. Given my estimation results from the previous section, in which it appears that contracts for the F-35 are, on average, less complete than contracts from any of the military branches, it seems prudent to examine the possibility that the heterogeneous characteristics of the F-35 are affecting my analysis. Fortunately, removing the F-35 from my data sample only results in the loss of fifteen contracts, reducing my overall sample size to 134.

Tables 2.10 and 2.11 recreate Tables 2.4 and 2.7 using the smaller sample. In removing the fifteen F-35 contracts, I also lose five of twelve dual source contracts and eleven of forty-six RDT&E contracts. The summary statistics for the non-binary independent variables are very similar with one very large exception. The mean initial contract price for the sample without the F-35 is almost \$200 million less than in the previous sample, and the standard deviation decreases by more than \$700 million. While the minimum contract price remains the same, the maximum contract price decreases by more than \$10 billion. Meanwhile, the average contract completeness rank increases to 4.11 with a standard deviation of 1.86. This comparison indicates that estimation of the smaller sample may be a worthwhile exercise in order to determine the impact of the inclusion of the

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[23] http://www.defense.gov.

F-35 on my empirical results.

Table 2.10: Summary Statistics for MDAP Contracts (without F-35)

	Total	% of Sample
Army	21	15.67
Navy	81	60.45
Air Force	32	23.88
RDT&E	35	26.12
Procurement	96	71.64
Acquisition O&M	3	2.24

Table 2.11: Summary Statistics for Explanatory Variables (without F-35)

	Mean	Std. Dev.	Min	Max
adjip ($M)	653.51	1321.58	0.33	9670.87
length	38.21	25.943	2.00	129.00
var (Thousands)	138.36	384.80	0.00	2262.86
winage	7.27	6.19	0.00	23.00
emp (Thousands)	141.92	62.04	32.00	319.00
rev ($M)	11393.72	8581.56	2275.76	30894.20
prevcont	15.38	11.19	0	46
cratio	0.90	0.19	0.48	1.38
leverage	0.16	0.06	0.05	0.38

Tables 2.12 and 2.13 display the results of OLS and ordered probit estimation of equation (2.2) for the reduced sample, respectively. In Table 2.12, we can see that the regression model suffers from the same multicollinearity issues after adding Firm and Year effects in columns (6) and (7). Additionally, the RDT&E indicator has a significant negative effect on the contract type decision in the first five specifications and is quite similar in magnitude to the OLS coefficients estimated from the larger sample. However, several new findings also emerge. The measure for contractor experience, *PREVCONT*, is positive and highly significant in all specifications. The coefficient for the *NSD* indicator is positive

and significant until we add the military branch dummies. Also, unlike the previous OLS results, the coefficient on the firm's current ratio is significant after controlling for military component but becomes insignificant with the addition of the interaction terms. Finally, the coefficients for the military branch indicators are never significant using the reduced sample.

In Table 2.13, we again have the result that, under ordered probit estimation, the coefficient for RDT&E is never significant. However, the procurement dummy exhibits a large, positive effect on the contract type in the specification with firm effects. This is in accordance with theoretical predictions, as one would expect initiation of the procurement phase to depend upon demonstration of the technology, production processes, etc. Therefore, a procurement contract should perhaps not be expected to accommodate as many hypothetical outcomes and potential pitfalls.

Also in contrast to previous results, the coefficient on initial price is positive and significant in the sixth specification. The uniquely expensive contracts for the F-35 were clearly affecting the previous outcome, as the simple correlation between the initial price and completeness level is reduced from -0.0947 to -0.0049 when I remove the F-35 from my sample. The finding of a positive relationship between price and contract completeness is in line with the theoretical model, as *ex post* opportunism could lead to higher surplus extraction for a contract covering a larger dollar amount, all else equal. A more complete contract ensures that the government's relatively large investment is protected from costly uncertainty.

Unlike the OLS results for the reduced sample, the coefficient on the dummy variable for Navy-controlled contracts is negative and significant in the specification that includes interaction terms. This finding supports the rankings from the larger sample. Given the technologically-advanced MDAPs that fall under the Navy's purview, the idea that Naval acquisition officials may issue less complete contracts, on average, is perhaps not surprising.

The findings for the firm characteristics are similar to the OLS results for the smaller sample. A firm's status as a non-subdivision, its current ratio, and the leverage ratio for non-subdivision firms are the only factors that exhibit significant effects on the contract type decision, and none of these variables remain significant across all specifications.

In summary, it appears that the inclusion of the F-35 program in my data sample indeed affected my statistical results. However, the qualitative findings for both samples were relatively uniform. The primary difference between the two samples is the significance of the effect of the previous number of contracts within the data sample. As I have previously discussed, this significant positive effect may be capturing something other than contractor experience as a result of the left-censoring of the data sample. Due to the fact that some of the contractors are only responsible for one project within the data set, it is entirely possible that this variable is mainly serving as a proxy for project sequence. Furthermore, it is possible that my conclusions regarding the relationship between contractor experience and contractor type suffer from an additional confounding issue. If the selection of a contractor with a certain experience level occurs in tandem with the selection of contract type, my previous results will exhibit bias due to a simultaneity problem. I discuss this possibility at length in the next section of the paper.

Table 2.12: Ordinary Least Squares Results without F-35

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	0.0290	0.0274	0.0098	0.0413	0.0736	0.1091	0.1017
	(0.0854)	(0.0857)	(0.0863)	(0.0887)	(0.0911)	(0.0908)	(0.0985)
rd	-2.0422**	-2.0361**	-2.0001**	-1.8295*	-1.6415*	-1.2186	-1.4629
	(0.9465)	(0.9495)	(0.9464)	(0.9478)	(0.9731)	(0.9460)	(1.1854)
proc	0.8820	0.9079	0.8426	1.0115	1.1809	1.3963	1.2493
	(0.9302)	(0.9345)	(0.9323)	(0.9344)	(0.9602)	(0.9280)	(1.1696)
length	0.0001	-0.0002	-0.0009	-0.0012	-0.0020	-0.0024	-0.0001
	(0.0055)	(0.0055)	(0.0055)	(0.0056)	(0.0056)	(0.0057)	(0.0065)
winage	-0.0220	-0.0234	-0.0256	-0.0473	-0.0528	-0.0297	-0.0633
	(0.0346)	(0.0348)	(0.0347)	(0.0386)	(0.0398)	(0.0450)	(0.0595)
duals		-0.2841	-0.2017	0.0924	0.2126	-0.0590	-0.0572
		(0.5761)	(0.5771)	(0.6011)	(0.6323)	(0.6180)	(0.6721)
lvar			0.0414	0.0479	0.0473	0.0398	0.0489
			(0.0301)	(0.0306)	(0.0309)	(0.0300)	(0.0326)
army				0.0395	0.0036	0.1656	0.1950
				(0.5537)	(0.5741)	(0.5690)	(0.6580)
navy				-0.5264	-0.5701	-0.1767	-0.3743
				(0.3992)	(0.4108)	(0.4334)	(0.5313)
lemp	0.2311	0.2488	0.2898	-0.0290	-0.2173	-0.5503	-0.9306
	(0.4062)	(0.4090)	(0.4086)	(0.4596)	(0.5026)	(1.0133)	(1.2091)
lrev	-0.2883	-0.3127	-0.2821	-0.2610	-0.2235	0.3003	0.3797
	(0.2317)	(0.2377)	(0.2378)	(0.2391)	(0.2676)	(0.4158)	(0.4519)
prevcont	0.0329**	0.0338**	0.0369**	0.0438***	0.0515***	0.0675***	0.1054**
	(0.0156)	(0.0158)	(0.0159)	(0.0166)	(0.0179)	(0.0228)	(0.0486)
nsd	0.5031*	0.5080*	0.4851*	0.3281	-3.8770	omitted	omitted
	(0.2930)	(0.2940)	(0.2934)	(0.3902)	(9.7673)		
cratio	-0.9308	-0.9259	-1.0691	-1.7201*	-1.7517	-0.4813	-0.5016
	(0.8050)	(0.8075)	(0.8113)	(0.8974)	(1.0909)	(1.3576)	(1.6606)
nsd × lrev					-0.7719	1.2228	1.1046
					(0.9134)	(1.3102)	(1.8132)
nsd × cratio					-2.5289	0.9196	-1.8136
					(2.4908)	(3.4709)	(4.2457)
nsd × lev					3.3029	16.3178***	16.9177**
					(3.5238)	(5.8285)	(7.6904)
nsd × lemp					1.1010	1.1746	1.0889
					(1.0822)	(1.5019)	(1.9735)
Constant	4.0598	4.0770	3.2773	7.4686	9.0394	6.9771	10.1565
	(4.5562)	(4.5704)	(4.5906)	(5.3415)	(5.6890)	(12.4973)	(15.0869)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
R-Squared	0.4234	0.4198	0.4240	0.4286	0.4316	0.4981	0.4843
F-Statistic	10.77	9.75	9.16	8.13	6.61	6.08	3.97
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N	134	134	134	134	134	134	134

Standard errors in parentheses
$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 2.13: Ordered Probit Results without F-35

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	0.0522	0.0511	0.0316	0.0673	0.1022	0.1541*	0.1483
	(0.0678)	(0.0679)	(0.0691)	(0.0731)	(0.0760)	(0.0840)	(0.0955)
rd	-1.1788	-1.1733	-1.1779	-1.0130	-0.8763	-0.2144	-0.6994
	(0.7981)	(0.8005)	(0.8038)	(0.7973)	(0.8184)	(0.9231)	(1.1174)
proc	0.8535	0.8884	0.8169	0.9967	1.2122	1.9219**	1.6884
	(0.7913)	(0.7959)	(0.7994)	(0.7940)	(0.8199)	(0.9224)	(1.1117)
length	-0.0012	-0.0014	-0.0019	-0.0025	-0.0027	-0.0039	-0.0017
	(0.0042)	(0.0043)	(0.0043)	(0.0044)	(0.0044)	(0.0049)	(0.0056)
winage	-0.0259	-0.0279	-0.0295	-0.0467	-0.0550*	-0.0278	-0.0200
	(0.0295)	(0.0298)	(0.0298)	(0.0323)	(0.0334)	(0.0433)	(0.0663)
duals		-0.3244	-0.2503	0.0209	0.0602	-0.1932	-0.1994
		(0.5050)	(0.5101)	(0.5300)	(0.5557)	(0.5828)	(0.6542)
lvar			0.0377	0.0470*	0.0483*	0.0438	0.0627**
			(0.0250)	(0.0260)	(0.0265)	(0.0278)	(0.0304)
army				0.0595	0.0112	0.1384	0.4642
				(0.4567)	(0.4753)	(0.5147)	(0.6149)
navy				-0.4936	-0.5819*	-0.2926	-0.1870
				(0.3296)	(0.3425)	(0.3954)	(0.5211)
lemp	0.1184	0.1316	0.1852	-0.0705	-0.2531	-0.4836	-1.0209
	(0.3399)	(0.3413)	(0.3437)	(0.3789)	(0.4114)	(0.8632)	(1.0568)
lrev	-0.2928	-0.3179*	-0.2983	-0.2920	-0.2902	0.1146	0.1796
	(0.1880)	(0.1923)	(0.1940)	(0.1984)	(0.2227)	(0.3625)	(0.4019)
prevcont	0.0346***	0.0360***	0.0393***	0.0452***	0.0512***	0.0762***	0.1612***
	(0.0139)	(0.0142)	(0.0144)	(0.0147)	(0.0160)	(0.0225)	(0.0527)
nsd	0.4104*	0.4175*	0.3938	0.2585	-9.0785	-36.6178	-33.6351
	(0.2422)	(0.2427)	(0.2444)	(0.3248)	(9.2589)	(310.0213)	(443.0198)
cratio	-0.8193	-0.8304	-0.9465	-1.5500*	-1.5763*	-1.0952	-0.8287
	(0.6404)	(0.6419)	(0.6474)	(0.7193)	(0.8769)	(1.2151)	(1.5141)
nsd × lrev					-0.5185	1.9047	2.4111
					(0.7704)	(1.2419)	(1.8026)
nsd × cratio					-2.3053	2.3978	0.0700
					(2.1524)	(3.0995)	(3.9136)
nsd × lev					3.4143	19.1263***	23.4710***
					(3.0236)	(5.8526)	(8.0655)
nsd × lemp					1.3276	1.9332	1.5629
					(1.0206)	(1.6288)	(2.1555)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
Likelihood Ratio	68.74	69.14	71.43	75.42	81.56	111.43	130.13
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N	134	134	134	134	134	134	134

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2.8 Effects of Repeat Interactions

Following Corts and Singh (2004), I now consider the possibility that the Department of Defense views repeat interactions and "high-powered" contracts (or complete contracts in the terminology of this paper) as either substitutes or complements. This is a possibility if a contractor's previous experience with the defense contracting process directly affects the DoD's selection of both the contractor and a particular contract type for the same contract.

If repeat interactions with a particular contractor naturally engender trust and a stronger alignment of incentives, one would expect the Department of Defense to issue less complete contracts to firms with more experience in defense acquisition (i.e., experience and contractual completeness are substitutes). On the other hand, if the prevalent effect of the repeat interactions is to familiarize defense firms with the FAR and the unique requirements of DoD acquisition and, thus, reduce the costs of contract formalization, one might observe more complete contracts for more experienced firms (a complementary relationship). According to Corts and Singh, it is not entirely clear, for a particular industry, whether repeat interactions should "primarily mitigate incentive problems or decrease contracting costs" (p. 238). Therefore, it is also unclear, *ex ante*, whether the two features are substitutes or complements within an industry.

The results of section 2.7 indicate that a contractor's number of previous contracts has a positive effect on the level of contractual completeness in my data sample. This finding suggests that the DoD views repeat interactions and contractual completeness as complements. While this is in contrast to Corts and Singh's findings for offshore drilling contracts, the positive relationship may be reflecting a sequencing effect rather than the true relationship between repeated interactions and contract power. Due to the fact that defense projects regularly aspire to advance the frontier of defense technology, initial contracts for a particular weapons system will involve a large amount of technological uncertainty, making cost-plus contracts more feasible. However, as the project continues and subsequent contracts are agreed upon, these technical issues are addressed and more complete contracts are naturally possible. As a result of the left-censoring of my data sample and the fact that several of the contractors work on only one MDAP, I would expect to see that repeat interactions will closely follow the production sequence of the defense program, leading to more complete contracts. This is clearly a separate effect from the one described by Corts and Singh (2004) and does not satisfactorily characterize the effect of repeat interactions in the defense industry.

Using Corts and Singh's methodology, I will now estimate the direction of the bias that results from simultaneity and endogenous matching in order to clarify the relationship between contractor experience and the contract type decision in DoD acquisition. The above discussion indicates that the selection of contract type and the selection of a winning firm with a certain experience level might be a simultaneous decision rather than sequential events, as previously modeled in this paper. In fact, the FAR indicates that the contract type decision and selection of a contractor are sequential rather than simultaneous events. During price negotiation, the FAR states that the contracting officer's primary goal is to "negotiate a contract of a type and with a price providing the contractor the greatest incentive for efficient and economical performance" (FAR,15.405b). However, it is certainly possible that for a given project, a specific contract type/contractor experience combination will be optimal. In other words, unique aspects of the project may simultaneously guide the acquisition officer towards a certain contractor and a certain contract type. This is a distinct possibility, given the FAR's guidance that the contract type should be discussed as early as the proposal phase, which occurs prior to any competitive bidding (FAR, 15.201c).

To account for this possibility, I now model the simultaneous choice of contract type (contractual completeness) and contractor experience. As an illustrative exercise, consider the following two equation version of my model in matrix notation:

$$C = \alpha_0 + \alpha_1 PREVCONT + \alpha_2 X + \varepsilon \tag{2.3}$$

$$PREVCONT = \beta_0 + \beta_1 C + \beta_2 W + \beta_3 Y + \upsilon. \tag{2.4}$$

In this version of the model, all variables are defined as before except W, which warrants further explanation. The matrix W contains all project characteristics except the indicators for controlling military component. This exclusion is based on the assumption that a contractor who produces an item for the Air Force could feasibly modify its production technology to produce a similar item for the Army. In other words, I am assuming that an Army acquisition official would not choose a firm that is inexperienced in the production of helicopters over a proven helicopter manufacturer merely because the more experienced contractor has only worked for the Air Force.

Note that the two-equation model implies that firm characteristics only affect the choice of contract type through the contractor's previous number of contracts. Due to the presence of the additional project characteristics (controls for component) in equation (2.3) and the firm characteristics in equation (2.4), this system of equations is numerically identified. Given this structure, we can now discuss potential modeling issues, which result directly from the possibility that the contract type/experience decision is simultaneous rather than sequential.

First, the two-equation model demonstrates the simultaneity issue caused by correlation between $PREVCONT$ and ε. If we ignore the existence of equation (2.4) and estimate only equation (2.3), the coefficient on $PREVCONT$ will be biased due to the presence of $\beta_1 C$. This effect can be negative or positive, depending upon whether repeat interactions and completeness are substitutes or complements, respectively. Based on the presence of the previously discussed sequencing effect, the sign of this bias is unclear. However, any change in the magnitude of the corrected coefficient will be informative in categorizing contractual completeness and previous experience as either substitutes or complements.

A second concern, raised first by Ackerberg and Botticini (2002) and addressed in Corts and Singh (2004), is that the simultaneously determined contract type and experience level may be affected by an endogenous matching phenomenon. For example, consider the scenario where a new security threat requires the DoD to develop a very specific and unique technological countermeasure. The technological uncertainty created by this new requirement will be exogenous from the DoD's standpoint. However, the technological issue may fall within the purview of a particular defense firm, which has worked on similar projects in the past. The defense firm's decision to compete for this particular project may therefore be endogenous. Given the contract data available for use in this paper, I would be unable to observe this technological heterogeneity and must account for the endogenous matching problem during estimation. In the presence of endogenous matching, Ackerberg and Botticini (2002) find that "the matching generates correlation between observable characteristics of one of the parties and proxy errors for the other party, potentially biasing many or all coefficients of interest" (p. 568). In the case of my empirical model, this problem would result in correlation between the observed firm characteristics (X's) and ε.

2.8.1 Estimation

Although the structure of the above model suggests that I might pursue three-stage least squares estimation of the system of equations, the presence of heteroscedastic errors in the first equation prevents the use of the 3SLS technique (Cameron and Trivedi, 2005). Therefore, in order to correct for both simultaneity and endogenous matching, I will use Two-Stage Least Squares estimation to instrument for the endogenous regressors, which include *PREVCONT*, *LEMP*, *LREV*, and *CRATIO*. I assume that the operating structure of a given firm (*NSD*) is exogenous to any specific contract type/firm experience decision. As the system of equations suggest, these instruments should be highly correlated with the characteristics of the selected firm. However, the instruments must only affect the contract type decision through their effect on the selected experience level and should have no other effect on the contract type decision.

As in Corts and Singh (2004), I use the "hypothetical expected value" of winning firm characteristics as instruments for the actual firm characteristics. To calculate these instruments, I construct a weighted average of the characteristic in question, using market shares from a three-period moving window. The window includes last period, the current period, and the next period.[24] For this purpose, a "market" is defined by aircraft type (unmanned aerial vehicle, helicopter, fixed-wing special purpose aircraft, or fixed-wing utility aircraft). I

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[24] For example, for a contract awarded in year 2, the three-period window includes contracts from year 1, year 2, and year 3.

restrict my instruments to include only characteristics from firms that produce similar aircraft types because I assume that it is prohibitively expensive for a firm to routinely switch its production technology from one aircraft type to another. Therefore, the relevant market for a helicopter producer is restricted to include only other helicopter producers. A firm's market share in this context is simply its percentage of the overall number of contracts within its market during the pertinent three-period window.[25]

Using the market-share weights, I then calculate expected values for the firm's previous contracts and financial characteristics. In order to use all available data for the purposes of instrumentation, I have also included an expected value for the firm's leverage ratio as an additional instrument. These instruments should have excellent predictive power for the characteristics of a winning firm. However, it seems much less likely that these aggregate measures of firm size and financial health within a market would directly affect an acquisition official's contract type decision for a specific project. Allowing for an indirect effect through the $PREVCONT$ variable, these instruments should be plausibly exogenous to the selection of an optimal completeness level (equation (2.3)). In support of this assumption, the Wu-Hausman test for endogenous instruments in my baseline regression fails to reject the null of exogenous instruments with a p-value of 0.5585.

In the following section, I will present only the results of the linear model. Although the econometric literature supports and provides tools for the estimation of an ordered probit model with instrumental variables (Wooldridge 2010, p. 660), the estimation of an ordered probit model in conjunction

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[25] The use of this three-period moving window results in the loss of ten contract observations from the first and last period.

with 2SLS methods does not seem to be a developed technique. While Roodman's conditional mixed process estimator will allow for the estimation of an ordered probit model with instrumental variables, it is recursive in nature and, thus, cannot incorporate the simultaneous structure of my model (Roodman, 2011). Therefore even if I pursued purely an IV estimation approach, the readily available econometric tools will not fully accommodate the unique issues presented in this paper. As a result, I will consider the estimation of this model via ordered probit as a future direction for research.

2.8.2 Results

Table 2.14 and Table 2.15 display the 2SLS estimation results for the samples with and without the F-35 program, respectively. In order to ensure continuity, these regression tables follow the same progression of analysis from previous tables. However, the explanatory power of the model is drastically reduced when I add the interaction terms, firm effects, and year effects in 2SLS estimation. In fact, the regression F-statistics for columns (6) and (7) indicate that these models do not explain a statistically significant amount of variation in contractual completeness. While this is not the case for column (5), the drastic reduction in the R-squared value due to the addition of the interaction terms suggests that I should restrict my analysis of valid models to the first four specifications.[26]

Comparing Tables 2.8 and 2.14, the 2SLS estimation results in the significance of the coefficient of the *PREVCONT* variable in specifications (2) through (4). Additionally, we can see that the magnitude of the coefficient on previous contracts also increases in each specification. This is evidence that

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[26] Due to the endogeneity of these interaction terms, I calculated instruments for these variables using the same moving-window technique in order to introduce them into the regression model.

the simultaneity between contract type and contractor experience induced a downward bias in my previous results. Therefore, this result suggests that contractual completeness and repeat interactions are treated as substitutes in the defense contracting environment. The results for the remaining coefficients are quite similar, with one exception. The coefficient on the procurement indicator is much larger in magnitude and significant in the 2SLS results, whereas the coefficient for the RDT&E indicator remains negative but is insignificant. This result suggests that the endogenous matching phenomenon was indeed causing bias in some or all of the coefficients of interest. Finally, the relative rankings of the military components in terms of average contractual completeness are also consistent with previous results (1. Air Force, 2. Army, 3. Navy).

In a similar fashion, the results listed in Table 2.15 are comparable to Table 2.12. Again, one can see that the addition of the interaction terms, firm intercepts, and year intercepts drastically reduces and even eliminates the explanatory power of the regression model. Also, a similar pattern emerges in terms of the coefficient for the *PREVCONT* variable. The coefficient from 2SLS estimation is distinctly larger in magnitude in specifications (1) through (4). This is further evidence that contract power and repeated interactions serve as substitutes in the defense contracting environment. Additionally, we also observe a reversal in magnitude and significance between the coefficients for the RDT&E and Procurement indicators, similar to the results for the sample including the F-35. This result and changes in magnitude and significance for other explanatory variables (*WINAGE*, *NSD*, *CRATIO*, *NAVY*) again suggests that the endogenous matching problem induced severe bias in the OLS coefficients.

In accordance with Corts and Singh (2004), the result that more interactions lead to less complete contracts in the defense contracting environment indicates that the primary effect of repeat interactions in the defense industry is to mitigate incentive problems (p. 238). This result seems intuitive as one would expect that a repeat contractor for the DoD to be largely dependent on future DoD contracts, given the specialized nature of the defense industry. This contractor would have a vested interest in meeting deadlines, controlling cost growth, and adhering to federal guidelines, as deviation could result in exclusion from the industry. The lack of an outside option for U.S. defense contractors virtually ensures that this would be the case. Therefore, one would naturally expect the alignment of DoD and contractor incentives to occur as a contractor becomes more experienced in defense acquisition and more dependent on future DoD projects.

Table 2.14: Two-Stage Least Squares Results with F-35

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	0.0237	0.0222	0.0060	0.1254	0.1083	0.6614	-25.0621
	(0.0930)	(0.0921)	(0.0947)	(0.1013)	(0.2216)	(1.5652)	(165438.05)
rd	-0.4782	-0.5164	-0.5947	0.0257	-0.4732	7.6032	3906.521
	(1.4105)	(1.3550)	(1.3441)	(1.3998)	(2.1611)	(24.1396)	(2528285)
proc	2.3889*	2.2936*	2.1670*	2.5512*	1.7071	8.1001	4726.208
	(1.406)	(1.3383)	(1.3307)	(1.3855)	(2.3741)	(19.5771)	(3057572)
length	-0.0042	-0.0040	-0.0043	-0.0017	-0.0000	-0.0460	16.2712
	(0.0061)	(0.0060)	(0.0059)	(0.0059)	(0.0082)	(0.1470)	(10541.7)
winage	-0.1423**	-0.1399**	-0.1367**	-0.1783**	-0.1679**	-0.0278	34.9373
	(0.0688)	(0.0649)	(0.0643)	(0.0789)	(0.1014)	(0.4496)	(22689.51)
duals		-0.1102	-0.0977	0.8542*	0.5501	-0.7543	307.3341
		(0.5036)	(0.4992)	(0.4896)	(1.7862)	(6.1243)	(198526.2)
lvar			0.0243	0.0587*	0.1049	0.1373	1.3296
			(0.0321)	(0.0320)	(0.1007)	(0.1853)	(830.8749)
army				2.9371***	2.2717	6.4531	-1157.706
				(0.8514)	(1.7334)	(6.5529)	(752844.6)
navy				1.9327***	1.7841*	4.1719	-311.0114
				(0.5715)	(1.0690)	(3.6009)	(203711.4)
af				3.3322***	3.4186**	4.9231	-1024.155
				(0.7756)	(1.5254)	(4.1744)	(665682.4)
lemp	-1.4766	-1.4299	-1.3503	-1.9232*	-1.7245	-36.6883	4638.29
	(0.9360)	(0.8879)	(0.8881)	(1.0773)	(1.7322)	(97.8572)	(3010600)
lrev	0.1421	0.1332	0.1528	0.2818	0.3775	1.3774	492.9534
	(0.4636)	(0.4655)	(0.4625)	(0.4420)	(0.6275)	(9.2239)	(317286.6)
prevcont	0.0495	0.0484*	0.0482*	0.0694**	0.0029	-0.0664	-467.4509
	(0.0306)	(0.0290)	(0.0288)	(0.0319)	(0.1214)	(0.2565)	(302620.1)
nsd	-0.0812	-0.0724	-0.0670	-0.5749	-61.1330	-460.6042	71602.68
	(0.3936)	(0.3828)	(0.3795)	(0.5292)	(96.3871)	(1282.947)	(4.65e07)
cratio	-3.0764	-3.0044	-2.9402	-4.9115**	-1.3743	-15.2101	12581.93
	(2.0537)	(1.9153)	(1.8931)	(2.2020)	(5.0382)	(46.0470)	(8147654)
nsd × lrev					1.9046	0.0701	-8619.857
					(10.1868)	(19.7419)	(5580301)
nsd × cratio					-17.9400	-35.8034	36893
					(14.7724)	(74.0233)	(2.39e07)
nsd × lev					7.2720	4.1772	-38487.43
					(24.2509)	(56.2263)	(2.49e07)
nsd × lemp					4.9928	39.8551	-2939.135
					(4.5992)	(95.8990)	(1910883)
Constant	21.7105**	21.2272**	20.0594**	23.8475	19.0057	439.2165	-51426.15
	(10.2243)	(9.5183)	(9.5600)	(12.0080)	(18.8546)	(1257.26)	(3.34e07)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
R-Squared	0.3859	0.3900	0.3993	0.4587	0.1031	.	.
Wald Statistic	99.73	100.89	102.84	129.47	83.17	12.94	0
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.9941	1.0000
N	139	139	139	139	139	139	139

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.15: Two-Stage Least Squares Results without F-35

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	0.0944	0.0928	0.0720	0.1432	0.1588	0.9892	0.08469
	(0.0925)	(0.0921)	(0.0938)	(0.1207)	(0.2640)	(4.4039)	(0.6785)
rd	-0.6184	-0.6737	-0.8063	0.1650	-0.0959	11.8811	11.4494
	(1.4160	(1.3971)	(1.3794)	(1.8493)	(2.8652)	(63.4359)	(20.8615)
proc	2.2426*	2.10977*	1.9785	2.8757*	2.1598	10.4406	16.1916
	(1.3740)	(1.3491)	(1.3402)	(1.7572)	(2.9604)	(45.3364)	(24.5357)
length	-0.0042	-0.0043	-0.0043	-0.0029	0.0010	0.0038	0.0139
	(0.0059)	(0.0059)	(0.0058)	(0.0062)	(0.0093)	(0.0999)	(0.0491)
winage	-0.1158*	-0.1136*	-0.1059	-0.1953*	-0.1884	-0.1294	-0.0847
	(0.0681)	(0.0671)	(0.0664)	(0.1102)	(0.1545)	(0.6936)	(0.2994)
duals		-0.1226	-0.0517	0.6620	0.7822	5.4986	-1.7743
		(0.6000)	(0.5941)	(0.7833)	(2.1884)	(23.6964)	(4.8052)
lvar			0.0332	0.0435	0.0946	0.4237	0.0514
			(0.0317)	(0.0335)	(0.1094)	(1.6980)	(0.1444)
army				-0.5758	-1.1280	-1.3070	3.9880
				(0.6427)	(1.0380)	(8.9337)	(6.3594)
navy				-1.4544*	-1.7893	-5.1766	3.6117
				(0.8314)	(1.4745)	(22.3765)	(7.2442)
lemp	-1.2382	-1.1972	-1.0300	-2.2195	-2.1936	-45.6289	-4.5764
	(0.9503)	(0.9633)	(0.9639)	(1.5931)	(2.5219)	(212.3794)	(19.5557)
lrev	0.1156	0.0995	0.1210	0.2518	0.4665	-4.5255	13.3478
	(0.4317)	(0.4534)	(0.4485)	(0.5001)	(0.6095)	(39.2989)	(19.9641)
prevcont	0.0587**	0.0582**	0.0564**	0.0811**	0.0163	-0.3636	-1.4642
	(0.0296)	(0.0291)	(0.0285)	(0.0380)	(0.1280)	(1.8829)	(2.6179)
nsd	0.0164	0.0310	0.0505	-0.7132	-58.6163	-631.0532	-45.6019
	(0.3972)	(0.3940)	(0.3880)	(0.7254)	(94.8081)	(3071.622)	(272.7507)
cratio	-2.5085	-2.3746	-2.3082	-4.6220	-2.1528	-17.7857	22.22403
	(2.1025)	(2.0359)	(2.0029)	(3.2022)	(5.4215)	(88.1338)	(45.9048)
nsd × lrev					1.1026	-4.8762	-22.942
					(9.6902)	(31.8133)	(45.2484)
nsd × cratio					-17.2518	-164.6821	112.6361
					(17.9059)	(725.0103)	(191.7837)
nsd × lev					5.7812	-52.30067	-69.4583
					(26.3595)	(279.8875)	(183.0146)
nsd × lemp					5.4323	66.56773	9.7484
					(5.5883)	(301.5148)	(28.5818)
Constant	18.0984*	17.6913*	15.4908	30.5350*	27.2473	603.5066	-14.0586
	(10.2863)	(10.1872)	(10.2869)	(18.1120)	(29.7260)	(2928.015)	(228.0056)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
R-Squared	0.4352	0.4385	0.4539	0.4087	0.0673	.	.
Wald Statistic	106.49	107.13	110.75	104.31	69.9	2.78	9.62
P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000
N	128	128	128	128	128	128	128

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2.9 Robustness Checks

2.9.1 Robust Regression

A separate method of addressing the F-35 as a possible outlier in my data sample is to perform a robust regression, which will weight the data in accordance with how well each observation behaves with respect to the overall sample. This method essentially represents a compromise between the OLS estimation of the entire sample and estimation using the reduced sample. The STATA command used to perform these regressions first performs an OLS regression and calculates the Cook's distance for each observation.[27] It then removes any observation for which Cook's Distance is greater than one. The results of this process can be found in Table 2.16.

Comparing these results with previous estimation techniques, the robust regression estimates are much more similar to the OLS results for the reduced sample than for the entire sample. However, the robust regression estimates include some differential results. The coefficient for the RDT&E indicator is negative and significant, but is larger in magnitude than the estimates in Table 2.12. Additionally, a contractor's number of previous contracts is significant in only one specification, column (5), but is similar in magnitude to previous results. One also observes expected and significant effects from both dual

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[27] Cook's Distance is calculated using the following formula:

$$D_i = \frac{\sum_{k=1}^{n}(\hat{Y}_k - \hat{Y}_{k(i)})^2}{pMSE},$$

where $\hat{Y}_k$ is the predicted value for observation k from the full model, $\hat{Y}_{k(i)}$ is the predicted value for observation k from a regression excluding observation k, p is the number of estimated coefficients, and MSE is the mean-squared error for the full regression. A more thorough explanation of the robust regression technique can be found at https://idre.ucla.edu/stats.

source contracts and firm current ratios. Finally, the indicators for the different military branches retain their relative ranking with the Air Force issuing the most complete contracts, followed by the Army and Navy. Given the results of robust regression, it appears that completely eliminating the F-35 from the sample may overstate the impact of both the contractor's previous number of contracts and understate the role played by the controlling military branch.

2.9.2 Alternative Ranking of Contract Completeness

In a seminal paper on incomplete contract theory, Hart and Moore (1999) provide two alternative characterizations of incomplete contracts. As in this paper, a contract can include incomplete descriptions of the contractual obligations of the involved parties and leave items such as reimbursement schemes, timelines, and profit rates open to future renegotiation. On the other hand, a contract can also be incomplete if it is impossible to fully describe the physical characteristics of the underlying project itself, perhaps due to unrealized states of nature. In this type of incomplete contract, the contract's incentive power is of paramount importance if the buyer hopes to motivate cost-minimizing behavior by the contractor.

This alternative definition of incomplete contracting, which hinges upon the physical describability of the work to be performed under the contract, also influences the language of the FAR. In fact, one can assign a separate "describability" ranking to the different contract types, based on the implied physical describability of the underlying projects from the contract type descriptions in section 16 of the FAR. This procedure results in swapping the ranks of the CPIF and CPFF contracts (i.e., C = 1 for CPFF and C = 3 for

CPIF). Tables 2.17 and 2.18 present the results of estimation with the re-ordered dependent variable.

The OLS results in Table 2.17 actually indicate that the fit of the regression model improves when the dependent variable is re-ordered using the alternative definition of completeness. The coefficient on the indicator for RDT&E contracts is now larger in magnitude and significant in all specifications. Also in contrast with previous results, the coefficient for the contractor's number of contracts is positive and highly significant, although the magnitude is quite similar. The indicator for dual source contracts has a significant and positive effect on the contract's describability ranking in columns (4) and (5), and the firms' current ratio and subdivision status have more consistent effects than when using the previous contract ranking. Meanwhile, the relative completeness ranking of the different military branches is once again maintained.

Comparing the ordered probit results in Table 2.18 with Table 2.9, I again see a larger and more significant effect of the RDT&E indicator, contractor experience, subdivision status, and current ratio. Additionally, the coefficient for dual source contracts is now significant in columns (4) and (5) and has doubled in magnitude. Overall, the results from this robustness check seem to indicate that an alternative definition of contractual completeness, derived from the ability to fully describe the scope of work, may be more influential in DoD acquisition officers' selection of contract types. However, this paper's comparison of the results attained by using alternative definitions of completeness help to reinforce Hart and Moore's assertion that these competing characterizations may have differential effects on contracting decisions.

Table 2.16: Weighted Regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	-0.025	-0.027	-0.033	-0.018	-0.003	-0.063	-0.090
	(0.073)	(0.074)	(0.075)	(0.082)	(0.082)	(0.071)	(0.072)
rd	-2.899***	-2.795**	-2.840**	-2.702**	-2.769**	-3.250***	-3.990***
	(0.842)	(0.859)	(0.858)	(0.904)	(0.912)	(0.775)	(0.896)
proc	0.192	0.280	0.231	0.249	0.078	-0.204	-0.591
	(0.828)	(0.843)	(0.843)	(0.890)	(0.899)	(0.759)	(0.877)
length	0.000	0.000	-0.000	0.001	0.002	-0.000	0.001
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)
winage	-0.042	-0.043	-0.045	-0.059	-0.071*	-0.021	-0.027
	(0.030)	(0.030)	(0.030)	(0.035)	(0.035)	(0.037)	(0.044)
lemp	0.046	0.017	0.031	-0.149	-0.419	-1.058	-1.483
	(0.342)	(0.348)	(0.348)	(0.398)	(0.425)	(0.795)	(0.856)
lrev	-0.170	-0.161	-0.146	-0.093	0.058	0.240	0.187
	(0.203)	(0.207)	(0.207)	(0.220)	(0.246)	(0.312)	(0.317)
prevcont	0.022	0.022	0.024	0.026	0.040*	0.027	0.058
	(0.013)	(0.013)	(0.013)	(0.015)	(0.017)	(0.018)	(0.035)
nsd	0.218	0.262	0.236	0.117	-4.955		
	(0.248)	(0.253)	(0.253)	(0.342)	(8.937)		
cratio	-0.654	-0.588	-0.639	-0.934	-2.074*	-1.917	-1.978
	(0.591)	(0.606)	(0.605)	(0.673)	(1.012)	(1.083)	(1.177)
duals		0.314	0.306	0.573	1.039*	0.219	0.089
		(0.405)	(0.404)	(0.451)	(0.467)	(0.403)	(0.416)
lvar			0.015	0.021	0.033	0.021	-0.010
			(0.026)	(0.028)	(0.028)	(0.024)	(0.024)
army				0.590	1.604*	0.414	0.372
				(0.577)	(0.642)	(0.544)	(0.561)
navy				0.474	1.336**	0.644	0.349
				(0.446)	(0.477)	(0.406)	(0.419)
af				0.833	1.916***	0.647	0.377
				(0.517)	(0.564)	(0.465)	(0.477)
nsd × lrev					-0.744	0.888	0.564
					(0.859)	(0.711)	(0.913)
nsd × cratio					-2.830	-0.008	-1.191
					(2.320)	(1.550)	(2.017)
nsd × lev					2.811	9.861**	9.446*
					(3.163)	(3.105)	(3.833)
nsd × lemp					1.171	1.206	1.097
					(0.981)	(1.140)	(1.376)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
F-Statistic	17.72	15.23	14.32	10.22	8.95	10.14	7.81
P-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	149	149	149	149	148	149	149

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.17: Alternative Contract Ranking: OLS Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	-0.019	-0.019	-0.024	0.016	0.020	0.023	0.031
	(0.083)	(0.084)	(0.084)	(0.083)	(0.077)	(0.082)	(0.083)
rd	-2.512***	-2.549***	-2.547***	-2.433***	-2.398**	-2.088***	-2.228**
	(0.797)	(0.807)	(0.809)	(0.858)	(0.981)	(0.716)	(0.917)
proc	0.276	0.249	0.234	0.142	0.197	0.355	0.371
	(0.804)	(0.813)	(0.813)	(0.864)	(0.984)	(0.700)	(0.906)
length	-0.001	-0.001	-0.001	-0.000	-0.000	0.000	0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
winage	-0.024	-0.022	-0.023	-0.020	-0.015	0.013	0.003
	(0.025)	(0.025)	(0.025)	(0.025)	(0.027)	(0.028)	(0.041)
lemp	-0.025	-0.030	-0.025	-0.021	-0.022	-0.129	-0.794
	(0.306)	(0.308)	(0.308)	(0.300)	(0.336)	(0.771)	(0.979)
ldrev	-0.143	-0.133	-0.129	-0.064	0.054	0.452	0.315
	(0.194)	(0.192)	(0.192)	(0.186)	(0.217)	(0.310)	(0.347)
prevcont	0.028***	0.028***	0.028***	0.027**	0.040***	0.035**	0.048
	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)	(0.015)	(0.033)
nsd	0.594***	0.602***	0.597**	0.525**	8.644		
	(0.227)	(0.229)	(0.229)	(0.257)	(6.139)		
cratio	-0.891**	-0.851**	-0.856**	-0.898*	-1.713**	-1.165	-1.273
	(0.422)	(0.424)	(0.426)	(0.505)	(0.771)	(1.063)	(1.371)
duals		0.242	0.243	0.634*	0.791**	0.608	0.472
		(0.328)	(0.326)	(0.359)	(0.367)	(0.387)	(0.449)
lvar			0.009	0.017	0.018	0.019	0.011
			(0.024)	(0.024)	(0.026)	(0.024)	(0.029)
army				1.105**	1.390**	1.532**	1.571**
				(0.520)	(0.560)	(0.626)	(0.728)
navy				1.091***	1.300***	1.681***	1.636***
				(0.300)	(0.319)	(0.360)	(0.454)
af				1.315***	1.528***	1.592***	1.606***
				(0.375)	(0.375)	(0.418)	(0.498)
nsd × lrev					-0.547	-0.320	0.402
					(0.573)	(0.541)	(0.702)
nsd × cratio					1.084	-0.343	-1.380
					(1.082)	(1.335)	(1.881)
nsd × lev					3.405	6.508*	8.864**
					(2.807)	(3.749)	(4.395)
nsd × lemp					-0.409	0.059	0.152
					(0.580)	(1.016)	(1.327)
Constant	6.647**	6.577**	6.455*	4.541	3.711	0.927	10.106
	(3.295)	(3.320)	(3.332)	(3.368)	(3.747)	(9.333)	(12.130)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
R-Squared	0.567	0.568	0.569	0.598	0.610	0.670	0.694
F-Statistic	38.603	36.721	33.193	29.512	26.628	.	.
P-Value	0.000	0.000	0.000	0.000	0.000	.	.
N	149	149	149	149	149	149	149

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.18: Alternative Contract Ranking: Ordered Probit Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable							
ladjip	0.005	0.006	-0.001	0.053	0.063	0.073	0.077
	(0.073)	(0.073)	(0.073)	(0.080)	(0.074)	(0.086)	(0.085)
rd	-2.063**	-2.113**	-2.118**	-2.030**	-2.029**	-1.939***	-2.192***
	(0.826)	(0.835)	(0.836)	(0.936)	(1.019)	(0.707)	(0.851)
proc	0.338	0.304	0.283	0.266	0.307	0.444	0.555
	(0.838)	(0.842)	(0.845)	(0.945)	(1.026)	(0.690)	(0.864)
length	-0.002	-0.002	-0.002	-0.001	-0.001	-0.000	0.001
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
winage	-0.027	-0.025	-0.026	-0.017	-0.012	0.030	0.054
	(0.024)	(0.024)	(0.025)	(0.025)	(0.027)	(0.031)	(0.055)
lemp	-0.127	-0.129	-0.121	-0.042	-0.061	0.079	-0.658
	(0.290)	(0.290)	(0.290)	(0.294)	(0.326)	(0.735)	(0.854)
ldrev	-0.137	-0.125	-0.121	-0.072	0.031	0.642*	0.552
	(0.184)	(0.182)	(0.181)	(0.174)	(0.212)	(0.346)	(0.350)
prevcont	0.032***	0.031***	0.032***	0.034***	0.044***	0.033**	0.090**
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.017)	(0.035)
nsd	0.614***	0.631***	0.623***	0.628**	9.557	11.271	-1.355
	(0.214)	(0.219)	(0.220)	(0.290)	(6.562)	(11.757)	(14.304)
cratio	-0.961**	-0.903**	-0.914**	-1.219**	-1.606**	-0.524	-0.273
	(0.453)	(0.452)	(0.454)	(0.561)	(0.736)	(1.087)	(1.312)
duals		0.307	0.307	0.878*	1.089**	0.862	0.705
		(0.371)	(0.367)	(0.513)	(0.517)	(0.564)	(0.577)
lvar			0.010	0.027	0.024	0.023	0.031
			(0.023)	(0.024)	(0.024)	(0.024)	(0.028)
army				1.457**	1.629**	2.090***	2.639***
				(0.600)	(0.638)	(0.684)	(0.719)
navy				1.361***	1.534***	2.271***	2.835***
				(0.384)	(0.406)	(0.459)	(0.487)
af				1.562***	1.788***	2.046***	2.474***
				(0.439)	(0.452)	(0.455)	(0.515)
nsd × lrev					-1.162*	-0.945*	0.205
					(0.615)	(0.572)	(0.742)
nsd × cratio					-1.033	-1.624	-3.476*
					(1.469)	(1.494)	(1.996)
nsd × lev					0.705	4.837	9.579**
					(3.147)	(4.310)	(4.443)
nsd × lemp					0.203	-0.055	0.332
					(0.688)	(0.986)	(1.198)
Firm Effects	No	No	No	No	No	Yes	Yes
Year Effects	No	No	No	No	No	No	Yes
Likelihood Ratio	119.41	120.93	125.02	142.68	145.38	545.30	1144.21
P-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	149	149	149	149	149	149	149

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2.10 Conclusion

The primary goal of this paper was to establish empirically whether DoD acquisition officials weight observed project and firm characteristics in a uniform manner in their contract type decision. Building upon the work of Crocker and Reynolds (1993), I extended a modified version of their theoretical model of optimal incompleteness to a larger array of aircraft projects undertaken by the US Department of Defense. After additionally controlling for simultaneity between the contract type decision and contractor experience, several patterns emerged, which suggest that DoD acquisition officials are acting in an efficient manner.

First, contracting officers tend to award more complete contracts during the procurement phase of an MDAP. This accommodation of decreasing levels of technological uncertainty aligns with the suggestions of Bajari and Tadelis (2001) and Bajari, McMillan, and Tadelis (2008). Second, we see that the different branches of the military are able to utilize the full menu of contract types to account for technological heterogeneity specific to their MDAPs. For example, the Navy appears to issue less complete contracts, on average, than the Army. This finding is intuitive, considering that the Navy's MDAPs, which include multiple new fixed-wing aircraft, are likely more technologically complex than the Army's modernization MDAPs. Third, the coefficient for the previous contracts variable is positive and significant. This net effect likely captures a sequencing effect due to the left-censoring of my data sample, indicating that contracting officials issue more complete contracts during later stages of an MDAP. This result suggests that acquisition officials issue more complete contracts as contractor risk diminishes and technological issues are addressed in later phases of production.

Perhaps the major contribution of this paper is the characterization of the relationship between repeat interactions and contractual completeness in the U.S. defense industry. Using the empirical foundation of Corts and Singh (2004), I modeled the choice of contract type and selection of contractor experience as a simultaneous decision using 2SLS estimation. These revised estimates revealed a negative bias on the OLS coefficient for previous contracts in my original analysis, indicating that completeness and previous contractor experience are substitutes in defense acquisition. Furthermore, this finding suggests that the primary effect of repeat interactions in defense acquisition is to align DoD and contractor incentives.

I suspect that the insignificance of many of the firm and project characteristics in my results is at least partly due to measurement error. Despite the fact that confidentiality rules prevent access to all of the firm and project variables available to the acquisition official at the time of his decision, this is only one area in which this model can be significantly improved. The proxy variables for internal uncertainty used in this paper are far from perfect and are based largely on assumption. Despite the fact that I've purposely selected aircraft programs to limit heterogeneity in the production process (an approach similar to Rogerson (1991)), the technological complexity of the MDAPs in my sample is far from uniform. Therefore, further information that would allow me to control for these differences in technological requirements or an estimation approach that would allow the data to "sort itself" by technological complexity would be natural considerations for future research.

Additionally, the robustness check for this model that introduces an alternative ranking for the dependent variable, based on a different characterization of contractual completeness, suggests that the definition of "incomplete" contracting must be carefully applied. A contract may be incomplete in terms of contractual obligations, or it may be incomplete in terms of the parties' ability to describe the scope of the project. As my results suggest, concern over contractual completeness may follow closely with one definition or the other, depending on the contracting environment. Given better characterization of technological heterogeneity within my data sample, one might be able to test Hart and Moore's conjecture that the competing definitions of contractual completeness are both relevant but may have very different effects on contract decisions and outcomes. For example, one could perform a split-sample analysis, varying the technological composition of the projects and the definition of contractual completeness, and perhaps provide evidence regarding which definition is pertinent in various project settings.

Chapter 3

The Relevance of Describability in the Performance of Defense Acquisition Contracts

Abstract

The incomplete contracting approach is used to solve the hold-up problem in several prominent areas of public procurement. However, economists have questioned both the optimality of incomplete contracts and the relevance of a project's physical describability. This paper contributes to this discussion by providing empirical results related to the relevance of physical describability in defense contracts for military aircraft. Despite attempts by government officials to account for technological uncertainty, the underlying describability of the project appears to have adverse effects on adherence to contractual timelines, generating additional costs due to project delays.

3.1 Introduction

The possibility of contractual hold-up, in which parties risk the loss of relationship-specific investments in the event of a failed trade, has served as the motivating force behind the economic literature pertaining to incomplete contracting. In order to incentivize cost-minimizing investment by the contracted parties prior to the actual trade, several economists have argued that the buyer and seller can agree to an incomplete contract, which outlines contractual obligations but allows for risk-sharing due to indescribable aspects of the project in question. As in the case of many theoretical mechanisms, this incomplete contracting approach has its fair share of proponents and detractors. However, its prevalence in several prominent areas of procurement makes this debate particularly interesting. The primary purpose of this paper is to bring empirical results into the conversation.

The hold-up problem can take several forms. Bös (1996) derives a model of optimal incomplete contracts in which hold-up stems from the non-verifiability of the relationship-specific investments. Alternatively, Hart and Moore (1999) present a model of optimal incomplete contracting in which the hold-up problem is due to the parties' *ex ante* inability to describe all possible physical states of nature. In contrast, Bös (2001) provides a unique characterization of the hold-up problem, specific to projects in which the intermediate product has no value (e.g., "construction ruins," p. 105). In this situation, the buyer can be burdened with the bill for the sunk costs but receives no actual benefit in the event of project failure. As a result, the parties foresee this possibility and may underinvest, the classic manifestation of the hold-up problem.

Despite these theoretical foundations and the fact that describability clearly plays a role in real world contract design, evidenced by the use of a menu of different contract types in areas such as defense procurement, public service provision, and petroleum drilling, a debate emerged in the late 1990s regarding the optimality of incomplete contracts.

Maskin and Tirole (1999) posited their irrelevance theorems, claiming that the *ex ante* indescribability of the *physical* outcomes of a project were insufficient to prevent the implementation of a complete contract so long as the parties were able to describe the spectrum of possible *payoff* outcomes. The authors criticize previous work in the incomplete contracting literature, stating that the authors "do not attempt to derive complete contract foundations for the restricted class of contracts they study" and that the invocation of significant transaction costs is not sufficient to relegate contract design to an incomplete approach (pp. 83-84).

In response to this criticism, Hart and Moore (1999) provide a model of incomplete contracting, which they use to address Maskin and Tirole's irrelevance theorems. The authors' results indicate that an optimal contract may be incomplete in the presence of unachieved states of nature (indescribability). Additionally, Hart and Moore find that Maskin and Tirole's irrelevance results are heavily dependent on restrictive assumptions, and "describability *does* matter" when these assumptions are relaxed (p. 116). These two competing results have spawned further research, which attempts to closely examine the ability of contracts to solve the hold-up problem and/or to extend the discussion on the relevance of describability. This literature includes Schmitz (2008), Kunimoto (2008) and (2010), and Hoppe and Schmitz (2011), among others. To summarize, there seems to be a lack of consensus regarding the use of incomplete contracts to achieve an optimal outcome in the contracting literature. While certain economists have asserted that describability is an "irrelevant" consideration in achieving optimal allocations, a second group of economists maintain that describability is a critical factor in contract design and, thus, claim that incomplete contracts warrant a separate classification.

In this paper, my goal is to bring new information to the aforementioned discussion in the form of empirical results. The Federal Acquisition Regulation (FAR) provides guidelines for the acquisition of major weapons systems by the U.S. Department of Defense (DoD). This regulation includes a menu of contract types from which an acquisition official may choose, given the specific characteristics of the project and the winning firm. Given the description of these contract types from the FAR, one can then rank contracts in terms of the implied describability of the associated defense projects. Using this measure of describability, project characteristics, winning firm characteristics, and efficiency parameters from the DoD's Earned Value Management System, I can then create a model of contract performance and attempt to estimate the empirical effect of describability on cost and schedule performance. While a lack of counterfactual evidence in this study will not allow me to comment on the "optimality" of the use of incomplete contracting methods, I hope to shed light on the relevance of describability in determining contracting outcomes.

In order to empirically test theoretical predictions regarding describability, this paper uses contract data from Selected Acquisition Reports, which are required reports from the DoD to Congress for substantial weapons programs. The contract data includes time series observations of 89 different contracts for major weapons systems, including standardized measures of cost- and schedule-related inefficiencies. These alternate dependent variables provide the possibility to distinguish between the explanatory variables' effects on overall cost performance versus schedule-related cost performance, a distinction highlighted in previous studies of DoD acquisition. The analysis in this paper, while far from conclusive, suggests that the physical describability of these projects is relevant to the contracting process in two ways. First, the complexity and technological uncertainty of the project in question are primary considerations in the contract type decision by DoD officials. Second, this technological uncertainty, even after accommodation by the DoD via the contract type decision, appears to have an adverse effect on contract schedule performance in the form of costly production delays.

This paper proceeds as follows. Section 3.2 surveys the economic literature on contractual solutions to the hold-up problem, discusses the Maskin/Tirole and Hart/Moore debate in detail, and considers previous attempts to evaluate the determinants of contract efficiency. Section 3.3 discusses specific features of the DoD acquisition process that are relevant to the empirical portion of this paper: Earned Value Management and contract types from the Federal Acquisition Regulation. Section 3.4 discusses the underlying model, Section 3.5 contains a detailed description of the data used for estimation, and Section 3.6 discusses estimation procedures. Section 3.7 presents the regression results and analysis, Section 3.8 presents robustness checks for the model, and Section 3.9 concludes.

3.2 Literature Review

3.2.1 Contractual Solutions to the Hold-Up Problem

The application of contracts to "solve" the hold-up problem is a well-documented subject in the contracting literature. Rogerson (1992) finds that first-best contractual solutions to the hold-up problem exist under extremely complex environmental conditions and in situations with a variety of assumptions regarding information asymmetries (p. 777). He provides a unique corollary of the hold-up problem: “the hold-up problem does not necessarily cause inefficiencies. Rather inefficiencies only occur if certain environmental properties are not satisfied or certain types of contracts cannot be written (p. 778).”

Fares (2006) surveys the literature pertaining to contractual solutions to the hold-up problem, specifically considering implementation of mechanisms that yield efficient investment even in the presence of contractual incompleteness. In particular the author’s main goal is to demonstrate the importance of renegotiation design in achieving efficient investment outcomes. Summarizing conclusions from his survey, Fares claims that his paper mainly shows 1) that renegotiation design is a necessary component of solving the hold-up problem via contracts, and 2) this finding holds in cases of both selfish and cooperative investment (p. 753). These conclusions suggest that contracts seeking to implement efficient levels of investment must address the renegotiation process and must include a mechanism for monitoring the relative allocation of bargaining power between parties.

Hoppe and Schmitz (2011) seek to determine whether experimental data supports the theoretical ability of contracts to mitigate the hold-up problem. The results of their study suggest the following conclusions: 1) a fixed-price contract does not improve investment incentives compared to the no-contract benchmark, 2) a non-renegotiable option contract improves investment incentives compared to the benchmark, and 3) the ability to commit to the contract (prevent renegotiation) has a significant effect on a contract’s ability to promote efficient investment (pp. 197-198).

Despite differences in the characterization of the hold-up problem itself and in underlying theoretical models, the above sample of papers from the contracting literature seem to agree that a solution to the problem exists in deliberate contractual design. Meanwhile, the existence of a hold-up problem during the Research and Development phase of DoD weapons projects is thoroughly described in Rogerson (1994), and the empirical work of Crocker and Reynolds (1993) analyzes the DoD's application of different contract types to accommodate varying levels of project risk. Therefore, one can conclude, at a minimum, that the DoD is attempting to contractually solve an incentive alignment problem with its contractors that originates from uncertainty regarding the technological feasibility of its weapons projects. This endeavor closely resembles the contractual situation at the heart of the Maskin/Tirole and Hart/Moore debate.

3.2.2 An Influential Debate

The stated goal of Maskin and Tirole (1999) is to "scrutinize" the concepts underlying the optimality of incomplete contracting (p. 83). The authors motivate this paper based on the lack of an accepted theoretical foundation for incomplete contracting, stating that many of the major contributions to the literature "do not attempt to derive complete contract foundations for the restricted class of contracts they study (p. 83)." They specifically take issue with the fact that the commonly assumed ability of dynamic programming for actors in the incomplete contracting literature should preclude the relevance of transaction costs in contract formulation (p. 84). In other words, even if the transaction costs prevent the ex ante description of physical outcomes, these costs should not affect the agents' abilities to forecast possible payoff outcomes. This assertion is the underlying foundation of the authors' irrelevance theorem:

"If parties have trouble foreseeing the possible physical contingencies, they can write contracts that ex ante specify only the possibly payoff contingencies (p. 84)."

Maskin and Tirole seek to determine when the "indescribability" of a good or service affects the efficiency of the contracted outcome. Under the assumptions of their model, the authors demonstrate that a welfare-neutral, Pareto-optimal, payoff-based contract can be implemented under subgame perfect equilibrium in the event that states are indescribable (p. 104). Furthermore, they use their framework to show that their irrelevance result holds even in the presence of renegotiation, given risk averse participants (p. 102). Maskin and Tirole's findings suggest that concerns surrounding the indescribability of physical outcomes (incomplete contracts) may be unfounded, given the ability to describe payoff outcomes.

Hart and Moore (1999) respond to Maskin and Tirole's (hereafter MT) criticism of incomplete contracting theory. The authors seek to develop a "rigorous foundation" for the theory, based on the following idea of contractual incompleteness: a buyer seeks to purchase an item from a seller; the precise nature of the item is uncertain or is dependent on a heretofore unrealized state of nature; if the number of possible physical outcomes for the item is substantial, the cost of accounting for all contingencies in contractual form would be "prohibitively expensive (p. 115)." Therefore, the parties agree to an incomplete contract, allowing renegotiation of the terms of the contract at a stage when the nature of the item is defined or its physical characteristics become describable.

MT (1999) describe mechanisms that allow the parties to circumvent these prohibitively expensive transaction costs, by detailing the possible outcomes of trade ex ante and thus preventing the parties' need to describe the actual characteristics of the item itself. Hart and Moore evaluate this critique and MT's underlying "irrelevance theorems." They show that it is possible that an optimal contract may be incomplete, a notion clearly disputed by MT (1999).

Hart and Moore provide two possible definitions of an incomplete contract: 1) the contractual obligations of the parties involved may not be fully described, or 2) the parties are unable to describe possible contingencies because possible states of nature are prohibitively expensive to describe ex ante (p. 134). Hart and Moore conclude that the issues raised by type-1) contracts may be overcome by the actions described by Maskin and Tirole (1999). However, the authors assert that their model shows that an optimal contract in a type-2) situation may be incomplete. Furthermore, the authors suggest that both of these incomplete contract types are "qualitatively" different from comprehensive and complete contracts typically studied in the mechanism design literature, and thus merit a separate classification (p. 135).

Therefore, the literature presents two diametrically opposing views of the importance of describability in determining whether an incomplete contract can serve as an optimal solution to the hold-up problem. While my goal in this paper is not to evaluate the theoretical approaches of these opposing economists, I certainly believe that the existence of real world contracts intended to accommodate differing levels of project uncertainty and describability suggest that the MT (1999) mechanisms may not be feasible, particularly in defense acquisition. It seems that their assumption regarding welfare-neutrality between a contract's indescribable physical states and its describable payoff outcomes is overly optimistic. This idea becomes particularly problematic if one chooses to place a metric (e.g., a dollar amount) on the welfare impact of a specific contract.

For example, suppose the DoD wants to purchase a new anti-aircraft missile.

If the DoD agrees to a contract that is based on a very specific set of technical specifications for this missile, one might expect an extremely different cost outcome than if the contract only specified "create an anti-aircraft missile." The first contract focuses research, development, and production in a detailed manner, while the second is much less defined and could lead defense firms in a variety of directions. If one measures welfare impact in terms of cost/benefit of the procurement program, these two methods could lead to significantly different welfare outcomes.

Frankly, incomplete contracts are frequently used in procurement, and it seems that the mere presence of a menu of different contracts with different levels of completeness solidifies the importance of "incomplete contracting." It seems that Maskin and Tirole's irrelevance theorem is relevant only in the context of environments where their mechanisms are feasible. However, this paper does yield at least one testable hypothesis: does the describability of a contract's physical characteristics influence its efficiency outcome?

3.2.3 Empirical Determinants of Contract Performance

Perhaps unsurprisingly, the efficient performance of defense acquisition programs is a politically-charged and contentious issue. Due to the United States' singular role in the international security environment, DoD expenditure on major weapons systems has largely dwarfed that of both its adversaries and allies, particularly following the end of the Cold War. The magnitude of this defense expenditure naturally attracts the attention of the US public, and the procurement of the nation's most ambitious projects typically receives a preponderance of this public scrutiny. As one might expect, economists have also shown interest in the efficient conduct of defense acquisition programs.

Peck and Scherer (1962) evaluate the outcomes of twelve military acquisition programs in terms of deviation from time, cost, and quantity baselines. These deviations are expressed using the final parameter value as a percentage of its original planned value. In their sample, the authors find that technological uncertainty plays a role in development cost overruns but has “little if any effect” on time overruns (p. 436). In contrast, urgency had more explanatory power for time overruns than did program costs, leading the authors to refute a common opinion (e.g., “unavailability of funds is a major villain in causing schedule slippages”) (p. 447). The authors also discuss service demands; lack of clarity in program decisions and objectives; delayed decisions (particularly in lower priority programs); contractor technical and managerial capability; and conflicting objectives between the contractor and the Government as possible determinants of cost, time, and quality variance in weapons procurement.

Marshall and Meckling (1962) focus on cost estimation during operational development, which they define as “the effort to take ideas or components that have been tested experimentally and embody them in useful equipment (p. 462-463).” The authors offer four separate categories which collectively describe the success or failure of a weapons program: cost, performance, time, and utility (p. 464-465). In a manner similar to Peck and Scherer (1962), the authors use percent deviations of the final program costs and timelines from the original estimates as measures of efficiency. Additionally, Marshall and Meckling present adjusted measures of the program cost deviations, which take into account quantity changes and inflation.

Using survey classifications of the different projects in their data sample, the authors demonstrate that the nature of technological advance (small, medium, or large) plays a significant role in the magnitude of total factor increases in costs (p. 472). In terms of schedule deviation, or "time slippages," their results indicate that the accuracy of baseline schedules is inversely related to technological advancement and program maturity (p. 473). Marshall and Meckling attribute the majority of the large deviations in program costs and schedules to overly optimistic initial estimates for the program parameters. In their summary, the authors discuss the incentive to be overly optimistic in cost estimation at the beginning of a weapons program: contractors want the DoD to accept their plan, and the DoD wants Congress to support their development goals. However, they also admit that contractor penalties for poor estimation were relatively weak in 1962 (p. 475).

Economists have also explored the determinants of contract performance in the provision of other public services, specifically considering the effect of contract type in addition to other pertinent factors. For example, Piacenza (2006) estimates X-inefficiency for public transportation firms in Italy using a stochastic frontier variable cost function. He models X-inefficiency as a function of regulatory scheme (cost-plus vs. fixed-price) and environmental factors (aggregating to the delivery speed), among other variables. Using this approach, the author finds that the incentive-maximizing regulatory structure provided by the fixed-price (FP) regime indeed results in X-inefficiency reduction for the firms that use fixed-price contracts (p. 268). Additionally, Piacenza finds a differential effect of the regulatory scheme based on the existing environmental factors affecting the transportation company's delivery speed (p. 274). His results indicate that high speed rail lines subject to FP contracts decreased X-inefficiency to a greater degree than average speed rail lines with FP contracts. Therefore, Piacenza suggests that a full evaluation of a company's existing infrastructure must accompany any regulatory scheme decision, as the company's ultimate performance may depend on both.

Similarly, Jensen and Stonecash (2009) use a difference-in-difference estimation approach to analyze the effects of a natural experiment involving the use of two different contract types in the provision of water services: cost-plus and fixed-price. This experiment results from a change in contract type by one provider while the other remains the same. In contrast to previous studies, the authors find that the change to cost-plus contracts by one of the firms led to significant additional savings, using three different measures of maintenance costs (p. 290). However, their results are confounded by the fact that they are unable to control for both unbalanced bidding on the cost-plus contracts and differences in work quality, which could affect the interpretation of their results.

These entries in the empirical literature suggest that technological uncertainty, project urgency, production/managerial capacity, and contract type play a critical role in the eventual performance outcomes of public sector contracts. Therefore, these elements must be considered in any model of contract performance for the DoD.

This paper will contribute to the aforementioned literature in the following manner. First, I will demonstrate the link between the physical describability of projects and contract types administered for those projects, utilizing application instructions for contract types from the Federal Acquisition Regulation. Second, I will attempt to model the efficiency outcome for an array of modern DoD aircraft programs as a function of project, firm, and contract characteristics. Finally, I will use this link to determine the empirical significance of describability in the cost outcome of DoD aircraft contracts, perhaps indicating relevance or irrelevance of describability in the DoD contracting environment. My main goal for this paper is to contribute empirical evidence to the incomplete contracting literature in support of a discussion that has been largely theoretical to this point.

3.3 Institutional Background: Earned Value Management (EVM) and Describability in DoD Contracts

The specialized technological nature of major weapons systems requires that the DoD employ distinctive approaches to both R&D and procurement. In order to simultaneously serve as good stewards of taxpayer money and advance the frontier of defense technology, the DoD uses both a stringent monitoring process to ensure compliance with contract guidelines and an extensive menu of contract types to accommodate varying levels of project uncertainty. Both of these features of the defense acquisition process are unique to the DoD and warrant further explanation, as they will serve prominent roles in the empirical portion of this paper.

3.3.1 EVM Background and Terminology

In order to synchronize management of defense acquisition programs across all military services, the US Department of Defense pioneered the Earned Value Management (EVM) System as a project management technique in the 1960s. EVM serves as the DoD's required standard for project management today, and the data from the EVM process is used to prescribe corrective actions and even cancellation of contracts for US weapons projects. The backbone of the EVM process is a set of 32 system guidelines, which are intended to guide contractors and acquisition officials in creating systems to monitor weapons contracts. These guidelines are quite general, allowing involved parties to tailor the EVM system to the project in question. A particular strength of the EVM process is its ability to simultaneously incorporate measures of project scope, cost, and schedule. According to the DoD EVM Guide, "EVM encompasses both performance measurement (i.e., what is the project status) and performance management (i.e., what can we do about it?)."[1]

While this system involves monitoring of multiple parameters related to contract performance, this paper will specifically focus on two variables from the EVM process: cost variance (CV) and schedule variance (SV). These are not, as one might reasonably expect, traditional second moments and require further explanation. In order to define these measures, I must also define several additional EVM terms. First, a project's planned value (PV) is defined as "the value to be earned as a function of project work accomplishments up to a given point of time" (Anbari, p. 13). Second, a program's actual cost (AC) is the cumulative total cost of work performed as of a specific point in time (Anbari, p. 13). Finally, the earned value (EV) of the contract is "the amount budgeted for performing the work that was accomplished by a given point in time" (Anbari, p. 13). Using these terms, we define the cost variance of a project as the difference between the program's earned value and actual cost at a given point in the project timeline (CV = EV-AC). Similarly, a project's schedule variance is determined by finding the difference between the project's earned value and planned value (SV = EV-PV).[2]

In examining these formulae, it is apparent that positive values of CV and

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[1] DoD EVM Guide, p.11

[2] The formulas for these parameters can be found in both the DoD EVM Guide and Anbari, 2003.

SV signify a project that is performing above expectations, zero values indicate a strictly efficient program, and negative values indicate adverse and inefficient performance outcomes. To illustrate these concepts, Figure 3.1 depicts the hypothetical EVM parameter curves for a project with negative CV and SV.[3] Alternatively, consider the following example of EVM in the administration of a hypothetical contract. A defense contract has an overall price of $10 million. Suppose the software development package and engineering design package for the contract consist of 30% and 20% of the total contract price, respectively. According to the contract's milestones, the firm should complete both the software package and the engineering design package before the first annual review. At the annual review, the firm reveals that it has completed only the software package at a cost of $4 million. This means that the cost variance for the project is (EV-AC) = ($3M - $4M) = -$1M. Meanwhile, the schedule variance is (EV-PV) = ($3M - $5) = -$2M. Therefore, one can assess that a project is over - budget and behind schedule at a given point in time merely by observing negative values of cost and schedule variance.

For each of the Major Defense Acquisition Programs (MDAPs) included in the data sample for this paper, I have annual measurements of both cost and schedule variance at the contract level. While previous studies have utilized empirical estimates of contract efficiency in testing theoretical hypotheses, these measures of CV and SV provide me with standardized measurements of efficiency, which I can use to test hypotheses regarding the determinants of contract performance.

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[3] I constructed this figure using Figure 4 from Anbari, 2003, as an example

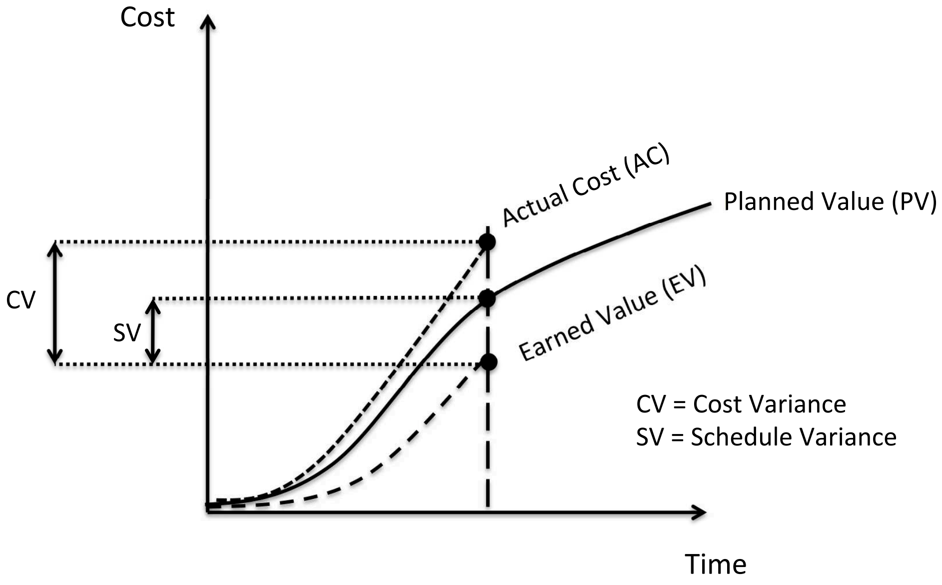

Figure 3.1: Earned Value Management (EVM) Parameters

3.3.2 Hierarchy of Describability in DoD Contracts

Among other factors, the US Government Federal Acquisition Regulation (FAR) directs that contracting officers should consider the "type and complexity" of contracted projects in negotiating contract types with winning defense firms. The FAR concedes that "complex requirements, particularly those unique to the government, usually result in greater risk assumption by the Government (16.104d)." This phrasing indicates that the DoD acquisition process is capable of accommodating projects with varying levels of technological uncertainty and complexity through the use of contract types that differ in terms of the amount of risk shouldered by the DoD. If one concedes that it is primarily internal uncertainty that the contracting officer is capable of evaluating during the initiation of a contract, the contracting officer's major focus in accommodating complexity should be selecting a contract type that reflects the level of physical describability of the project in question. This physical describability of the project could feasibly include aspects of design, scope, scale of production, and input materials.

In fact, the application instructions for various contract types in the FAR reflects this suggested relationship between describability and contract type. Given these directions from the FAR, one can then establish an implied ranking of the physical describability of the projects that different contracts are able to accommodate. For example, the data sample for this paper includes the following contract types: Cost-Plus-Incentive-Fee (CPIF), Cost-Plus-Award-Fee (CPAF), Cost-Plus-Fixed-Fee (CPFF), and Fixed-Price-Incentive-Fee (FPIF). Using the application instructions for these contract types from the FAR, I can then infer the relative describability of the contracted projects.

- **FPIF** > **CPIF**: Contracting officials are only able to use cost-reimbursement contracts when uncertainty does not allow for a sufficiently accurate cost estimation (16.301-2). Therefore, projects covered by fixed-price contracts should be relatively more describable than all cost-reimbursement contracts.[4]

- **CPIF** > **CPAF**: Award-fee contracts are to be used when the creation of incentive targets is not feasible. This indicates that the physical describability of projects covered by an incentive fee contract should be more conducive to establishing cost and performance targets than one covered by an award fee contract.[5]

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[4] According to FAR section 16.301-2, acquisition officials are able to use cost-reimbursement contracts only in the event that "(1) Circumstances do not allow the agency to define its requirements sufficiently to allow for a fixed-price type contract; or (2) Uncertainties involved in contract performance do not permit costs to be estimated with sufficient accuracy to use any type of fixed-price contract."

[5] Section 16.401e directs that acquisition officials should employ an award fee contract when "The work to be performed is such that it is neither feasible nor effective to

- **CPAF > CPFF**: Cost-plus-fixed-fee contracts provide the least incentive for cost minimization and the most secure profits for the defense firm. The FAR's description of this contract type suggests that it should be used as a last resort, when incentive fees aren't practical and "the level of effort" is unknown (16.306b).[6]

Using these relationships, I can order the contract types in terms of describability from most to least: FPIF, CPIF, CPAF, CPFF. These relative describability "rankings" serve as a variable that I can test as a determinant of contract efficiency, which is indicated by contract EVM parameters. The empirical results from this procedure would then allow me to comment on the overall impact of describability on contract performance and the relevance of describability in contract theory. Given that the FAR's contract menu is intended to afford flexibility to the acquisition official in acquiring complex projects at the best value to the government, this empirical approach will also serve as a test of the efficacy of acquisition officials' application of the FAR in controlling cost growth in defense projects.

3.4 Model

In order to test for the impact of a project's relative level of physical describability on eventual contract efficiency via the contract type decision, I will

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devise predetermined objective incentive targets applicable to cost, schedule, and technical performance."

[6] Section 16.306b indicates that contracting officers should employ cost-plus-fixed-fee contracts when "(i) The contract is for the performance of research or preliminary exploration or study, and the level of effort required is unknown; or (ii) The contract is for development and test, and using a cost-plus-incentive-fee contract is not practical." Due to the fact that the fixed fee does not vary with the performance costs of the contract and is determined at the award date of the contract, the FAR indicates that this type of contract provides little incentive for the contractor to minimize costs and should be used only to facilitate "contracting for efforts that might otherwise present too great a risk to contractors (16.306a)."

use a reduced form model of contract performance. While previous evaluations of contract type (e.g., Piacenza, 2006) have estimated efficiency measures using structural equations, the availability of EVM performance statistics ensures that I am not imposing any additional restrictions on my analysis due to structural assumptions. This approach is certainly acceptable, according to the contract evaluation literature surveyed in this paper.

One can speculate that multiple different project characteristics could have a significant impact on the corresponding contract's ability to adhere to price and schedule guidelines. For example, contract type may influence the government's level of involvement in administration of the contract, corresponding to the relative amount of risk that the government shares for cost growth. As previously mentioned, the contract type may also serve as an indicator of the relative physical describability of the project in question. Therefore, it is possible that a project requiring a low-powered contract (CPFF for instance) may be relatively more prone to production difficulties, which could ultimately result in a relatively lower level of performance efficiency. Along the same line of reasoning, a research and development contract may naturally be more prone to technological obstacles than a production contract in which proof of concept and system validation have already occurred.

Other identifying features of the project/contract in question could potentially have a significant impact on the contractor's ability to adhere to contractual guidelines. In the case of a dual source project (e.g., the DoD often procures aircraft engines for a single platform from two different manufacturers), the defense firms may have additional motivation to adhere strictly to contract requirements due to the presumed ability of the government to terminate one of the contracts in the case of poor relative performance. The length of the contract may also affect its performance outcome. In one sense, the government may not engage in lengthier contracts for projects with high levels of technological uncertainty to limit its exposure to unexpected cost growth. However, longer contracts may also enable the contractor to exercise greater flexibility in the application of corrective action and eventually result in desirable efficiency outcomes. These two competing theories suggest that the effect of contract length could be different if measured at the end of a contract versus in the interim.

Learning curve effects are also well documented for various manufacturing process and, specifically, for the aircraft industry. (See, for example, Benkard, 2000.) In repeat iterations of an identical contract, one therefore might expect contracting efficiency measures to improve relative to past versions of the same contracts. Similarly, a firm's familiarity with defense manufacturing and the DoD procurement process may have an impact on their ability to provide reliable cost estimates and projected timelines, thereby directly influencing the firm's performance in adhering to contractual requirements. As a result, a firm's previous contracting history with the DoD may affect its ability to adhere to cost and schedule milestones.

To test these hypotheses regarding the effect of specific contract characteristics on the efficiency outcome of the contract in question, I can use the following reduced form model for contract performance:

$$P_i = F(d_i, x) + \epsilon_i, \tag{3.1}$$

where P is the contract performance in EVM terminology (cost or schedule variance), $F(\cdot)$ is a contract-invariant efficiency function, d is the physical describability of the contract indicated by its contract type, x is a set of identifying contract characteristics, and ϵ is a contract specific error term.

One possible confounding feature of this empirical approach is the possibility that, as I have briefly alluded to above, the physical describability of a project may affect contract performance other than through the selected contract type. For example, a more complex, next generation technology may warrant a less complete contract type (e.g., CPFF) during its research and development phase. Clearly, the selection of this type of contract indicates that the possible outcomes for this project will be numerous and difficult to foresee, but the additional oversight from the DoD that accompanies this contract type should serve to control or impede cost growth. However, it remains a possibility that the contract will not fully accommodate ALL complications due to the indescribable nature of the project. Therefore, it is possible that describability can affect both the contract type decision and the contract performance simultaneously, creating an endogeneity issue. In order to account for this possibility, I will use an instrumental variable for contract type, which I will further discuss in the estimation section of this paper.

3.5 Data

This paper uses data collected directly from Selected Acquisition Reports (SARs), which are submitted to Congress annually by the US Department of Defense. Congress uses SARs to guide funding decisions for major defense projects. In order to qualify for SAR submission, a project must either a) exceed \$365 million in total research, development, training, and evaluation (RDT&E) or b) exceed \$2.19 billion in total procurement costs (FY 2000 constant \$).[7]

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[7] Defense Acquisition University, www.acc.dau.mil.

The data sample used for estimation in this paper consists of contracts from active military aircraft programs with SARs submitted from December 1997 to December 2011. These programs include multiple aircraft procured by each branch of service (Army, Navy, Air Force) and one managed by the DoD as a whole (F-35 Lightning). Due to differences in program start dates and duration of procurement, the data has an unbalanced panel structure.[8]

Due to the contractor's sole responsibility for cost performance and resulting profits in firm-fixed-price (FFP) and fixed-price-with-economic-price-adjustment (FPEPA) contracts, the US government does not apply EVM in the administration of these contracts. As a result, program managers do not collect and report cost and schedule variances for these contracts as part of the SAR process. As an additional restriction, the database includes "combination" contracts, indicating that one contract type could not accommodate the work performed under the contract. In these contracts, it is impossible to align the contract type with the physical describability rankings previously discussed in this paper. Table 3.1 depicts the distribution of contracts in the entire sample and their translation into contract-year observations. Note the exclusion of FFP, FPEPA, and Combination contracts from the "relevant" sample leads to a reduction of 93 contracts and 310 contract-year observations. Additionally, the distribution of contract types in the relevant sample (FPIF, CPIF, CPAF, CPFF) is indicative of the government's increasing responsibility for cost growth as the contract becomes less complete. FPIF contracts appear most frequently, followed by approximately equivalent amounts of CPIF and CPAF contracts, and CPFF contracts are issued almost half as often as FPIF. This distribution belies the

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[8] There is no indication in the available SARs that the DoD terminated any of the projects contained in my data sample due to poor contract performance. All of the projects include a natural progression of R&D and procurement phases.

government's efforts to incentivize cost minimization to the maximum possible degree in each contract.

Table 3.2 details the available cost variance and schedule variance observations for the contracts in the data sample. Of the 367 relevant contract-year observations, 331 include cost variation observations and 322 include schedule variance observations. Nine total contracts experienced cost variance without schedule variance, but no contract demonstrated schedule variance without simultaneous cost variance. The ratio of positive to negative observations is similar across the two types of performance measures: a 45/55 split in cost variance and a 40/60 split in schedule variance. Table 3.3 lists summary statistics for different expressions of cost and schedule variances from the estimation sample. Note the change in sign when cost variance is expressed as a percentage of the initial contract price. This is due to the common occurrence of major changes to contract price between the award date and a contract's first appearance in a SAR. As a result, the initial price is typically not representative of the eventual price of the contract. With this exception, the mean values of the other statistics are all negative, perhaps indicating a tendency for contracts to perform over budget and behind schedule in major aircraft programs.

Table 3.1: Distribution of Contracts by Type

	Contract Observations	**Contract-Year Observations**
FFP	62	205
FPEPA	6	30
FPIF	33	92
CPIF	26	88
CPAF	25	127
CPFF	18	60
Combination	25	75
Total	195	677
Relevant Sample	102	367

Table 3.2: Observations of Cost and Schedule Variance

	Cost Variance	**Schedule Variance**
Total Observations	331	322
Relevant Observations	298	290
Positive Obs. (Raw)	135	118
Positive Obs. (Percentage)	45.30	40.69
Negative Obs. (Raw)	163	172
Negative Obs. (Percentage)	54.70	59.31

Table 3.3: Summary Statistics for Cost Variance and Schedule Variance

Variable	Observations	Mean	Std. Dev.	Min	Max
Cost Variance (CV)	305	-4.282	67.524	-376.5	779.1
CV/Current Price	305	-0.002	0.028	-0.171	0.097
CV/Initial Price	305	0.002	0.176	-1.347	1.812
Cumulative CV	89	-15.236	58.508	-315	130.6
Average (CV/Current Price)	85	-0.002	0.019	-0.076	0.043
Average (CV/Initial Price)	85	0.003	0.064	-0.28	0.269
Schedule Variance (SV)	305	-3.125	51.751	-457.2	581.6
SV/Current Price	305	-0.003	0.024	-0.161	0.114
SV/Initial Price	305	-0.018	0.267	-2.488	2.382
Cumulative SV	89	-12.02	26.867	-130.6	7.4
Average (SV/Current Price)	85	-0.007	0.02	-0.125	0.04
Average (SV/Initial Price)	85	-0.027	0.085	-0.591	0.04

In addition to the previously described information, the contract section of each SAR provides each contract's managing military branch; initial price and quantity; current price and quantity; funding category (R&D vs. Procurement); award date; basic contractor information; contractor and military program manager estimates of price at completion; and brief explanations of factors contributing to the current levels of cost variance and schedule variance. I will describe and analyze these explanations in greater detail in the estimation section of this paper.

While the database that produces each SAR relies on the Federal Procurement Database System (FPDS) to provide contractor characteristics, many of these entries are incomplete, missing, or recorded in a non-uniform manner. Therefore, I collected firm employment, revenue, and other financial figures from annual investor reports and Securities and Exchange Commission filings (form 10-K) for each of the contractors in the data sample. Additionally, while the FPDS information on firm characteristics was less than desirable, I was still able to use this system to collect detailed information regarding contract length, as it contains the actual completion date for each contract. Due to my need to use outside sources to collect additional data, I was unable to find all pertinent information for each contract, and data availability ultimately reduced the estimation sample to 89 contracts with 305 contract-year observations. Tables 3.4 and 3.5 list the distributions of contract types and contracting firms in the estimation sample, respectively.[9]

Table 3.4: Contract Type Distribution (Estimation Sample)

	Total	% of Sample
FPIF	30	35.29%
CPIF	21	24.71%
CPAF	24	28.24%
CPFF	14	16.47%

3.6 Estimation

The main goal of this paper is to comment on the relevance of physical describability in contract performance outcomes, using defense contracts to provide empirical information for the debate regarding the use of incomplete contracting. My main variable of interest is, therefore, the physical describability

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[9] Due to business confidentiality concerns, I am unable to provide actual firm names for the contractors in my data sample.

Table 3.5: Distribution of Contracts by Firm (Estimation Sample)

Firm	Total Contracts	% of Sample
A	5	5.62%
B	1	1.12%
C	15	16.85%
D	16	17.98%
E	1	1.12%
F	1	1.12%
G	14	15.73%
H	23	25.84%
I	13	14.61%

of the underlying project as indicated by the contract type chosen by the acquisition official. Due to the fact that this variable, along with many of a contract's other identifying characteristics, is time-invariant, I cannot use the within transformation and achieve my intended purpose. As a result, I will conduct cross-sectional analysis of my data sample and supplement this with panel analysis using the pooled OLS and between effects panel estimators. More concretely, I will estimate the following contract performance equations, using a) a cross-sectional structure and b) an unbalanced panel structure:

$$a)P_i = \beta_0+\beta_1 DRNK_i+\beta_2 CUMDQ_i+\sum_{j=3}^{4}\beta_j SUMEXPL_{ji}+\sum_{l=5}^{m}\beta_l x_{li}+\epsilon_i, \quad (3.2)$$

and

$$b)P_{it} = \beta_0 + \beta_1 DRNK_i + \beta_2 DQ_{it} + \sum_{j=3}^{14}\beta_j EXPL_{jit} + \sum_{l=15}^{m}\beta_l x_{lit} + \epsilon_{it}. \quad (3.3)$$

In equation (3.2), P_i is either the contract's cumulative cost variance or schedule variance for the duration of the contract, $DRNK_i$ represents the describability ranking of the contract's type in accordance with the previous discussion, $CUMDQ_i$ is the cumulative change in quantity over the duration of the contract, the $SUMEXPL_i$s are the sum of the positive and sum of the negative variance explanations offered by the program manager over the duration of the contract, and the x_{li}s are control variables, which account for identifying characteristics of the contract in question.

For equation (3.3), I have a similar set of explanatory variables, consisting of disaggregated versions of the variables used in equation (3.2). P_{it} is the cost or schedule variance for contract i in time period t, $DRNK_i$ is the same time-invariant describability ranking used in equation (3.2), DQ_{it} is the change in quantity for contract i in time period t, the $EXPL_{jit}$s are the categorized variance explanations for the contract in period t, and the x_{lit}s are time variant and invariant characteristics of contract i. The primary importance of the panel analysis is the inclusion of the more robust set of variance explanations, which cannot be included in the cross-sectional analysis due to more limited degrees of freedom.

3.6.1 Dependent Variables

The cost variance and schedule variance figures for each contract are expressed in dollar amounts as of the date of the Selected Acquisition Report in which they appear. For sake of comparison across contracts, it is necessary to adjust these figures for inflation. Additionally, it is reasonable to expect that higher-priced projects may result in relatively higher cost and schedule variance dollar amounts relative to less expensive projects. Therefore, it may also be worthwhile to normalize cost and schedule variance figures by contract price at the time of the recorded cost or schedule variance.[10] Table 3.6 lists the names and definitions of the dependent variables used in both cross-sectional and panel analysis.

Table 3.6: List of Dependent Variables

Cost Variance (CV)	Definition
cumcv	Cumulative Cost Variance for of contract, adjusted for inflation
avcvpercurp	Average ratio of Cost Variance to Current Price over duration of contract
cv	Inflation-adjusted Cost Variance
cvpercurp	Cost Variance/Current Contract Price
Schedule Variance (SV)	
cumsv	Cumulative Schedule Variance for duration of contract, adjusted for inflation
avsvpercurp	Average ratio of SV to Current Price over duration of contract
sv	Inflation-adjusted Schedule Variance
svpercurp	Schedule Variance/Current Contract Price

3.6.2 Instrumental Variable for Describability Ranking

Given the previous discussion of the link between the physical describability of a project and the resulting contract type chosen by acquisition officials, I can rank projects covered by FPIF, CPIF, CPAF, and CPFF contracts in terms of implied describability as in Table 3.7. However, for estimation purposes, I must account for the possibility that the describability of the project affects the subsequent performance of the contract via a separate channel other than the contract type decision. In other words, the inclusion of the ordered describability ranking in Table 3.7 may create an endogeneity issue in estimating equations (3.2) and (3.3).

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[10] Note that cost variance observations always occur with respect to the current contract price. In other words, the current price will not also include previously accumulated cost variance. In scenarios when acquisition officials adjust the contract price due to performance issues, the cumulative cost variance is reset to zero. In this sense, there should be no concern that the current price of the contract is moving with the cumulative cost variance.

In order to address this problem, I will use an instrumental variable approach in my regression analysis.

Table 3.7: Describability Rank of Contract Types

DRNK (Describability Rank) =	1 if type =	CPFF
	2 if type =	CPAF
	3 if type =	CPIF
	4 if type =	FPIF

In a previous paper, I demonstrated the ability to model the acquisition official's contract type decision for these same aircraft programs as a function of both project and firm characteristics. To create the instrumental variable for describability ranking, I will utilize this same contract type selection model to predict the expected contract type, $EDRNK_i$, for each contract, given its associated project and firm characteristics.[11] Due to the fact that the contract selection model uses many of the same explanatory variables that I will use as control variables for this paper, I will not discuss this estimation process at length here. For transparency, the regression results for this procedure are presented in Appendix B.

Using this method, the regression model accounts for 61% of the variation in the $DRNK$ variable. Table 3.8 presents a comparison of $DRNK$ and the instrumental variable produced via the contract choice model, $EDRNK$. The contract choice model provides me with a variable that is highly correlated with the $DRNK$ variable but is plausibly exogenous to the actual performance

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[11] The previous paper mentioned here used a ranking of contractual "completeness," which measured actual portions of the contract that were left open to subsequent renegotiation. The "describability" ranking for this same set of contracts is very similar, as only the ranking of the CPIF and CPFF contracts differ. As one of the robustness checks for my previous paper, I estimated the model using the describability scale. This distinction between "completeness" and "describability" mirrors the two possible definitions of incomplete contracts provided by Hart and Moore.

outcome of the project at hand. The lack of a controlling variable for technological uncertainty or complexity in the contract choice model is likely a) responsible for the imprecision of the contract type predictions and b) cause to believe it will be not be highly correlated with the contract's cost and schedule variances.[12] Additionally, the predicted describability ranking from OLS estimation is a continuous variable, which should further diminish problematic correlation between the predicted contract type and the contract's performance outcome.

Table 3.8: Summary Statistics for DRNK and EDRNK

	Obs.	Mean	Std. Dev.	Min	Max
drnk	149	4.020	1.772	1	6
edrnk	149	4.020	1.388	0.441	6.153

3.6.3 Control Variables

Despite the fact that all of the contracts in my estimation sample are part of large-scale military aircraft programs, the details of each contract are quite diverse. In order to isolate the effect of the project's physical describability on the subsequent performance outcome for the associated project, it is essential to account for these potentially confounding factors. In addition, it may be informative to uncover the independent statistical effect of these variables on contract performance, as empirical evidence from the defense industry is quite sparse and outdated. Table 3.9 provides a list of the explanatory variables used in estimation of equations (3.2) and (3.3). Note that in some cases I have listed both the individual and aggregated variables, which I then use in the appropriate data setting (e.g., *cumdq* is used for equation (3.2) and *dq* is used in equation (3.3)).

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[12] This inability to control for technological heterogeneity in a precise manner is due to the lack of any uniform measure of this variable across contracts.

Several of these variables may be of particular interest in comparing the contracting environment for military aircraft to other industrial settings. For example, the *iteration* variable could provide further evidence on the effects of learning on defense manufacturing. One might expect the cost and schedule performance of a military contractor to improve for the tenth lot (*iteration*=10) of aircraft produced relative to the first lot (*iteration*=1). Additionally, a contractor's ability to implement and follow EVM procedures may improve as they become more experienced with military contracting. The variable *prevcont* is intended to capture this administrative learning effect. As the theoretical foundations for this paper rely heavily on the power of incentives in contracting, I have also included a control for the use of a passive incentive mechanism, dual source contracting. Although dual source contracts make up only a small portion of the overall estimation sample, the effect of competitive pressure could be substantial for these select contracts.

To further account for heterogeneity between projects, I have also included controls for military branch, source of funding (*rd* versus *proc*), firm size (*employment* and *revenue*), and firm risk level (*cratio* and *lev*). Tables 3.10 and 3.11 provide summary statistics for the continuous and binary control variables, respectively.

Table 3.9: Control Variables

Variable	Definition
dq	Change in quantity over the current period
cumdq	Cumulative quantity change over duration of contract
prevcont	Number of Existing Contracts for Firm Prior to Award Date
duals	Indicator Variable for Presence of Multiple Sources (=1 if Multiple)
length	Number of Months between Contract Award Date and Scheduled Completion
iteration	Control for repeat procurement of same item (i.e., Lot 9 = 9)
winage	Within Program Age (Years): Contract Award Date - Initial Award Date for Program
wincage	Within Contract Age (Years): Observation Date - Initial Award Date for Contract
rd,proc	Separate Intercepts for RDT&E and Procurement (O&M excluded)
army, navy, af	Separate Intercepts for Army, Navy, AF (DoD excluded)
Firm Controls	
lemp	Log of Annual Employment
lrev	Log of Inflation- and Exchange Rate- Adjusted Annual Revenue (Segment Level)
cratio	Firm’s Current Ratio (Current Liabilities/Current Assets)
lev	Firm’s Leverage Ratio (Long-Term Debt/Total Assets)

Table 3.10: Summary Statistics for Continuous Control Variables

	Obs.	Mean	Std. Dev.	Min	Max
dq	305	0.256	1.876	-7	21
cumdq	89	0.976	4.189	-12	30
prevcont	89	13.011	11.012	0	46
length	89	43.461	29.125	2	138
iteration	89	2.843	3.118	1	15
winage	89	6.854	6.728	0	23
wincage	305	1.803	1.916	0	9
emp	305	142081.4	59656.11	32000	293000
rev	305	11962.4	8879.696	2275.759	20894.2
cratio	305	0.87	0.216	0.422	1.38
lev	305	0.163	0.054	0.064	0.381

Table 3.11: Summary Statistics for Binary Control Variables

	Obs.	Mean
duals	7	0.079
rd	45	0.506
proc	43	0.483
army	12	0.135
navy	45	0.506
af	17	0.191

3.6.4 Program Manager Variance Explanations

In addition to the hypothetical effects of the explanatory variables mentioned above, I must also account for the fact that the SAR format provides other concrete, yet imprecise, information regarding the performance of each contract. For example, this will prevent the model from falsely attributing poor performance to project describability that is actually due to contractor labor disputes. For each contract subject to EVM monitoring listed in the SAR, the program manager must provide explanatory comments regarding the net change in cost (CV) and schedule variation (SV). These comments provide brief explanations of the underlying causes leading to changes in the contract's performance measures. Unfortunately, the program manager does not attach dollar amounts or even percentages of the total contract value attributable to these factors, which would allow me to fully account for their impact on the CV and SV. Alternatively, I have created six general categories and recorded the program manager's explanation of net changes in CV and SV in terms of these categories for each contract-year observation. Due to the fact that acquisition officials report separate effects of these underlying problems on CV and SV, I record the effects separately and also record whether the issue has a positive (improvement) or negative (degradation) effect on contract performance. This leads to a total of 24 indicator variables that capture the underlying causes of contract performance in accordance with the program manager's explanatory comments.[13] These categories and corresponding indicator variables are listed below. Appendix A provides actual explanations from the subject SARs,

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[13] There are six total categories, which are further divided into positive and negative effects. Additionally, there are separate explanations of the categories' effects on CV and SV: 6 × 2 × 2 = 24.

categorized in accordance with the following framework.

1. **Change in Manufacturing Inputs**: This category includes changes in material costs or changes in the amount of materials required. In addition, this category includes external changes in the price of labor. Examples of positive changes include the use of less material than originally budgeted and decreased wage costs due to a manufacturer's decision to hire locally. Examples of negative changes include an increase in material prices and underestimation of required amounts of materials. (CV: *poscdpc(+), negcdpc(-)*; SV: *possdpc(+), negsdpc(-)*)

2. **Supply Chain Management**: The execution of a MDAP contract often includes multiple outside vendors and subcontractors, who supply components and parts to the prime contractor for integration and assembly. Negative examples from this category include delinquent deliveries of parts from subcontractors, parts shortages, chain reaction production delays, and delays in the awarding of subcontracted efforts by the prime contractor. Positive effects from this category are typically due to early delivery of parts and components. (CV: *poscsuppman(+), negcsuppman(-)*; SV: *posssuppman(+), negssuppman(-)*)

3. **Corrective Actions in Production**: The Earned Value Management System (EVMS) requires the use of process monitoring and periodic reviews to assist the defense contractor in preemptively identifying issues in the manufacturing process that will cause cost or schedule overruns. The resulting prescribed actions from this review process can have positive or negative short run effects on both cost and schedule variation, depending on the magnitude of the change to the production process. Examples in

this category include accelerated timelines that may incur greater short run costs to mitigate future schedule delays,[14] additional product testing mandated by the review team, correction of deficiencies identified during product testing, and staffing adjustments to address problem areas. (CV: *posccorract(+), negccorract(-)*; SV: *posscorract(+), negscorract(-)*)

4. **Fundamental Change to Contract Details**: Due to the challenging level of technological complexity of the typical MDAP, program managers and defense contractors are often forced to make fundamental changes to the design or scope of the MDAP, which in turn has an effect on the contract costs and schedule performance. Additionally, an MDAP's priority level may result in its relegation to a standby status or a loss of resources in the event of a national defense emergency, leading to adverse cost and schedule outcomes. Examples from this category include design changes to major components, contract amendments to incorporate additional capabilities, loss of resources due to other operational requirements, incorporation of funds spent before contract definitization, and other major contract revisions (e.g., restructures and re-designs). Additionally, this category includes "over-target-baseline" revisions, which reset the cost and schedule variances to zero as the contractor and Government essentially agree that the original baseline contract was inadequate or overly ambitious. (CV: *poscdbase(+), negcdbase(-)*; SV: *possdbase(+), negsdbase(-)*)

5. **Administrative Factors**: As with any production contract, administrative parameters can have a significant effect on contract outcomes for MDAPs, despite the fact that these parameters may be insignificant

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[14] In this situation, the manufacturer implements an internal timeline that is more demanding than the basline contract schedule

to the physical execution of the contract. Administrative errors and the correction of these errors can, thus, have a significant effect on the cost and schedule variance outcomes for MDAPs. Examples from this category include accounting errors, EVMS reporting errors, changes in General and Administrative (G&A) and overhead rates, expenditure of funds prior to contract definitization, and invoicing problems. (CV:*poscadmin(+), negcadmin(-)*; SV: *possadmin(+), negsadmin(-)*)

6. **Changes to Required Effort**: The final category includes changes in the amount of "effort" or billed hours of work. Program managers often report that a particular component or work package requires "more effort than originally planned" or "more hours than originally planned." Alternatively, the execution of the contract can require less effort/fewer hours than specified in the project. These explanations indicate that the contractor's employees completed the contractual task in question in a greater or shorter amount of billable time than estimated in the original contract, or the contractor adjusted the amount or skill level of the labor assigned to the contract. (CV: *posceffort(+), negceffort(-)*; SV: *posseffort(+), negseffort(-)*)

The inclusion of these factors in an estimation equation results in an additional twelve explanatory variables, which the 305 observations of the unbalanced panel supports with ease. However, the aggregation of these variables over the duration of the contract, which would be necessary to use all of the categories in a cross-sectional setting, seems to be a very imprecise treatment. It is impossible to attribute exact portions of the cost and schedule variance within a single contract-year observation to these factors, and the aggregation of these variables would require that I assign relative impacts over the entire duration of the contract. Rather than make an inevitably poor assumption, I will sum the positive variance explanations and negative variance explanations over the life of the contract and use this generic result in the cross-sectional model. While this is still not an ideal method of accounting for these factors, it prevents me from assigning potentially misleading importance to the individual variance categories. (CV: *sumposcv(+), sumnegcv(-)*; SV: *sumpossv(+), sumnegsv(-)*)

Tables 3.12 and 3.13 provide summary statistics and distribution for the variance explanations, respectively. Note from Table 3.12 that it is quite common for the program manager to provide no explanation for observed cost and schedule variance (approximately 35% in both cases). It is even more common that only one explanation is provided (approximately 45% for instances of cost variance and 43% for schedule variance). Anecdotally, these trends are likely due to the prevalence of singular "problem areas," which continue to cause problems over the life of a contract, and to the imprecise method by which program managers are required to account for cost and schedule variances for SAR purposes. Meanwhile, in Table 3.13, the tendency to provide explanatory comments in the case of negative cost or schedule variance outcomes is much greater than for positive outcomes. This is particularly striking given the overall ratio of positive to negative observations in the case of both performance measures (45:55 for CV and 40:60 for SV).

Table 3.12: Collected Explanation Data

	Cost Variance	**Schedule Variance**
Total Observations	298	290
Number of Explanations		
$\geq$ 1 (Raw)	193	184
$\geq$ 1 (% of Total)	64.77	63.45
$>$ 1 (Raw)	57	29
$>$ 1 (% of Total)	19.13	10.00
None (Raw)	105	106
None (% of Total)	35.23	36.55

Table 3.13: Distribution of Explanations by Type and Effect

	1A	**1B**	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**	**6A**	**6B**	**Total**
CV Exp.	18	24	10	27	9	19	19	33	21	36	19	33	268
SV Exp.	0	2	16	66	30	13	19	28	4	37	0	3	218

Enumeration based on order from Section 3.6.4.
A = Positive Effect. B = Negative Effect.

3.7 Results and Analysis

3.7.1 Cross Sectional Model

Tables 3.14 and 3.15 present the 2SLS estimation results for equation (3.2) with cost variance and schedule variance as the dependent variable, respectively. Each table presents the results of four regressions, including two sets of results for each version of the contract's cumulative variance (adjusted for inflation and expressed as a percentage of current price). Within these sets, one regression includes only the baseline regression, while the second column includes controls for military branch.[15] In order to assist the reader in understanding these regression results, it may be prudent to again mention the EVM definitions of the cost and schedule variances. A positive cost or schedule variance is a desirable outcome, indicating that the contract is under-budget or on-schedule. Conversely, a negative cost or schedule variance is an adverse outcome, suggesting that the contract is over-budget or behind-schedule.

In Table 3.14, column (1) shows that the coefficient for a contract's describability ranking has, on average, a marginally significant positive effect on the adjusted cumulative cost variance. This indicates that the cost variance improves as the describability ranking of the contract increases, suggesting that increased describability of the underlying project improves the chances of keeping the contract under budget. The program manager cost variance explanations,

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[15] The bottom row of each regression table reports the P-Value of the Durbin-Wu-Hausman Chi-Squared test for exogenous regressors. The null hypothesis for this test is that the regressors are exogenous. Also, several of the specifications do not report an R-Squared value for the regression. This is due to the fact that, in a 2SLS regression, there is no constraint forcing the residual sum of squares to be less than the total sum of squares, potentially leading to negative R-squared values. In specifications where this occurs, I have chosen to suppress the R-squared value rather than report a negative value. For a more thorough explanation, see Sribney, et al. (1999).

sumposcv and sumnegcv, enter with the expected sign and significance. In column (2), the addition of the controls for military branch results in the insignificance of the describability ranking, while the coefficient on the indicator variable for Army contracts is positive and significant. This is likely due to the fact that the excluded military category, DoD projects, includes only the F-35, which is the most expensive acquisition program in the history of the DoD.

As previously mentioned, it is reasonable to expect that more expensive projects would be naturally prone to larger dollar amounts of cost and schedule variance. Therefore, expressing the variance as a percentage of the contract price may provide a more reasonable comparison across contracts. In columns (3) and (4), I see the effects of this transformation. The contract describability ranking no longer has a significant effect on the cost variance outcome when cost variance is expressed as a percentage of the contract's current price, and the contract's parent branch no longer has a significant effect on cost performance. This finding is supportive of my assertion that the significance of the branch control in column (2) was due to the magnitude of the cost variance in the excluded category, which only includes contracts from the F-35 project.

In Table 3.15, I use the same progression of analysis as in Table 3.14 with versions of schedule variance as the dependent variable. In column (1), I again see a marginally significant, positive effect of the describability ranking. In contrast to Table 3.14, however, I see additional significant effects, some of which are counterintuitive. For example, I observe negative and significant effects from the procurement indicator and iteration variable. These findings suggest that contracts in more advanced stages of acquisition and repeat iterations of the same contract will perform poorly in terms of schedule adherence relative to contracts in early phases of production. However, when the branch controls are added in column (2), these coefficients become insignificant and the iteration coefficient becomes positive. A possible explanation for the negative impact of the procurement indicator is linked to the use of procurement funds during full rate production. At this stage, engineering changes and additional equipment added to aircraft impact a much larger number of units than in the RDT&E-phase contracts. As a result, the schedule impact of these changes may be greater in procurement contracts even though changes should occur with less frequency. Meanwhile, the branch coefficients and the indicator for dual source contracts become positive. The positive effect of the the dual source contracting environment is intuitive, as one might expect contractors in pseudo competition to adhere more closely to contract guidelines.

When I use the normalized dependent variable in columns (3) and (4), none of the coefficients for describability ranking are significant and both are positive. Comparing the results for the iteration coefficient in Table 3.15 to those in Table 3.14, it appears that there is a differential effect of repeat iterations on CV and SV. Specifically, it appears that production lots procured later in the acquisition process are more likely to fall behind schedule than to exceed budgeted costs. Upon inspection of the data sample, this is likely due to the fact that production lots tend to increase in quantity as contractors perform a repeat contract. Alternatively, there appears to be no significant effect of repeat iteration on the cost performance (CV) of a contract. Summarizing the results of my cross-sectional analysis, the evidence for the effect of describability via the selected contract type on subsequent performance outcomes remains unclear. However, additional information from the panel model may allow me to use the results of both approaches to draw conclusions about the relevance of describability in the defense acquisition process.

Table 3.14: IV Regressions for Cost Variance

	(1) cumcv	(2) cumcv	(3) avcvpercurp	(4) avcvpercurp
drnk	43.554*	47.957	-0.005	-0.030
	(25.649)	(69.080)	(0.009)	(0.023)
cumdq	-0.672	-0.732	-0.000	0.000
	(0.726)	(0.853)	(0.000)	(0.000)
prevcont	-1.145	-1.390	0.000	0.000
	(0.697)	(1.024)	(0.000)	(0.000)
duals	4.369	17.389	0.007	0.016
	(20.403)	(26.752)	(0.005)	(0.011)
length	-0.230	-0.259	-0.0000986*	-0.000
	(0.291)	(0.262)	(0.0000535)	(0.000)
winage	0.536	1.205	-0.000	-0.000
	(0.932)	(1.562)	(0.000)	(0.001)
iteration	-3.100	-2.859	0.001	0.003
	(2.988)	(6.014)	(0.001)	(0.002)
proc	12.596	13.777	0.005	0.010
	(21.753)	(23.099)	(0.007)	(0.011)
rd	62.416	78.213	-0.000	-0.026
	(39.998)	(85.361)	(0.012)	(0.029)
sumposcv	10.169*	12.138**	0.006***	0.005*
	(6.113)	(6.005)	(0.001)	(0.003)
sumnegcv	-12.290**	-12.856**	-0.003***	-0.003**
	(5.031)	(5.039)	(0.001)	(0.001)
army		60.191**		0.014
		(27.953)		(0.013)
navy		8.928		0.020
		(47.828)		(0.014)
af		7.938		0.027
		(49.750)		(0.017)
Constant	-130.089	-167.663	0.012	0.066
	(83.024)	(179.658)	(0.029)	(0.065)
N	89	89	85	85
R-Squared	.	.	0.244	.
Wald	20.34**	27.82**	44.16**	22.57*
DWH P-Value	0.063	0.423	0.985	0.039

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.15: IV Regressions for Schedule Variance

	(1) cumsv	(2) cumsv	(3) avsvpercurp	(4) avsvpercurp
drnk	26.789*	-18.443	0.026	0.012
	(14.649)	(24.687)	(0.018)	(0.016)
cumdq	0.391	0.701***	0.000	0.000
	(0.284)	(0.192)	(0.000)	(0.000)
prevcont	-0.403	-0.112	-0.000	-0.000
	(0.437)	(0.323)	(0.000)	(0.000)
duals	0.316	20.452**	-0.001	0.005
	(8.642)	(9.642)	(0.007)	(0.008)
length	-0.173	-0.097	0.000	0.000
	(0.126)	(0.089)	(0.000)	(0.000)
winage	-0.626	-0.665	-0.000	-0.000
	(0.627)	(0.480)	(0.001)	(0.001)
iteration	-3.051*	0.361	-0.002	-0.001
	(1.838)	(2.326)	(0.002)	(0.002)
proc	-34.806**	-18.584	-0.016	-0.012
	(13.697)	(11.471)	(0.011)	(0.011)
rd	1.489	-36.763	0.011	-0.000
	(16.636)	(25.202)	(0.020)	(0.020)
sumpossv	-0.343	1.628	0.004*	0.005**
	(3.060)	(2.974)	(0.002)	(0.002)
sumnegsv	-4.687**	-3.877**	-0.002	-0.002*
	(2.159)	(1.760)	(0.001)	(0.001)
army		36.099***		0.014
		(10.741)		(0.013)
navy		38.402**		0.008
		(16.295)		(0.012)
af		49.586***		0.018
		(18.823)		(0.013)
Constant	-35.898	45.612	-0.071	-0.045
	(39.265)	(57.105)	(0.056)	(0.051)
N	89	89	85	85
R-Squared	.	0.269	.	0.088
Wald	23.28**	74.92***	13.69	24.25**
DWH P-Value	0.019	0.393	0.127	0.443

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.7.2 Panel Model

As an alternative method, I will now estimate equation (3.3) using both a pooled OLS estimator and the between panel estimator. Columns (1) and (2) of Table 3.16 present the results of panel IV estimation for cost variance, using a pooled OLS estimator. I again present two different versions of the dependent variable: inflation-adjusted cost variance and cost variance expressed as a percentage of the contract's current price.[16] In columns (1) and (2) of Table 3.16, I again see inconclusive evidence of the direction of the effect of the underlying physical describability of the project. Neither of the coefficients for the describability ranking variable are significant, but the sign of the coefficient is uniform across both specifications. Of the additional regressors, only the program manager variance explanations are significant, and I observe that the relative magnitudes of the coefficients on the variance explanations suggest that the design change indicator (poscdbase) produces the largest effect. This is supported by the fact that this category includes over-target-baseline adjustments of a contract's budget. In most cases, this type of adjustment occurs in projects that are performing extremely poorly, and a large positive cost variance is used to reset the cumulative cost variance to zero.

In columns (3) and (4) of Table 3.16, I use the between effects panel estimator to estimate equation (3.3).[17] The reported p-values for the Hausman test statistic suggest that either a) the IV estimator is inefficient in these specifications, or b) I have chosen a weak instrument. This finding must be taken into consideration

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[16] In the panel setting, the underlying data are individual contract-year observations rather than the cumulative figures used in the previous section.

[17] For columns (3) and (4) of Tables 3.16 and 3.17, I include the P-value of the Hausman specification test statistic. The null of this test is that there is no systematic difference between the two estimators (OLS vs. IV). Therefore, a failure to reject the null in this case suggests that the IV estimator does not offer an improvement in terms of consistency.

while interpreting the following results. The dependent variables are identical to those used in columns (1) and (2), but the results are quite different. In column (3), the coefficient on describability ranking is positive and marginally significant. However, the coefficient is insignificant once the variance is normalized by current price in column (4). In contrast to columns (1) and (2), much fewer of the cost variance explanations are significant when estimated using the between estimator, which one might expect as this method identifies the effect of variation in the averages of these values across contracts.[18]

Columns (1) and (2) of Table 3.17 present the results of pooled OLS estimation of equation (3.3). In both specifications, the variation in the dependent variable is primarily accounted for by the program manager variables. Generally speaking, the pooled OLS estimator performs poorly for the schedule variance specifications. In column (2), the coefficient on describability ranking is positive and marginally significant, but the F-statistic for this regression suggests that this model does not predict a significant amount of variation in the dependent variable. However, the results of using the between estimator in columns (3) and (4) of Table 3.17 support the pooled OLS results, as the coefficient for describability ranking is again positive and significant.[19] I again observe decreased significance for many of the variance explanation categories in comparing the pooled OLS and between estimates of the regression coefficients.

Interestingly, it appears that there is an observable difference in the categories affecting cost variance compared to those in the schedule variance. In Table 3.16, I observe that cost variance is consistently affected by corrective actions. Meanwhile, schedule variance is consistently affected by supply management

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[18] The branch controls were insignificant in all of the panel specifications for CV and SV.

[19] Again, note the p-values of the Hausman test statistic. It is likely that the IV estimator does not provide an improvement in consistency over the OLS estimator in this case.

issues and administrative issues in Table 3.17. Unsurprisingly, both types of variance are affected by baseline changes, which is likely due to the use of over-target-baseline corrections that set both CV and SV to zero.

Although it is difficult to draw any firm conclusions given the precision of my models, it is possible to observe several trends when one considers both the cross-sectional and panel results from the preceding sections. First, in the case of cost variance, the sign of the coefficient on the cost variance is inconsistent in the cross-sectional model. Specifically, the effect is negative when I use cost variance as a percentage of current contract price as the dependent variable. In speaking with DoD EVM officials, this is likely due to differential administrative procedures across different contract types.[20] For example, in a CPFF contract, the government will likely require more frequent cost monitoring and will quickly demand corrective action in response to deficiencies, primarily due to the fact that it bears the entire cost burden for this type of contract. As a result, annual reports of cost variance for a CPFF could be reflecting active government management of the contract. Conversely, in a FPIF contract, the contractor bears the majority of the cost-growth burden, and the government's administration of the contract will be relatively more passive. Given this discussion, it might then be possible to see, on average, a tendency for more describable projects and contract types to report poorer annual contract performance measures, reflective of the government's willingness to let the contractor address the situation on its own. Second, although the significance of the coefficient on the describability ranking in the schedule variance regressions is inconsistent, the coefficient itself is positive in every specification save one. Third, combining the two previous observations,

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[20] My explanation of this phenomenon is attributable to a personal interview with an official in the DoD's Earned Value Management Division on 14 December 2012.

it appears that the effect of the describability ranking of the underlying project on contract performance occurs in the expected direction. In six of eight cost variance specifications, describability ranking has a positive effect. Additionally, the negative coefficient for describability ranking in the cross-sectional model, using *avcvpercurp*, seems to be explainable given the government's approach to administering less complete contract types. Meanwhile, contracts using contract types that are generally more "complete," presumably stemming from the subject parties' ability to accurately describe the work at hand, seem to perform better in terms of adherence to production schedule than those covering less describable projects.[21]

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[21] Note that I have also estimated each model without including the program manager explanations. In the cross-sectional model, the results are robust only when I include the program manager explanations. Specifically, the coefficient on *drnk* only achieves significance when I include program manager explanations. However, in the panel model, the results presented here are robust with and without the program manager explanations, exhibiting classic signs of omitted variable bias when the program manager explanations are not included in the specification. I attribute the difference between the two models to the relatively imprecise nature of the control variables in the cross-sectional setting. I am unable to finely capture the effects of standard complications in the cross-sectional model due to the smaller data sample and the resulting smaller number of degrees of freedom.

Table 3.16: Panel IV Estimation: Cost Variance

	(1) cv	(2) cvpercurp	(3) cv	(4) cvpercurp
drnk	13.661	0.008	19.836*	0.011
	(25.659)	(0.011)	(11.675)	(0.012)
dq	0.104	0.000	-1.421	0.000
	(1.863)	(0.001)	(2.512)	(0.003)
prevcont	-0.497	-0.000	-0.455	-0.000
	(0.440)	(0.000)	(0.302)	(0.000)
duals	-2.114	0.005	-5.893	0.003
	(12.051)	(0.005)	(10.040)	(0.010)
length	0.044	-0.000	0.051	-0.000
	(0.127)	(0.000)	(0.092)	(0.000)
iteration	0.093	0.000	-1.186	0.000
	(2.301)	(0.001)	(1.473)	(0.001)
wincage	0.510	0.000	-0.110	-0.001
	(2.026)	(0.001)	(3.276)	(0.003)
proc	-9.298	-0.018	-11.878	-0.042
	(41.899)	(0.019)	(32.473)	(0.033)
rd	1.376	-0.004	11.828	-0.024
	(41.246)	(0.018)	(26.020)	(0.026)
poscdpc	6.017	0.008	0.234	-0.012
	(17.941)	(0.008)	(24.051)	(0.024)
negcdpc	-4.533	-0.000	10.960	0.016
	(15.825)	(0.007)	(19.117)	(0.019)
poscsuppman	-9.742	0.003	-14.327	-0.008
	(25.653)	(0.011)	(21.678)	(0.022)
negcsuppman	-52.103***	-0.006	-34.918	0.010
	(13.694)	(0.006)	(21.305)	(0.022)
posccorract	26.218	0.012	47.636**	0.031
	(20.725)	(0.009)	(21.209)	(0.021)
negccorract	-43.944***	-0.016**	-48.619*	-0.044*
	(16.083)	(0.007)	(25.808)	(0.026)
poscdbase	90.642***	0.034***	18.486	0.026
	(14.604)	(0.007)	(22.230)	(0.023)
negcdbase	-5.257	-0.016***	-9.730	-0.033
	(13.188)	(0.006)	(20.405)	(0.021)
poscadmin	13.730	0.010	-2.340	0.003
	(14.900)	(0.007)	(22.014)	(0.022)
negcadmin	-13.837	-0.016**	-36.682	-0.038
	(17.035)	(0.008)	(26.589)	(0.027)
posceffort	8.198	0.026***	8.803	0.022
	(18.984)	(0.008)	(16.146)	(0.016)
negceffort	-8.544	-0.011*	4.534	0.003
	(12.848)	(0.006)	(22.397)	(0.023)
Constant	-43.788	-0.033	-62.497*	-0.034
	(88.598)	(0.039)	(36.739)	(0.037)
Firm Controls	Yes	Yes	Yes	Yes
N	305	305	305	305
R-Squared	0.250	0.261	0.001	0.218
F-Statistic	4.011	4.994	N/A	N/A
DWH P-Value	0.269	0.269	N/A	N/A
Wald	N/A	N/A	45.84***	38.53**
Hausman P-Value	N/A	N/A	1.000	1.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.17: Panel IV Estimation: Schedule Variance

	(1) sv	(2) svpercurp	(3) sv	(4) svpercurp
drnk	14.449	0.022**	16.538*	0.020**
	(21.018)	(0.011)	(8.925)	(0.010)
dq	-0.158	0.000	-0.054	0.003
	(1.651)	(0.001)	(2.335)	(0.003)
prevcont	-0.537	-0.000323*	-0.509**	-0.000
	(0.369)	(0.000186)	(0.252)	(0.000)
duals	-1.629	-0.005	-1.443	-0.002
	(10.473)	(0.005)	(8.934)	(0.010)
length	-0.018	0.000	-0.038	0.000
	(0.108)	(0.000)	(0.093)	(0.000)
wincage	-0.205	0.001	1.035	0.004
	(1.873)	(0.001)	(3.059)	(0.003)
iteration	-1.118	-0.001	-1.242	-0.000
	(1.839)	(0.001)	(1.074)	(0.001)
proc	-16.677	-0.027	-36.744	-0.036
	(34.099)	(0.017)	(24.055)	(0.027)
rd	-0.129	0.002	-16.369	-0.015
	(34.336)	(0.017)	(22.116)	(0.025)
negsdpc	-9.719	-0.016	-35.236	-0.038
	(35.976)	(0.018)	(52.859)	(0.059)
posssuppman	3.486	0.013	-5.913	0.012
	(17.924)	(0.009)	(17.042)	(0.019)
negssuppman	-15.036	-0.016***	-13.080	-0.031***
	(9.551)	(0.005)	(9.743)	(0.011)
posscorract	13.624	0.012**	3.518	0.012
	(11.644)	(0.006)	(17.318)	(0.019)
negscorract	0.174	-0.019*	-3.996	-0.027
	(19.073)	(0.010)	(21.860)	(0.024)
possdbase	65.554***	0.017***	7.698	0.019
	(13.132)	(0.007)	(22.631)	(0.025)
negsdbase	-20.716*	-0.006	-10.814	-0.010
	(11.088)	(0.006)	(16.678)	(0.019)
possadmin	5.152	-0.001	-39.945	-0.012
	(26.604)	(0.013)	(53.129)	(0.059)
negsadmin	-8.565	-0.026***	-33.199***	-0.040***
	(10.374)	(0.005)	(11.321)	(0.013)
negseffort	27.587	0.006	60.430	0.063
	(31.331)	(0.016)	(39.850)	(0.045)
Constant	-24.416	-0.059	-22.054	-0.060
	(72.339)	(0.036)	(33.423)	(0.037)
Firm Controls	Yes	Yes	Yes	Yes
N	305	305	305	305
R-Squared	0.105	.	.	0.153
F-Statistic	2.006	3.729	N/A	N/A
DWH P-Value	0.451	0.020	N/A	N/A
Wald	N/A	N/A	18.42	32.42*
Hausman P-Value	N/A	N/A	1.000	1.000

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.8 Robustness Checks

3.8.1 Split Sample Results

In the previous chapter, I demonstrated the outlier effect of the F-35 program on my estimation results. Additionally, the cross-sectional results from this chapter indicate that the identity of the controlling branch of the US military may have a differential effect on a contract's performance in terms of cost and schedule adherence. Any effect of this nature likely stems from differing technological requirements of the military branches and resulting technological heterogeneity in the projects controlled by each branch. For example, the programs controlled by the Army in the data sample include several modernization programs for existing airframes, whereas the Navy's projects include procurement of new fixed-wing and rotary aircraft. As a result of the differing levels of technological complexity associated with these programs, one might expect the contract performance outcomes to also vary. In order to further examine this possibility, I now present split-sample regression results, divided by controlling military branch, for both the cross-sectional and panel models.

Tables 3.18, 3.19, and 3.20 provide estimation results of the cross-sectional model for Army, Navy, and Air Force contracts, respectively. Note that the binary control variables do not apply to each sample. For example, none of the Army contracts in the data sample were dual source projects. Columns (1) and (2) of each table list the results for cost variance, while columns (3) and (4) list results for schedule variance. The model performs particularly well for the Army and Air Force contracts in the schedule variance specifications. Comparing these results to the cross-sectional estimation for the entire data sample, several trends are preserved. I continue to observe a negative and significant effect of the procurement indicator variable on schedule performance, which is present for all three military branches. The effect of the describability ranking on schedule performance is positive for all three branches and significant in both specifications for the the Air Force contracts. However, the effect of describability on cost performance is negative in four of six specifications and is never significant.

In moving to the panel model, sample size becomes a primary issue when I attempt to use the between estimator. Due to the limited number of contracts for the Army and Air Force, I am unable to use the between transformation in those samples due to the resulting restriction on degrees of freedom. However, I will present pooled OLS estimation results for all three branches and additionally include between estimation results for the Navy sample. Note that in these regression tables, I have elected to only display the program manager variance explanations that produce a significant effect on the dependent variable, despite the fact that I have included all of the explanations in each specification.

In Table 3.21, there is evidence of a positive effect of moving into the procurement phase of a program on contract cost performance, while repeat iterations appear to have a negative effect on cost performance for both versions of the dependent variable. Alternatively, only the re-baseline program variance explanation has a significant effect on schedule performance. In contrast to the cross-sectional results, contract describability ranking has a positive effect on cost performance but a negative effect on schedule performance in the pooled OLS model.

Table 3.22 presents the estimation results of the panel model for the sample of Navy contracts, using cost variance measures as the dependent variables. Columns (1) and (2) are the results from the pooled OLS estimator, while columns (3) and (4) use the between transformation. In these specifications, only the program manager variance explanations exhibit any significant effect on cost variance. The describability ranking coefficient is never significant and is negative in three of four specifications. Table 3.23 presents pooled OLS and between effects estimates of the panel model with schedule variance as the dependent variable. Again, I observe that only the coefficients for select program manager explanations are significant, and the effect of the describability ranking is again negative in three of four specifications.

In Table 3.24, the only variables exhibiting a high degree of significance are program manager explanations of the effects of negative corrective actions and positive re-baseline changes on the contract's cost performance. However, these findings are not robust to normalization of the cost variance by the contract price. The coefficient estimates for describability ranking reveal a negative but insignificant effect on cost variance and an insignificant and non-uniform effect on schedule variance.

A clear concern in conducting this type of split-sample analysis would be the effects of small-sample bias. While I see evidence of a significant effect of describability on schedule performance in the cross-sectional results for the Air Force sample, this result is based on a sample of seventeen contracts. Alternatively, I see no clear evidence of any significant effect of describability from the split-sample analysis of the panel model estimates, and only the program manager variance explanations appear to have any significant effect across the different branches. In summary, it appears that the differential effects on contract performance of management by each military branch, which one observes in the estimation results for the full sample, are likely due to unobserved technological heterogeneity that is indicative of branch-specific projects. The significant positive effects of the branch controls in the full sample are likely due to the presence of the F-35, as split-sample analysis does not reveal any information suggesting that the branch-controlled contracts are administered in a unique manner.

Table 3.18: Cross-Sectional IV Regressions: Army Contracts

	(1) cumcv	(2) avcvpercurp	(3) cumsv	(4) avsvpercurp
drnk	-13.748	-0.015	0.980	0.004
	(12.708)	(0.022)	(2.589)	(0.004)
cumdq	11.696	0.018	1.044	0.003**
	(13.765)	(0.021)	(0.798)	(0.001)
prevcont	1.319	-0.003	-2.800**	0.000
	(4.161)	(0.010)	(1.426)	(0.003)
length	0.182	0.000	-0.202	-0.001***
	(0.211)	(0.000)	(0.131)	(0.000)
winage	-2.647	0.010	9.938***	0.010*
	(12.004)	(0.028)	(3.813)	(0.006)
iteration	-2.313	-0.012*	-2.317	-0.016*
	(3.101)	(0.006)	(5.207)	(0.009)
proc	52.690	0.094	-22.288*	-0.056***
	(51.435)	(0.099)	(12.225)	(0.021)
sumposcv	-22.762	-0.017		
	(28.178)	(0.049)		
sumnegcv	5.770	0.007		
	(9.316)	(0.014)		
sumpossv			6.666***	0.018***
			(2.031)	(0.004)
sumnegsv			-1.059	-0.008*
			(2.314)	(0.004)
Constant	-12.259	-0.015	20.075**	0.033**
	(22.189)	(0.048)	(9.944)	(0.014)
N	12	12	12	12
R-Squared	0.517	0.839	0.699	0.688
Wald	1177.78***	3272.93***	787.96***	684.25***
DWH P-Value	0.035	0.332	0.412	0.068

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.19: Cross-Sectional IV Regressions: Navy Contracts

	(1) cumcv	(2) avcvpercurp	(3) cumsv	(4) avsvpercurp
drnk	84.669	-0.031	14.006	0.010
	(105.210)	(0.036)	(16.957)	(0.018)
cumdq	-0.311	-0.000	0.640***	0.000
	(0.598)	(0.000)	(0.110)	(0.000)
prevcont	-1.019	0.000	0.068	-0.000
	(1.178)	(0.000)	(0.204)	(0.000)
duals	0.365	0.005	-0.303	0.005
	(40.891)	(0.017)	(5.854)	(0.007)
length	-0.265	-0.000	-0.057	0.000
	(0.678)	(0.000)	(0.140)	(0.000)
winage	1.968	-0.000	0.003	0.000
	(2.380)	(0.001)	(0.463)	(0.001)
iteration	-6.356	0.002	-3.204*	-0.001
	(7.461)	(0.002)	(1.669)	(0.002)
proc	21.436	0.018	-14.401	-0.003
	(45.985)	(0.016)	(12.068)	(0.016)
rd	117.731	-0.012	3.389	0.001
	(122.895)	(0.042)	(18.304)	(0.025)
sumposcv	9.778	0.006*		
	(8.367)	(0.003)		
sumnegcv	-14.471*	-0.003		
	(8.683)	(0.002)		
sumpossv			-1.222	0.005
			(2.445)	(0.003)
sumnegsv			-5.011	-0.001
			(3.049)	(0.002)
Constant	-282.192	0.073	-25.556	-0.041
	(319.757)	(0.108)	(48.660)	(0.067)
N	45	45	45	45
R-Squared	.	.	0.250	0.266
Wald	25.12***	16.39	153.47***	19.88**
DWH P-Value	0.186	0.063	0.171	0.949

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.20: Cross-Sectional IV Regressions: Air Force Contracts

	(1) cumcv	(2) avcvpercurp	(3) cumsv	(4) avsvpercurp
drnk	-15.582	0.009	2.993**	0.021***
	(14.461)	(0.013)	(1.295)	(0.008)
cumdq	0.547	-0.001	0.911***	0.001*
	(1.844)	(0.001)	(0.317)	(0.001)
prevcont	-0.838	0.000	0.214**	0.001**
	(1.012)	(0.001)	(0.088)	(0.000)
length	-0.288**	-0.000	0.136***	0.000
	(0.133)	(0.000)	(0.036)	(0.000)
winage	2.024	-0.002	-0.505**	-0.003***
	(2.467)	(0.002)	(0.202)	(0.001)
iteration	0.822	0.001	0.016	0.001
	(1.240)	(0.001)	(0.118)	(0.001)
proc	24.646	-0.015	-6.250***	-0.045***
	(25.921)	(0.026)	(2.214)	(0.011)
sumposcv	-8.159	0.004		
	(6.528)	(0.004)		
sumnegcv	1.959	-0.002		
	(3.098)	(0.002)		
sumpossv			0.049	0.002
			(1.457)	(0.005)
sumnegsv			-1.152***	-0.001
			(0.282)	(0.001)
Constant	43.423	-0.017	-10.867***	-0.049*
	(33.918)	(0.039)	(3.958)	(0.025)
N	17	17	17	17
R-Squared	0.184	.	0.915	0.687
Wald	41.49***	24.32***	804.93***	85.73***
DWH P-Value	0.083	0.363	0.970	0.136

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.21: Panel IV Estimation: Army Contracts

	(1) cv	(2) cvpercurp	(3) sv	(4) svpercurp
drnk	1.994	0.033	-0.463	-0.010
	(3.753)	(0.032)	(1.669)	(0.013)
dq	0.894	0.006	-0.160	0.001
	(0.961)	(0.008)	(0.542)	(0.004)
prevcont	0.109	0.000	0.067	-0.001
	(0.343)	(0.003)	(0.252)	(0.002)
length	0.133	0.001	-0.095	-0.001
	(0.171)	(0.001)	(0.105)	(0.001)
iteration	-6.974	-0.080*	-1.041	0.006
	(5.092)	(0.044)	(2.795)	(0.021)
wincage	0.355	-0.000	0.910	0.005
	(1.384)	(0.012)	(0.967)	(0.007)
proc	14.996*	0.187**	-0.816	-0.005
	(8.040)	(0.069)	(4.504)	(0.034)
possdbase			17.500***	0.118***
			(5.121)	(0.039)
negsdbase			-3.660	-0.047*
			(3.447)	(0.026)
Constant	-5.396	0.058	17.170	0.213
	(26.252)	(0.225)	(18.918)	(0.145)
Firm Controls	Yes	Yes	Yes	Yes
PM Explanations	Yes	Yes	Yes	Yes
N	34	34	34	34
R-Squared	0.659	0.609	0.734	0.636
F-Statistic	1.217	1.069	2.057	1.382
DWH P-Value	0.091	0.053	0.305	0.112

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.22: Panel IV Estimation for Cost Variance: Navy Contracts

	(1) cv	(2) cvpercurp	(3) cv	(4) cvpercurp
drnk	-24.799	-0.083	7.114	-0.005
	(101.364)	(0.213)	(9.568)	(0.013)
dq	-1.504	-0.002	-1.407	-0.003
	(2.637)	(0.006)	(2.095)	(0.003)
prevcont	0.065	0.001	0.120	0.001
	(0.366)	(0.001)	(0.360)	(0.000)
duals	6.244	0.014	-3.997	-0.001
	(26.379)	(0.056)	(12.647)	(0.017)
length	0.113	0.000	-0.036	-0.000
	(0.237)	(0.000)	(0.091)	(0.000)
iteration	1.765	0.004	-0.002	0.000
	(4.486)	(0.009)	(1.018)	(0.001)
wincage	-0.810	-0.003	-1.314	-0.001
	(4.891)	(0.010)	(3.040)	(0.004)
proc	30.953	0.066	-8.798	0.011
	(90.369)	(0.190)	(23.886)	(0.032)
rd	-7.461	-0.036	-2.076	0.015
	(48.837)	(0.103)	(17.595)	(0.023)
negcdpc	-16.899*	-0.001	-13.230	0.019
	(8.750)	(0.018)	(10.205)	(0.014)
negcsuppman	-34.777**	-0.014	8.185	-0.009
	(14.214)	(0.030)	(23.387)	(0.031)
posccorract	47.516**	0.008	70.626***	0.004
	(20.487)	(0.043)	(19.598)	(0.026)
poscdbase	36.722***	0.031	4.049	0.022
	(11.954)	(0.025)	(19.923)	(0.027)
posceffort	5.246	0.027	-5.162	0.050**
	(14.320)	(0.030)	(17.058)	(0.023)
negceffort	-23.177**	-0.017	-18.951	-0.030
	(11.030)	(0.023)	(16.299)	(0.022)
Constant	51.789	0.212	-17.245	-0.006
	(277.527)	(0.585)	(23.971)	(0.032)
Firm Controls	Yes	Yes	Yes	Yes
PM Explanations	Yes	Yes	Yes	Yes
N	160	160	160	160
R-Squared	0.190	.	0.794	0.721
F-Statistic	3.624***	0.607	N/A	N/A
DWH P-Value	0.688	0.290	N/A	N/A
Wald	N/A	N/A	75.94***	46.42***
Hausman P-Value	N/A	N/A	1.000	1.000

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.23: Panel IV Estimation for Schedule Variance: Navy Contracts

	(1) sv	(2) svpercurp	(3) sv	(4) svpercurp
drnk	-4.331	0.065	-1.913	-0.001
	(47.535)	(0.174)	(7.449)	(0.024)
dq	0.167	0.002	-0.522	0.004
	(1.391)	(0.005)	(1.317)	(0.004)
prevcont	0.018	-0.000	0.004	-0.000
	(0.142)	(0.001)	(0.187)	(0.001)
duals	2.401	-0.015	2.288	0.014
	(11.476)	(0.042)	(7.841)	(0.026)
length	-0.003	-0.000	-0.011	0.000
	(0.090)	(0.000)	(0.068)	(0.000)
wincage	0.000	0.005	1.328	0.003
	(2.948)	(0.011)	(2.654)	(0.009)
iteration	-0.670	-0.003	-0.984	0.001
	(2.006)	(0.007)	(0.809)	(0.003)
proc	-1.081	-0.034	1.855	0.009
	(26.936)	(0.098)	(10.463)	(0.034)
rd	-8.688	0.047	-2.080	0.003
	(37.173)	(0.136)	(10.300)	(0.034)
negssuppman	-9.892	-0.024	-2.481	-0.041*
	(7.373)	(0.027)	(7.173)	(0.023)
negsdbase	-10.442	0.013	-19.963**	0.000
	(13.792)	(0.050)	(9.449)	(0.031)
Constant	19.995	-0.217	9.937	-0.036
	(151.422)	(0.553)	(19.780)	(0.064)
Firm Controls	Yes	Yes	Yes	Yes
PM Explanations	Yes	Yes	Yes	Yes
N	160	160	160	160
R-Squared	0.347	.	0.544	0.495
F-Statistic	3.744***	0.428	N/A	N/A
DWH P-Value	0.909	0.325	N/A	N/A
Wald	N/A	N/A	28.28	22.40
Hausman P-Value	N/A	N/A	1.000	1.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.24: Panel IV Estimation: Air Force Contracts

	(1) cv	(2) cvpercurp	(3) sv	(4) svpercurp
drnk	-10.170	-0.096	94.307	-0.004
	(54.983)	(0.230)	(2608.284)	(1.287)
dq	0.793	0.001	1.064	-0.004
	(1.182)	(0.005)	(33.694)	(0.017)
prevcont	0.092	0.001	-2.133	0.000
	(1.400)	(0.006)	(58.698)	(0.029)
length	-0.179	-0.001	0.867	0.000
	(0.449)	(0.002)	(23.112)	(0.011)
iteration	-0.163	0.001	2.966	0.001
	(0.903)	(0.004)	(81.448)	(0.040)
wincage	-0.931	-0.001	-0.102	0.002
	(1.138)	(0.005)	(11.160)	(0.006)
proc	13.560	0.160	-180.886	0.013
	(98.179)	(0.410)	(5022.863)	(2.479)
negccorract	-47.336***	-0.054		
	(15.857)	(0.066)		
poscdbase	32.990***	0.039		
	(8.822)	(0.037)		
Constant	59.693	0.305	-284.248	-0.059
	(191.203)	(0.799)	(7516.958)	(3.710)
Firm Controls	Yes	Yes	Yes	Yes
PM Explanations	Yes	Yes	Yes	Yes
N	52	52	52	52
R-Squared	0.709	.	.	0.628
F-Statistic	3.803***	0.563	0.062	2.919***
DWH P-Value	0.739	0.080	0.787	0.988

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.8.2 Effect of Describability on Contract Administration

It is possible that the physical describability of a project and the resulting contract type may affect the dynamics of the administration of the contract in addition to the performance outcome. For example, in conversations with DoD officials, it is apparent that contracts in which the government shoulders a larger share of the cost burden often require more frequent cost reporting from the contractor.[22] Additionally, the describability of a contract may affect the ability of the government and the contractor to determine an accurate price for the contract or to estimate future costs. It is quite common in my data sample to observe changes to the baseline contract, which drastically alter the contractual details. This, in turn, often resets the cost and schedule variances to zero by incorporating over-target costs into the contract. While the panel analysis conducted in this paper takes this possibility into account, the cross-sectional analysis is unable to account for this type of effect. A poorly performing contract that is re-baselined could have a cumulative positive variance upon completion. Therefore, it may be appropriate to consider whether a contract's describability rank has a distinct effect on the intermediate dynamics of the contract in addition to looking at the performance outcomes. Given this discussion, I will now estimate equation (3.2) with a set of variability measures as dependent variables, using a reduced form approach to model the effect of describability on contract administration via the contract type decision.

Table 3.25 lists the additional dependent variables and a definition of each. A brief explanation of each type of statistic is perhaps warranted at this point.

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[22] This information is attributable to a personal interview with DoD EVM officials, 14 December 2012.

- **Sharpe Ratio**: The Sharpe Ratio is a statistic used in the finance literature to measure the ratio of return to risk for a financial portfolio. It is calculated by dividing the mean of the excess return of an asset by the standard deviation of the excess return (Schuster and Auer, 2012). This excess is relative to a benchmark asset, often a risk-free investment. Clearly, if one compares two assets to an identical benchmark, a higher Sharpe ratio indicates more return per unit of risk. Due to the fact that cost and schedule variances can take positive and negative values, this seems to be an appropriate way to measure the government's return per unit of risk for a contract. Underperformance would result in a verifiable loss (negative cost or schedule variance), while over-performance would result in a gain (positive cost or schedule variance). Additionally, the DoD contracting environment has its own risk-free benchmark: the firm fixed price contract. Due to the fact that the contractor bears full responsibility for all cost growth in an FFP contract, EVM is not applied, and the variances are always zero from the government's point of view. Therefore, I can calculate the Sharpe Ratio for either cost or schedule variance for a particular contract using the following formula (using cost variance as an example):

$$SR_{CV} = \frac{\mu_{CV}}{\sigma_{CV}} \tag{3.4}$$

- **Coefficient of Variation**: In contrast to the Sharpe Ratio, the coefficient of variation is purely a measure of variability and is appropriate in comparing variables with widely differing mean values (Scheel, 1978). In this case, a comparison of coefficients of variation for two different measures allows one to determine which of the two measures is more variable. I have calculated the coefficient of variation for several different measures in my data sample: contract price, unit price (with initial price), unit price (without initial price), difference in the contractor's estimate at completion and the program manager's estimate at completion, difference in the contractor's estimate and the current price, and difference in the program manager's estimate and the current price. The formula for the coefficient of variation is (for a generic variable x):

$$CoefV_x = \frac{\sigma_x}{\mu_x} \tag{3.5}$$

- **Mean Squared Forecasting Error**: In each SAR, both the contractor and program manager provide estimates for the cost of the contract at completion(EAC). In the next annual SAR, I observe an update to the contract's price and a new estimate from each party. Presumably, the estimate from the previous SAR should serve as a forecast of the contract price in the current SAR. Therefore, I can calculate the forecasting error for each party for every contract-year in which there is a preceding estimate and use these forecast errors to calculate a mean square forecasting error for each contract. The formula for this statistic is (using the PM as an example):

$$MSFE_{PM} = \frac{\sum_{t=2}^{N}(EAC_{t-1} - CP_t)^2}{N} \tag{3.6}$$

Table 3.25: Variability Measures

Cost Variance (CV)	Definition
cvsr	Cost Variance Sharpe Ratio
svsr	Schedule Variance Sharpe Ratio
pcoefv	Contract Price Coefficient of Variation
upcoefvi	Unit Price Coefficient of Variation (including initial price)
upcoefv	Unit Price Coefficient of Variation (without initial price)
diffcoefv	Coeff. of Variation of Difference in PM & Contractor Estimates
diffcoefvc	Coeff. of Variation of Difference in Contractor Est. & Current Price
diffcoefvp	Coeff. of Variation of Difference in PM Estimate & Current Price
lcmsfe	Log of Contractor's Mean Squared Forecasting Error
lpmsfe	Log of PM's Mean Squared Forecasting Error

Tables 3.27 and 3.28 display the estimation results for equation (3.2) using the Sharpe ratios for cost variance and schedule variance, respectively. In each table, I list three specifications, including a baseline regression, baseline with variance explanations, and baseline with variance explanations and branch controls. In the case of the cost variance Sharpe ratio, columns (1) and (2) show a significant and negative effect from the length of the contract. This indicates that the government is more likely to receive a poor "return" for a longer duration contract, on average. However, this effect becomes insignificant when military branch controls are added. For the schedule variance Sharpe ratio in Table 3.28, I observe a positive and significant effect from cumulative quantity change and a negative and significant effect from repeat iteration. Meanwhile, column (2) suggests a positive and marginally significant effect from describability ranking, which becomes insignificant upon the addition of the branch controls. From these

Table 3.26: Summary Statistics for Variability Measures

Variable	Observations	Mean	Std. Dev.	Min	Max
cvsr	69	0.053	1.107	-4.699	4.142
svsr	69	-0.231	0.523	-2.67	1
pcoefv	89	0.331	0.47	0	2
upcoefvi	54	0.198	0.236	0	0.956
upcoefv	55	0.13	0.177	2.78E-16	0.814
diffcoefv	50	1.373	0.639	0.073	3.068
diffcoefvc	58	0.176	0.533	0.146	2.236
diffcoefvp	56	1.178	0.463	0.146	2.236
cmsfe	70	963069.5	6839603	0.00E+00	5.68E+07
pmsfe	71	987887.8	6769086	0	5.68E+07

results, it does not appear that the describability of the project via the contract type has a consistently significant effect on the DoD's "return" per unit of risk for a contract.

Tables 3.29, 3.30, and 3.31 present the results of IV estimation of equation (3.2) using coefficients of variation for different measurements of the contract's price. I have specific reasons for considering each of these. Due to the fact that quantity changes often account for substantial increases in contract price, particularly for full-scale production contracts, I wanted to compare the effects on overall contract price to effects on the unit price. Additionally, I have previously mentioned that the initial price of a contract is often not representative of the eventual price of the contracts, and the largest changes in price often occur between the award date and the first SAR (the dates at which the parties record initial and current prices). Therefore, I am presenting results for the coefficient of variation of the unit price both with and without the initial price.

In Table 3.29, the analysis proceeds as follows. Columns (1) and (3) include schedule variance explanations and explanations with branch controls, respectively. Columns (2) and (4) use cost variance explanations and cost variance explanations with branch controls, respectively. The results show a consistently negative and significant effect on the variability of the overall price due to the contractor's previous number of in-sample aircraft contracts. This perhaps indicates that firms develop an aptitude for estimating prices as they become more experienced in DoD contracting. In addition, I observe a positive and significant effect from the iteration variable in columns (1) and (2), but this becomes insignificant and even changes sign as military branch controls are introduced. There is no consistent sign or effect of the describability ranking on the coefficient of variability for the overall contract price. The model performs particularly poorly in Tables 3.30 and 3.31, and the model fails to predict a statistically significant amount of variation in either the upcoefvi or upcoefv variables.

Tables 3.32, 3.33, and 3.34 present results related to the variability of the contractor and program manager estimates of the contract price at completion. Table 3.32 suggests that the variability in the difference between the two parties' estimates is significantly decreased in repeat iterations of the same contract. However, this effect becomes insignificant when I control for firm attributes. In Table 3.33, columns (5) and (6) show that the coefficient on the describability ranking has a positive and significant effect on the variability between the current contract price and the contractor's estimate at completion. Table 3.34 shows a negative and significant effect for the coefficient on the procurement indicator variable, indicating that the program manager's estimates follow the current price of the contract more closely for the later stages of an acquisition project, on average. While the results in Table 3.34 do not show a significant effect for the describability ranking on the dependent variable, the sign of the coefficient is consistent with the estimates from Table 3.33. Perhaps it is possible that the

DoD is more willing to accept variable cost estimates from the contractor in cases where the contractor bears a larger share of the cost burden. Conversely, it may be the case that the government is more active or willing in implementing corrective actions or incorporating unforeseen costs in contracts in which it bears a greater share of the cost burden.

Tables 3.35 and 3.36 use the mean squared forecasting error of the contractor and program manager estimates at completion in comparison to the next period's price of the contract. The effect of describability ranking is positive but insignificant in eleven of twelve specifications. Both tables report a positive and significant coefficient for the length variable in every specification. This indicates that longer contract periods will complicate each party's ability to accurately estimate the contract's price at completion. Also, I observe in both tables that the firm employment has a significant and negative effect, whereas the firm revenue has a significant, positive effect. This is an interesting result, considering that both of these variables are being considered as a proxy for firm size. Due to the fact that I'm using total employment but segment revenue, this may be an indication of a difference in the estimation capabilities of defense firms versus defense divisions of larger corporations.[23] For example, a large corporation with a defense segment may employ a much larger number of people than a stand-alone defense firm. Conversely, the defense firm's revenues may be much greater than the revenues of the defense segment of a larger corporation. The results of Tables 3.35 and 3.36 suggest that the overall effect may be more accurate price estimation results from the defense segments of larger corporations. However, this may be due to a tendency for these segments to contract for less complex

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[23] I'm forced to use these differing measures due to the unavailability of sector employment data for large firms

projects than the specialized defense firms.

In summary, the regression results from this section of the paper do not suggest a definitive role for the describability ranking of the contract on the ability of the contractor and program manager to administer the contract. Almost all of the results indicate a positive relationship with these measures of variability, but the relationship is rarely significant and marginal at best. However, this relationship supports the cost-sharing structure of the different contract types. As project describability increases, the contract type will become more complete, and the contractor will bear a greater share of the cost burden. As a result, one might expect the cost estimates of the two sides to increase in variability as the contractor becomes more invested in tying the contract price to its own estimates, while the government will likely be less actively involved in the contractor's estimation and administration processes.

Table 3.27: IV Regressions for Cost Variance Sharpe Ratio

	(1) cvsr	(2) cvsr	(3) cvsr
drnk	0.647	0.609	-0.561
	(0.632)	(0.558)	(0.612)
cumdq	0.003	-0.006	-0.000
	(0.009)	(0.011)	(0.010)
prevcont	-0.007	-0.002	0.002
	(0.012)	(0.009)	(0.010)
duals	-0.176	0.037	0.685
	(0.250)	(0.308)	(0.520)
winage	-0.011	-0.000	0.017
	(0.036)	(0.028)	(0.027)
length	-0.006*	-0.006*	-0.005
	(0.004)	(0.003)	(0.005)
iteration	0.031	0.007	0.051
	(0.086)	(0.071)	(0.072)
proc	-0.870	0.177	0.895
	(0.820)	(0.700)	(0.591)
rd	0.079	1.143	0.344
	(0.983)	(0.810)	(0.894)
sumposcv		0.263***	0.249**
		(0.096)	(0.111)
sumnegcv		-0.160***	-0.149***
		(0.060)	(0.053)
army			1.003
			(0.630)
navy			1.072
			(0.678)
af			1.739**
			(0.789)
Constant	-0.986	-2.008	-0.090
	(2.114)	(1.842)	(1.923)
N	69	69	69
R-Squared	.	0.123	0.210
Wald	18.24**	22.32**	35.27***
DWH P-Value	0.342	0.289	0.210

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.28: IV Regressions for Schedule Variance Sharpe Ratio

	(1) svsr	(2) svsr	(3) svsr
drnk	0.209	0.310*	0.536
	(0.151)	(0.182)	(0.384)
cumdq	0.012***	0.012***	0.011***
	(0.004)	(0.003)	(0.004)
prevcont	0.008	0.009	0.007
	(0.006)	(0.006)	(0.007)
duals	-0.252	-0.316	-0.451*
	(0.175)	(0.192)	(0.241)
winage	0.002	-0.001	0.002
	(0.010)	(0.010)	(0.012)
length	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)
iteration	-0.094*	-0.092*	-0.111*
	(0.052)	(0.051)	(0.058)
proc	-0.027	-0.130	-0.238
	(0.211)	(0.200)	(0.253)
rd	0.172	0.236	0.424
	(0.267)	(0.305)	(0.474)
sumpossv		0.115**	0.123*
		(0.050)	(0.071)
sumnegsv		-0.078**	-0.086*
		(0.039)	(0.047)
army			-0.200
			(0.270)
navy			-0.327
			(0.237)
af			-0.190
			(0.315)
Constant	-0.750	-0.981	-1.331
	(0.517)	(0.642)	(1.078)
N	69	69	69
R-Squared	0.164	0.162	.
Wald	38.71***	52.89***	53.22***
DWH P-Value	0.217	0.065	0.047

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.29: IV Estimation: Coeff. of Variation in Contract Price

	(1) pcoefv	(2) pcoefv	(3) pcoefv	(4) pcoefv
drnk	-0.125	-0.113	0.551	0.738
	(0.232)	(0.222)	(0.671)	(0.683)
cumdq	0.005	0.004	0.000	-0.004
	(0.005)	(0.005)	(0.008)	(0.008)
prevcont	-0.012***	-0.011***	-0.018*	-0.019**
	(0.003)	(0.004)	(0.009)	(0.010)
duals	0.382	0.386	0.083	0.083
	(0.286)	(0.288)	(0.398)	(0.412)
winage	-0.004	-0.004	0.001	0.006
	(0.008)	(0.008)	(0.014)	(0.017)
length	-0.001	-0.001	-0.002	-0.003
	(0.001)	(0.001)	(0.002)	(0.003)
iteration	0.058**	0.058**	0.003	-0.010
	(0.029)	(0.028)	(0.056)	(0.061)
proc	-0.076	0.040	-0.316	-0.097
	(0.147)	(0.185)	(0.385)	(0.414)
rd	-0.136	0.011	0.433	0.919
	(0.299)	(0.295)	(0.646)	(0.825)
sumpossv	-0.070*		-0.083	
	(0.036)		(0.067)	
sumnegsv	0.012		-0.004	
	(0.022)		(0.052)	
sumposcv		0.022		0.079
		(0.038)		(0.082)
sumnegcv		-0.035*		-0.051
		(0.020)		(0.045)
army			-0.457	-0.458
			(0.324)	(0.379)
navy			-0.660	-0.875
			(0.461)	(0.548)
af			-0.659	-0.868
			(0.549)	(0.643)
Constant	0.849	0.683	-0.354	-1.069
	(0.799)	(0.779)	(1.482)	(1.620)
N	89	89	89	89
R-Squared	0.226	0.236	.	.
Wald	67.29***	62.67***	35.00***	25.47**
DWH P-Value	0.780	0.844	0.127	0.038

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.30: IV Estimation: Coeff. of Variation in Unit Price (with initial price)

	(1) upcoefvi	(2) upcoefvi	(3) upcoefvi	(4) upcoefvi
drnk	1.017	0.672	-1.162	0.624
	(4.789)	(1.835)	(45.232)	(19.051)
cumdq	-0.004	-0.004	0.007	-0.006
	(0.021)	(0.013)	(0.272)	(0.201)
prevcont	-0.014	-0.010	0.006	-0.012
	(0.038)	(0.012)	(0.438)	(0.194)
duals	-0.541	-0.259	0.484	-0.179
	(2.342)	(0.539)	(19.781)	(4.759)
winage	0.043	0.033	-0.053	0.042
	(0.199)	(0.092)	(2.251)	(1.100)
length	0.003	0.001	-0.003	0.001
	(0.012)	(0.003)	(0.126)	(0.005)
iteration	-0.115	-0.069	0.190	-0.073
	(0.680)	(0.274)	(6.603)	(2.850)
proc	-1.090	-0.673	1.481	-0.587
	(5.597)	(2.128)	(53.412)	(21.745)
sumpossv	0.032		-0.107	
	(0.269)		(3.721)	
sumnegsv	-0.055		0.083	
	(0.265)		(2.998)	
sumposcv		0.088		0.098
		(0.314)		(3.552)
sumnegcv		-0.014		0.008
		(0.063)		(0.305)
army			-0.450	0.202
			(17.850)	(4.179)
navy			0.013	-0.039
			(1.131)	(3.792)
af			-0.021	0.252
			(7.233)	(0.684)
Constant	-1.965	-1.352	2.564	-1.381
	(9.796)	(4.018)	(98.920)	(40.506)
N	54	54	54	54
R-Squared	.	.	.	.
Wald	4.31	6.95	12.23	9.96
DWH P-Value	0.387	0.333	0.921	0.918

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.31: IV Estimation: Coeff. of Variation in Unit Price (no initial price)

	(1) upcoefv	(2) upcoefv	(3) upcoefv	(4) upcoefv
drnk	0.338	0.309	0.214	0.143
	(0.641)	(0.522)	(0.448)	(0.330)
cumdq	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.003)	(0.002)	(0.003)
prevcont	-0.002	-0.003	-0.002	-0.002
	(0.006)	(0.005)	(0.005)	(0.004)
duals	-0.195	-0.156	-0.116	-0.045
	(0.337)	(0.226)	(0.249)	(0.159)
winage	0.017	0.016	0.016	0.014
	(0.032)	(0.028)	(0.027)	(0.023)
length	0.000	-0.000	-0.000	-0.000
	(0.002)	(0.001)	(0.001)	(0.001)
iteration	-0.036	-0.034	-0.029	-0.024
	(0.074)	(0.064)	(0.058)	(0.047)
proc	-0.434	-0.377	-0.261	-0.136
	(0.876)	(0.694)	(0.610)	(0.445)
sumpossv	0.027		0.027	
	(0.077)		(0.066)	
sumnegsv	-0.021		-0.013	
	(0.034)		(0.028)	
sumposcv		-0.003		-0.004
		(0.048)		(0.047)
sumnegcv		0.009		0.017
		(0.021)		(0.016)
army			0.068	0.089
			(0.148)	(0.130)
navy			0.007	0.055
			(0.112)	(0.140)
af			0.155	0.206
			(0.153)	(0.157)
Constant	-0.579	-0.537	-0.379	-0.306
	(1.400)	(1.174)	(0.953)	(0.695)
N	55	55	55	55
R-Squared	.	.	.	.
Wald	2.17	1.91	3.72	5.01
DWH P-Value	0.264	0.235	0.316	0.356

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.32: IV Estimation: Coeff. of Variation in PM/CTR Est. Difference

	(1) diffcoefv	(2) diffcoefv	(3) diffcoefv	(4) diffcoefv	(5) diffcoefv	(6) diffcoefv
drnk	0.405	0.431	0.071	0.069	1.195	1.252
	(0.483)	(0.459)	(0.503)	(0.450)	(1.210)	(1.183)
cumdq	-0.008	-0.009	-0.007	-0.007	-0.017	-0.018
	(0.008)	(0.009)	(0.007)	(0.007)	(0.013)	(0.014)
prevcont	0.006	0.007	0.006	0.007	-0.033	-0.033
	(0.008)	(0.010)	(0.010)	(0.010)	(0.038)	(0.039)
duals	-0.692	-0.632	-0.529	-0.464	-0.770	-0.759
	(0.507)	(0.424)	(0.469)	(0.385)	(0.768)	(0.730)
winage	-0.019	-0.019	-0.008	-0.008	0.102	0.108
	(0.012)	(0.012)	(0.019)	(0.018)	(0.105)	(0.107)
length	0.006	0.006	0.006	0.006*	0.010	0.010
	(0.004)	(0.004)	(0.004)	(0.004)	(0.008)	(0.008)
iteration	-0.102*	-0.111*	-0.094*	-0.099*	-0.170	-0.181
	(0.060)	(0.058)	(0.057)	(0.055)	(0.134)	(0.133)
proc	-0.161	-0.173	0.212	0.235	-1.222	-1.287
	(0.561)	(0.530)	(0.645)	(0.536)	(1.503)	(1.460)
sumpossv	0.044		0.058		0.022	
	(0.073)		(0.094)		(0.156)	
sumnegsv	0.016		0.016		0.033	
	(0.064)		(0.052)		(0.089)	
sumposcv		0.040		0.017		0.056
		(0.109)		(0.090)		(0.181)
sumnegcv		0.000		0.016		0.002
		(0.047)		(0.034)		(0.085)
army			0.250	0.238		
			(0.458)	(0.396)		
navy			0.171	0.191		
			(0.331)	(0.326)		
af			0.557	0.580		
			(0.394)	(0.387)		
lavgemp					0.815	0.855
					(0.699)	(0.708)
lavgdrev					0.298	0.299
					(0.530)	(0.533)
avgcrat					0.701	0.756
					(1.471)	(1.537)
avglev					4.480	4.409
					(5.510)	(5.586)
Constant	0.433	0.389	0.783	0.782	-15.017	-15.657
	(0.961)	(0.926)	(1.060)	(0.990)	(14.058)	(14.152)
N	50	50	50	50	50	50
R-Squared	0.052	0.016	0.345	0.339	.	.
Wald	19.33**	18.46**	26.90**	26.53**	13.61	10.94
DWH P-Value	0.728	0.897	0.819	0.799	0.218	0.195

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.33: Coeff. of Variation of Difference in CTR Estimate & Current Price

	(1) diffcoefvc	(2) diffcoefvc	(3) diffcoefvc	(4) diffcoefvc	(5) diffcoefvc	(6) diffcoefvc
drnk	0.242	0.253	0.416	0.442	0.434*	0.475*
	(0.270)	(0.286)	(0.351)	(0.338)	(0.238)	(0.283)
cumdq	-0.000	0.000	-0.003	-0.003	-0.002	-0.002
	(0.004)	(0.005)	(0.005)	(0.005)	(0.007)	(0.008)
prevcont	0.008	0.007	0.004	0.003	-0.008	-0.011
	(0.006)	(0.007)	(0.009)	(0.009)	(0.012)	(0.014)
duals	0.628**	0.530	0.413	0.329	0.578**	0.395
	(0.285)	(0.343)	(0.436)	(0.436)	(0.235)	(0.273)
winage	-0.018	-0.019	-0.014	-0.016	0.022	0.024
	(0.012)	(0.012)	(0.013)	(0.013)	(0.031)	(0.034)
length	0.000	-0.000	-0.000	-0.001	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
iteration	-0.033	-0.023	-0.032	-0.024	-0.034	-0.024
	(0.031)	(0.030)	(0.030)	(0.029)	(0.028)	(0.029)
proc	-0.411	-0.482	-0.696	-0.783	-0.724**	-0.849**
	(0.368)	(0.404)	(0.518)	(0.497)	(0.333)	(0.424)
sumpossv	-0.150**		-0.105		-0.167**	
	(0.060)		(0.074)		(0.075)	
sumnegsv	0.005		-0.012		0.028	
	(0.030)		(0.038)		(0.026)	
sumposcv		-0.042		-0.002		-0.076
		(0.067)		(0.070)		(0.080)
sumnegcv		-0.034		-0.046		-0.019
		(0.031)		(0.031)		(0.028)
army			0.215	0.205		
			(0.405)	(0.384)		
navy			-0.273	-0.375		
			(0.343)	(0.351)		
af			-0.214	-0.314		
			(0.337)	(0.348)		
lavgemp					0.137	0.239
					(0.290)	(0.304)
lavgdrev					0.191	0.115
					(0.233)	(0.245)
avgcrat					0.461	0.452
					(0.971)	(1.072)
avglev					3.165	3.810*
					(2.243)	(2.309)
Constant	0.905	0.917	0.759	0.814	-3.927	-4.554
	(0.559)	(0.572)	(0.614)	(0.572)	(3.359)	(3.536)
N	58	58	58	58	58	58
R-Squared	0.093	0.046	.	.	0.042	.
Wald	23.80***	19.55**	27.41***	22.28**	41.52***	30.23***
DWH P-Value	0.348	0.343	0.240	0.222	0.129	0.128

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.34: Coeff. of Variation of Difference in PM Estimate & Current Price

	(1) diffcoefvp	(2) diffcoefvp	(3) diffcoefvp	(4) diffcoefvp	(5) diffcoefvp	(6) diffcoefvp
drnk	0.252	0.267	0.194	0.208	0.302	0.354
	(0.226)	(0.249)	(0.214)	(0.198)	(0.221)	(0.266)
cumdq	0.003	0.003	0.002	0.001	0.001	-0.000
	(0.005)	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)
prevcont	0.010	0.009	0.009	0.008	0.002	-0.002
	(0.006)	(0.006)	(0.006)	(0.006)	(0.010)	(0.012)
duals	0.510	0.412	0.605	0.548	0.601**	0.434
	(0.326)	(0.360)	(0.407)	(0.401)	(0.288)	(0.302)
winage	0.006	0.005	0.015	0.015	0.036	0.044
	(0.012)	(0.012)	(0.010)	(0.011)	(0.027)	(0.031)
length	-0.001	-0.001	-0.001	-0.001	0.001	0.001
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
iteration	-0.032	-0.022	-0.023	-0.016	-0.021	-0.009
	(0.026)	(0.028)	(0.024)	(0.025)	(0.021)	(0.021)
proc	-0.496*	-0.561*	-0.476	-0.525*	-0.648**	-0.795**
	(0.287)	(0.324)	(0.319)	(0.289)	(0.299)	(0.384)
sumpossv	-0.127**		-0.078		-0.140**	
	(0.061)		(0.061)		(0.057)	
sumnegsv	0.018		0.000		0.024	
	(0.023)		(0.028)		(0.020)	
sumposcv		-0.027		-0.002		-0.082
		(0.069)		(0.054)		(0.080)
sumnegcv		-0.017		-0.020		-0.001
		(0.035)		(0.027)		(0.039)
army			0.582*	0.612**		
			(0.307)	(0.292)		
navy			0.061	0.010		
			(0.246)	(0.244)		
af			0.218	0.178		
			(0.257)	(0.270)		
lavgemp					0.139	0.249
					(0.261)	(0.273)
lavgdrev					-0.084	-0.168
					(0.153)	(0.179)
avgcrat					0.946	1.104
					(0.607)	(0.771)
avglev					3.977**	4.444**
					(1.781)	(2.064)
Constant	0.754	0.739	0.666	0.665	-1.849	-2.656
	(0.485)	(0.517)	(0.513)	(0.520)	(3.469)	(3.670)
N	56	56	56	56	56	56
R-Squared	0.022	.	0.212	0.187	0.148	0.042
Wald	15.54	12.07	29.01***	32.12***	41.90***	34.98***
DWH P-Value	0.173	0.209	0.295	0.290	0.130	0.154

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.35: IV Estimation: Contractor's Mean Squared Forecasting Error

	(1) lcmsfe	(2) lcmsfe	(3) lcmsfe	(4) lcmsfe	(5) lcmsfe	(6) lcmsfe
drnk	0.824	0.593	1.746	1.454	0.258	-0.229
	(1.394)	(1.638)	(1.654)	(1.812)	(1.667)	(1.984)
cumdq	-0.051	-0.051	-0.060*	-0.058	-0.007	-0.003
	(0.041)	(0.042)	(0.036)	(0.038)	(0.045)	(0.046)
prevcont	0.038	0.050	0.034	0.045	0.121	0.154*
	(0.061)	(0.059)	(0.066)	(0.065)	(0.089)	(0.091)
duals	-1.178	-0.655	-1.810	-1.342	-0.663	-0.080
	(1.414)	(1.560)	(1.526)	(1.557)	(1.558)	(1.763)
winage	0.095	0.111	0.043	0.064	-0.252	-0.302
	(0.075)	(0.078)	(0.082)	(0.088)	(0.192)	(0.203)
length	0.049***	0.052***	0.046***	0.049***	0.046***	0.045***
	(0.013)	(0.013)	(0.015)	(0.014)	(0.013)	(0.013)
iteration	-0.126	-0.171	-0.103	-0.154	-0.084	-0.113
	(0.193)	(0.187)	(0.187)	(0.186)	(0.199)	(0.198)
proc	0.535	0.995	-0.582	-0.073	1.364	2.172
	(1.847)	(2.117)	(2.180)	(2.333)	(2.000)	(2.307)
sumpossv	1.146**		1.101**		0.953**	
	(0.502)		(0.530)		(0.458)	
sumnegsv	0.382*		0.423*		0.445**	
	(0.230)		(0.248)		(0.193)	
sumposcv		0.779*		0.707		0.902**
		(0.436)		(0.432)		(0.420)
sumnegcv		0.416*		0.427**		0.377
		(0.219)		(0.214)		(0.244)
army			-1.664	-1.741		
			(1.919)	(1.903)		
navy			-0.634	-0.594		
			(1.771)	(1.844)		
af			-2.474	-2.115		
			(1.813)	(1.801)		
lavgemp					-4.324**	-4.887***
					(1.703)	(1.627)
lavgdrev					1.572	1.796*
					(1.018)	(0.965)
avgcrat					-4.202	-5.579
					(4.335)	(4.570)
avglev					-6.351	-11.522
					(10.098)	(9.825)
Constant	-0.447	-0.471	-1.068	-0.959	42.824*	50.077**
	(3.235)	(3.686)	(3.628)	(4.068)	(22.997)	(23.650)
N	66	66	66	66	66	66
R-Squared	0.326	0.343	0.319	0.345	0.393	0.422
Wald	55.61***	82.03***	75.34***	93.91***	75.61***	101.61***
DWH P-Value	0.904	0.980	0.387	0.561	0.949	0.805

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.36: IV Estimation: PM's Mean Squared Forecasting Error

	(1) lpmsfe	(2) lpmsfe	(3) lpmsfe	(4) lpmsfe	(5) lpmsfe	(6) lpmsfe
drnk	1.231	1.042	1.919	1.602	0.848	0.519
	(1.263)	(1.465)	(1.610)	(1.781)	(1.513)	(1.731)
cumdq	-0.043	-0.040	-0.045	-0.038	0.012	0.017
	(0.058)	(0.056)	(0.048)	(0.047)	(0.053)	(0.052)
prevcont	0.027	0.035	0.031	0.038	0.108	0.134
	(0.064)	(0.062)	(0.068)	(0.066)	(0.097)	(0.096)
duals	-0.468	0.067	-1.378	-0.983	0.267	0.881
	(1.981)	(2.126)	(2.036)	(2.084)	(1.636)	(1.814)
winage	0.057	0.076	-0.005	0.016	-0.340*	-0.381*
	(0.078)	(0.084)	(0.085)	(0.090)	(0.206)	(0.214)
length	0.034**	0.036**	0.032*	0.036**	0.034**	0.033**
	(0.017)	(0.017)	(0.017)	(0.016)	(0.015)	(0.015)
iteration	-0.074	-0.128	-0.068	-0.120	-0.061	-0.096
	(0.188)	(0.187)	(0.192)	(0.191)	(0.193)	(0.189)
proc	-0.231	0.242	-0.997	-0.402	0.204	0.839
	(1.809)	(2.053)	(2.202)	(2.409)	(2.067)	(2.193)
sumpossv	1.463**		1.235**		1.123**	
	(0.572)		(0.529)		(0.462)	
sumnegsv	0.236		0.329		0.407*	
	(0.270)		(0.258)		(0.209)	
sumposcv		0.651		0.489		0.823*
		(0.461)		(0.433)		(0.441)
sumnegcv		0.485**		0.504**		0.477**
		(0.226)		(0.211)		(0.243)
army			-3.408*	-3.689*		
			(2.017)	(2.060)		
navy			-0.803	-0.521		
			(1.819)	(1.846)		
af			-2.422	-1.909		
			(1.794)	(1.728)		
lavgemp					-5.744***	-6.388***
					(1.974)	(1.929)
lavgdrev					2.943***	3.289***
					(1.090)	(1.049)
avgcrat					-5.676	-6.858
					(4.136)	(4.228)
avglev					-11.167	-16.332
					(11.070)	(11.307)
Constant	-0.340	-0.411	-0.127	-0.047	48.937*	55.507**
	(2.885)	(3.188)	(3.276)	(3.571)	(26.299)	(26.398)
N	69	69	69	69	69	69
R-Squared	0.238	0.239	0.262	0.285	0.374	0.412
Wald	30.30***	48.24***	43.77***	55.62***	59.39***	78.47***
DWH P-Value	0.873	0.987	0.396	0.563	0.872	0.999

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.9 Conclusion

The primary purpose of this paper was to provide empirical evidence in support of the debate surrounding the relevance of physical describability in contracting outcomes. Given the presence of the "menu" of contracts made available to US government acquisition officials by the Federal Acquisition Regulation, it seems unnecessary to justify whether or not the describability or complexity of an underlying project is a relevant consideration in the defense contracting environment. However, the internal theoretical debate in economics pertains to whether or not this describability warrants its own contracting approach. The empirical results of this paper seem to suggest that the physical describability of the underlying project can have a tangible effect on the performance outcome for the associated contract in the defense contracting environment. While far from definitive, it seems that military aircraft projects that are capable of being assigned a more "complete" style of contract may perform better, on average, particularly in terms of adherence to contractual timelines. The effect on cost performance is much less clear. Therefore, it seems that the relevance of physical describability is two-fold in the case of DoD contracting. First, it is a major criterion in determining the risk-sharing structure and administrative environment under which a project will operate. Second, even given attempts to accommodate technological complexity with an appropriate contract type, the underlying indescribable nature of the project may produce unforeseeable production difficulties and delays.

Possible extensions of this paper would likely focus on quasi-experimental conditions in which projects of similar complexity were administered under contract types with differing incentive structures. The set of projects under consideration in this paper does not lend itself to this type of scenario as the projects are separated by great degrees of technological heterogeneity. In this sense, I cannot currently comment on the "optimality" of the incomplete contracting approach, only on its relevance in certain environments. Additionally, it would be interesting to further research the underlying costs of EVM application as a matter of policy analysis. Although the FAR clearly views the application of EVM as a costly endeavor, I am not able to directly observe these costs in my data set. It would be interesting to conduct an *ex post* cost-benefit analysis in terms of EVM costs versus contract performance. A study of this type would certainly be useful for policymakers looking to apply EVM in a non-DoD environment.

Chapter 4

A Model of Contract Design: Procurement under Exogenous Uncertainty

Abstract

In certain procurement environments, exogenous events and concerns induce uncertainty surrounding the common cost component of manufacturing or construction projects. The acquisition of major weapons systems by the US Department of Defense and highway procurement during post-disaster recovery are two examples of procurement environments characterized by this type of uncertainty. This paper models the contract design problem for procurement officials in these environments as an *ex ante* screening problem. In this model, the deciding official must weigh the potential for inaccurate cost estimates in standard procurement (fixed-price) procedures against the possibility for contractor surplus extraction under a cost-plus framework. Additionally, the paper provides examples of modular incentive structures aimed at reducing the overall cost of procurement under uncertain conditions.

4.1 Introduction

The ability to properly design and execute procurement contracts in an efficient manner depends directly on the procuring agency's understanding of and ability to describe the extent and nature of the work to be performed. In certain situations, this ability will be affected by elements beyond the control of the procurer, and the resulting contract design must take these factors into account. Especially in the case of major acquisitions, such as large pieces of infrastructure or DoD weapons programs, the possibility of contractual hold-up is particularly strong, as contractors will be forced to make large, relationship-specific investments in projects for which there is likely no other buyer or seller. Unforeseen contingencies in these situations can cause costly delays, particularly if the contract in place does not provide flexibility in addressing necessary changes. The primary goal of this paper is to provide a theoretical model of procurement contract design (award mechanism + incentive structure), which explicitly accounts for the ability of the involved parties to accurately describe the costs of the underlying project. In order to provide context for this model, I will primarily rely on examples from the procurement environments surrounding DoD weapons acquisition and post-disaster infrastructure repairs.

In defense contracting, the underlying project is often advancing the current frontier of defense technology in response to a new external threat, leading to complex design and production processes. Additionally, the DoD's budget for large acquisition projects is closely scrutinized and ultimately determined in the political arena. As a result, support for any one project may be subject to shifts in political power or agenda. These concerns principally define the defense acquisition process but are also largely beyond the DoD's control. However, defense acquisition officials are able to employ a spectrum of contract types and incentive structures in the procurement process, greatly enhancing their ability to accommodate contingencies.

According to transportation officials, the infrastructure damage caused by natural disasters shrouds the procurement process in a similar type of uncertainty. While bridge repair, culvert replacement, and highway re-surfacing are typical projects that transportation officials might oversee on a daily basis, the post-disaster environment often changes the scope of the work required for these projects and presents unique challenges that may not be apparent during the cost estimation process. Due to this exogenous change in procurement conditions, transportation officials are often allowed to procure construction projects using a more streamlined and flexible approach.

The contracting procedures employed by the Vermont Agency of Transportation (VTrans) after Tropical Storm Irene are evidence of the value placed on increased flexibility in an uncertain procurement environment. While major projects, such as new bridges and overpasses, continued to be governed by fixed-price contracts with varying incentive structures, many projects, which would have been covered by standard procurement procedures prior to the emergency, were instead administered using a cost-reimbursement contract. From correspondence with VTrans officials, it is apparent that these cost-plus contracts were preferred due to their flexibility in accommodating unforeseen construction challenges and tasks. Therefore, one of the determining factors in awarding these maintenance rental agreements, instead of fixed-price variants, was certainly transportation officials' ability to fully define the work involved in each project.

As in contracting for major weapons systems, we might expect several possible consequences of using standard procurement procedures in the presence of increased uncertainty surrounding the scope or physical describability of a road construction project. First, bidders may incorporate a large risk premium into their fixed-price bid. The intent of this premium would be to shield the contractor from suffering losses in the event of unforeseen cost growth. A fixed-price contract provides the contractor with the greatest cost minimization incentives and maximum control over resulting profit. However, any adverse cost performance will be the sole responsibility of the contractor under the fixed-price contract, perhaps leading the contractor to build an expensive "cushion" into his bid. Second, the use of a fixed-price contract for a project with high levels of technological uncertainty may lead otherwise attractive contractors to refrain from participation due to the risk of contractual hold-up. Finally, one must consider the effect of transaction costs. Whereas a fixed-price contract may increase efficiency, it may be very difficult to amend in the case of substantial changes to the scope of work. Meanwhile, cost-plus contracts are more flexible in accommodating changes to the original plan. See Bajari and Tadelis, 2001 for more on transaction cost theory.

The contract design model in this paper attempts to capture all of these concerns regarding the choice of optimal incentive power by procurement officials. Given the structure and supporting assumptions of the model, I provide a decision rule for a theoretical official who is attempting to choose the appropriate contract type based on *ex ante* expectations of procurement costs under the different incentive structures. This procurement official ultimately must weigh the potential effects of inaccurate cost estimation in the fixed-price contract against the weak cost-minimization incentives of the cost-plus contract and make a decision based on the specific characteristics of the underlying projects.

This paper proceeds as follows. Section 4.2 provides further background information and a comparison of the contracting approaches in DoD weapons procurement and post-disaster highway projects from Vermont in the aftermath of Tropical Storm Irene. Section 4.3 provides a brief summary of the relevant literature involving highway procurement auctions and contract design. Section 4.4 models the contract design problem facing procurement officials when confronted with extreme amounts of uncertainty regarding the common cost of a procurement project. Section 4.5 examines the possibility of incorporating incentive/disincentive payments in order to limit both social costs and the final payment to the contractor. Section 4.6 discusses the different administrative costs for each contract type and extends the model to a procurement environment with risk averse bidders. Section 4.7 concludes.

4.2 Contracting Similarities: Defense Acquisition and Post-Disaster Road Repair

Defense Acquistion

The procurement environment for the US Department of Defense is largely characterized by elements of internal and external uncertainty, as first described by Peck and Scherer (1962). Internal uncertainty originates from the complexity of major weapons systems: difficulty in describing the physical characteristics of the project, incorporating frontier-expanding technologies into a single product, and coordination issues between multiple contractors. Alternatively, external uncertainty exists due to the unique nature of the defense industry. Demand and innovation are driven by existing and imminent threats to security, and the entire acquisition process is subject to changes in the domestic and international political climates.

Within the catalogue of major defense contracts, there exists a broad spectrum of technological requirements and project complexity. These requirements differ from program to program. For example, the technology required to produce a next-generation fighter jet is far more demanding and *ex ante* difficult to describe than in the case of a helicopter modernization program, which will be largely dependent on existing technologies. Additionally, when one considers the contracts that collectively produce a major weapons system, uncertainty surrounding the budget, timeline, and product of an initial research and development contract is likely to dwarf identical concerns in a full-rate production contract. As a result of these considerations and the resulting need for flexibility in contract administration, the Federal Acquisition Regulation (FAR) provides government officials with a menu of contract types to accommodate the specific requirements of the project and task at hand. This menu of contracts serves to encourage participation and innovation in an industry that might otherwise be prone to severe underinvestment due to contractual hold-up.[1]

The FAR contract type menu provides acquisition officials with the choice between fixed-price and cost-plus contracts along with variations of these types, including different types of incentive structures and price-adjustment formulas. For major weapons systems, the contract type and price are negotiated jointly with the contractor, and the flexibility of the resulting contract should mirror underlying concerns regarding the parties' ability to fully specify the project in question. As specified in the FAR, cost-reimbursement contracts are only to be used in the event that the project cannot be described with a sufficient amount

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[1] See Rogerson (1994) for a thorough description of unique issues in the DoD procurement environment and government policies that address these problems.

of accuracy to implement a fixed-price contract (FAR, 16.301). As a result, the contract administration requirements that accompany a cost-plus contract, thus, provide the government and the contractor with the ability to modify contractual obligations as necessary. On the other hand, the language of the FAR clearly indicates that the government prefers the fixed-price contract when feasible due to its high-powered, cost-minimization incentives for the contractor. In summary, DoD procurement of major weapons systems is plagued by issues of exogenous uncertainty, and the FAR provides acquisition officials with a tool to address these concerns in a systematic manner.

Post-Disaster Infrastructure Procurement

While a multitude of government procedures and policies for awarding infrastructure contracts using a standard procurement process (i.e., a competitively-awarded, fixed-price contract) are extensively covered in the economic literature, the procurement of these same types of projects in a post-disaster environment has received relatively little attention. Based on conversations with officials form the Vermont Agency of Transportation (VTrans), it is clear that procurement procedures for highway infrastructure projects were drastically altered due to emergency conditions in the aftermath of Tropical Storm Irene. The storm's impact on Vermont's road network increased the urgency with which repairs were required, stretched the state's limited resources for procurement due to the simultaneous emergence of numerous projects, and complicated standard cost estimation procedures due to uncharacteristic damage to structures and terrain[2]

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[2] All factual information in this section of the paper is taken from electronic correspondence with VTrans officials, who actually participated in post-disaster procurement following Tropical Storm Irene.

In order to accommodate the unique conditions imposed by Irene, Vermont's existing disaster response protocols provided VTrans officials with a more flexible set of procurement guidelines. For example, formal permit, cost estimation, and plan development requirements were suspended by the state government for a period of 180 days following declaration of the natural disaster. Furthermore, VTrans officials were able to utilize a special cost-plus contracting formant, the Category III Maintenance Rental Agreement (MRA), in the event of the declared emergency.

A MRA consists of a list of prices for labor, equipment, and key component materials provided to VTrans by the contractor. These prices include any markups for profit, overhead, and general/administrative support.In the case of other MRA categories, the acquisition official is required to solicit and consider at least three bids and award the contract based on price, quality, and availability. However, in the case of Category-III MRAs, the competitive requirement is suspended, and the contract is typically awarded via direct solicitation. According to VTrans officials, government representatives typically anticipate the need for higher spending limits and contractors anticipate higher price requirements due to uncertain work conditions and a greater potential for equipment damage in post-disaster conditions. This often leads to the use of Category-III MRAs even when VTrans has an existing alternative MRA in place with the contractor. The following quote from an official with VTrans, summarizes the perceived benefit of using the cost-plus format:[3]

> In a disaster there is always the element of uncertainty as you don't always know what you are dealing with. Sometimes the ground or river is unstable and you lose some of the gains you made. Sometimes the hole becomes bigger once you open it up. That's why both the

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[3] This quote is from email correspondence dated 16 January 2013.

> state and the contractors like the MRAs. By the hour contracting allows for nasty surprises to be handled a bit easier.

Based on this comment, VTrans officials' ability to choose a more flexible but incomplete contract approach was instrumental in reacting to the uncertain procurement conditions following Tropical Storm Irene.

The parallels between defense acquisition and post-disaster infrastructure procurement are primarily rooted in uncommon levels of exogenously-driven uncertainty regarding the actual cost of the project. This uncertainty will inevitably affect participants' ability to accurately estimate construction costs, and the application of high-powered incentive contracts in this type of scenario can lead to classic manifestations of contractual hold-up. The application of the FAR contract menu in DoD acquisition and VTrans' choice between standard procurement procedures and the MRA format are examples of the use of incomplete contracting to address this uncertainty and prevent hold-up issues. My intent for the remainder of this paper is to model the contract design decisions of acquisition officials in these two unique procurement environments, eventually providing theoretical support for selecting a specific course of action based on the level of uncertainty surrounding the actual costs of procurement.

4.3 Literature Review

This paper is intended to extend the considerable body of economic analysis regarding the effects of uncertainty in both the general auction and public procurement environments. With this goal in mind, I now survey previous contributions to both the theoretical and empirical literature, supporting the relevance and applicability of the model presented in this paper.

4.3.1 Relevant Mechanism Design Literature

Goeree and Offerman (2003) present a model of strategic bidding behavior in which the participants receive separate signals for both the private and common value of the object for sale. Their model combines the two independent signals into a "surplus" signal, which is then used to derive the equilibrium bidding strategy and revenue results for comparison between standard auction formats. The authors experiment with the weighting of the common value in the surplus statistic, demonstrating that a policy causing the bidders to place less weight on their common value for the object results in higher expected revenues for the seller (p. 607). Although Goeree and Offerman conclude that their model firmly predicts the inevitability of inefficiencies in the auction process for an object with both private and common values, they temper this result by stating that the auction only approaches random allocation in the case that the common value signal completely "overrides" the private value signal (p. 611).

Bajari and Tadelis (2001) present a model of procurement contract selection in which the primary consideration is the *ex post* expected cost of renegotiation between the buyer and seller. Their model is based on the experiences of construction industry officials and characterizes the "procurement problem" as one of "*ex post adaptations* rather than *ex ante screening*" (p. 388). This is an important distinction, as the authors' solution to the procurement problem hinges upon the relative costs of renegotiation under the different contract types. The authors show that projects accompanied by complete descriptions of the work required and consisting of tasks relatively simple in nature will be procured using fixed-price contracts, whereas cost-plus contracts will typically be used in more complex projects (p. 404). Their model endogenizes the efficiency of renegotiation, as the contract type selected directly determines the efficiency of any subsequent negotiation. In the public procurement environment, possibilities for renegotiation during construction may be limited by existing regulation, as regulators attempt to prevent issues like cronyism and kickbacks within the procurement bureaucracy. If this aversion to renegotiation is systematic, the model proposed by Bajari and Tadelis may not fully conform to the procurement environment. Therefore, a model that addresses the contract type decision as an *ex ante* screening problem may be appropriate in some cases.

In a closely related paper, Tadelis (2012) summarizes the major theoretical factors at play in contract design, comparing existing practices in private and public procurement. Through the use of a simple theoretical framework, Tadelis demonstrates that project complexity, completeness of design, and contractor experience should be decisive considerations in the procuring agency's selection of both contract type and award mechanism. Specifically, more complex projects with incomplete designs are more suitable for cost-plus procurement, which should optimally be arranged through direct negotiation (p. 300). Alternatively, simple and moderately complex project should be assigned fixed-price contracts, and special attention should be paid to attracting well-qualified firms to compete in an open auction for the contract (p. 300). As in Bajari and Tadelis (2001), Tadelis's main conclusions are tied to the cost-plus contract's *ex post* flexibility in adapting to construction contingencies (p. 299).

Lewis and Bajari (2011) present a model of procurement in which the buyer attempts to force the contracting firm to internalize the costs associated with a negative externality caused by the project. Specifically, the authors model a mechanism in which the buyer uses a scoring auction to evaluate each participant's bid, consisting of both an estimate for the cost of the project and a required amount of time for construction (p. 1179). The buyer then uses an incentive/disincentive structure to incentivize completion of the project in an amount of time that optimizes the social welfare function (p. 1181). This mechanism accounts for the fact that the new project will have social value, yet its construction will be costly in terms of both payment to the contractor and negative externalities imposed on users. Lewis and Bajari demonstrate that this "A+B" contract design is particularly effective at reducing total costs of highway procurement projects in California in which the government accounts for costs of traffic delays to commuters.

4.3.2 Empirical Analysis of Uncertainty in Common Value Auctions

Athey and Levin (2001) examine the role of private information in the bidding outcomes for U.S. timber auctions conducted by U.S. Forestry Service. Participating firms bid a unit price for the timber, and officials tabulate each firm's resulting total bid by multiplying the unit prices by Forestry Service estimates of the available timber. However, payments by the winning firm to the Forestry Service are based on actual quantities of timber harvested. The authors portray timber estimation as an inexact science, as gaps between actual amounts and predicted amounts are quite typical. Athey and Levin find that bidders incorporate private estimates of timber amounts into their initial unit price bidding strategy. Specifically, firms are able to bid such that their expected payments to the Forestry Service are less than their bids by skewing bids towards timber species which the government has overestimated (p. 377). The authors conclude that rents to this private information are largely diminished via the competitive bidding mechanism, and, furthermore, the unit-price bidding format provides the winning bidder with "insurance" against uncertainty surrounding the actual total volume of harvestable timber on a given tract (p. 408).

Goeree and Offerman (2002) provide experimental results regarding the efficiency of auctions with both private and common value components. The authors find that increased uncertainty regarding the common value of the item results in a reduction in the efficiency of the auction, an increase in the winning bidder's profit, and decreased revenue to the seller (p. 641). Additionally, the results of the authors' experiment suggests that increased competition leads to more efficient results for two reasons. First, more bidders naturally lead to a higher statistical probability that the winning bidder possesses "better information," and, second, the increased competition causes individual bidders to place less weight on their privately-observed common value signal (p. 461).

De Silva, et al., (2008) use highway procurement data from Oklahoma and Texas to test theoretical results regarding the impact of information release on the outcome of auctions with both private and common cost components. Using a difference-in-difference approach, the authors find that the release of engineering cost estimates by the Oklahoma Department of Transportation leads to lower average bids and a differential effect of the policy in projects with a relatively larger common cost component (p. 175). Their results show that, on average, the policy results in a decline in bids for bridge projects and a much smaller effect in paving projects. Of these two types, the authors argue, with support from construction experts, that the actual costs of completing the bridge projects are more uncertain and depend on specific design and construction decisions (pp. 162-163). Therefore, uncertainty surrounding the common cost of construction exists prior to the auction, and the main effects of the release of the government's cost estimate occur via reduction of this uncertainty.

Raviv (2009) studies the effects of uncertainty in a common value setting, using auction sales data for used vehicles. The author's model estimates the variance in the underlying distribution of bidders' common value signals via demonstrated correlation between the variance of the distribution and the difference between the first bid and the winning bid (pp. 334-335). Raviv assumes that the variance of this distribution is correlated with uncertainty regarding the actual common value of the item for sale. His empirical results show that increased uncertainty leads to a higher number of overall bids, a reduced ratio of winning bid to pre-sale estimate, and, thus, a substantial effect on auction "progress and outcome" (p. 342).

Bajari, Houghton, and Tadelis (2010) attempt to estimate the procurement costs associated with incomplete contracting. The authors use data from unit-price auctions conducted by the California Department of Transportation for highway construction projects. Their model assumes that contractors are able to foresee changes and adaptations to the original plan and pass the transaction costs associated with these changes back to the procuring agency through strategic bidding (p. 3). Using structural estimation techniques, the authors find an average ratio of adaptation costs to winning bid of almost seven percent for the projects in their data sample (p. 40). This research demonstrates the importance of contract design in achieving cost-efficiency goals.

Kosmopoulou and Zhou (forthcoming) empirically examine the effect of price adjustment clauses for major input materials on bidder behavior in highway procurement auctions. The stated purpose of these clauses is to mitigate risk for construction firms that is directly tied to fluctuations in the price of essential construction materials (p. 1). The authors find that the resulting reduction in uncertainty regarding the common cost of construction has the expected effect on bidding behavior for Oklahoma highway construction projects. Firms in their data sample bid more aggressively and the dispersion of bids is reduced (p. 15). The results of this paper provide an empirical example of the effect of exogenous uncertainty on expectations of cost and the importance of mechanism design in generating more efficient procurement outcomes.

This paper contributes to the mechanism design and auction literature in the following ways. First, I consider the alternative situation from Bajari and Tadelis (2001): the "procurement problem" modeled in this paper is precisely one of *ex ante* screening, and decisions regarding the contract type are based on the magnitude of the expected costs, which are heavily influenced by the completeness of the project description. Therefore, the cost difference in fixed-price versus cost-plus contracts arises from the contractor's required compensation for a one-time estimate of the cost in comparison to a more fluid compensatory agreement. Second, I derive an optimal bidding strategy in the presence of exogenous concerns, which directly affect the variance of the distribution of bidders' common cost signals. Using this result, I analyze the question of overall contract design (mechanism and incentive structure) and consider other factors which may affect the contract type decision (competition, additional incentive structures, administrative costs, and contractor risk aversion). Third, the model seeks to capitalize on recent empirical accomplishments, which use itemized bids to study bidder behavior in procurement auctions. By modeling estimates and costs of contingencies as functions of the required inputs, this model lends itself to the empirical identification of underlying bidding strategy through the examination of idiosyncratic pricing in itemized bids. A recent report by the Transportation Research Board of the National Academy of Sciences synthesizes information regarding the current state of emergency procurement procedures from departments of transportation across the US (Gransberg and Loulakis, 2012). One of the primary findings of this report is that the actual economic impact of current emergency contracting practices remains unknown and untested (pp. 71-72). Therefore, the final contribution of the theoretical foundations presented in this paper is to facilitate empirical analysis of existing emergency procurement practices in hopes of suggesting a generalized, optimal approach to post-disaster procurement.

4.4 Theory

4.4.1 A Model of Procurement in Uncertain Conditions

Following Goeree and Offerman (2003), each contractor's bid for the price of a construction project consists of two, privately-observed components: 1) the contractor's independent private cost of performing the task (c_i), and 2) the common cost of construction for the project (v_i). The private costs of construction may depend on the firm's current capital structure, profit requirement, backlog, labor idiosyncrasies (i.e., unionized labor), and other internal considerations only pertinent to the individual firm. The common cost of the project might consist of labor, material costs, equipment rental, and costs of tasks standardized across firms (e.g., pouring a cement footing in accordance with a specified design). In this paper, I will augment the standard private and common value model with the possibility that exogenous uncertainty affects expectations of the common cost of the procurement project. As an initial step, I will provide baseline examples by modeling the composite cost signal for a cost-plus contract with a uniform common cost, the cost-plus signal for the realized common cost, and the fixed-price signal with estimated common cost.

In order to support empirical identification through the use of itemized bids, I assume that all common construction costs (v_i) for the project in question can be uniformly described as a linear function of daily rates for Labor/Equipment (L) and Materials (M), which I restrict to be the same for all contractors in performing a specific project. Furthermore, I assume that the private costs (c_i) of construction are only dependent on the number of days worked and are independent of the actual amounts of labor and materials used. This indicates that the contractor's markup required for profitability will vary only due to changes in the required number of construction days for a given project in the cost-plus environment. An equivalent statement is that the contractor would charge the same price per unit of labor and material, independent of the amounts required, plus a daily charge to cover overhead, administration, and profit. Incorporating these assumptions, I can express the daily rate for reimbursement (D_i) in the case of a cost-plus contract without uncertainty as:

$$D_i = \frac{c_i}{d} + (L + M),$$

where d represents the total number of construction days. Therefore, the privately-observed composite signal for the cost-plus contract without uncertainty (s_{nu}^{CP}) will be:

$$s_{nu}^{CP} = c_i + d(L + M).$$

Now, assume each project consists of $g \in [1, ..., K]$ possible tasks or dimensions along which the project can vary, where each incremental task requires an additional g_k units of labor and material. Given this assumption and the structure of the common cost component, the sum of these tasks will translate into the number of days required for construction of the project. Furthermore, I assume that the possible dimensions, $\sum_{k=1}^{K_{possible}} g_k$, associated with any given project are common knowledge for both government officials and potential contractors. Each contractor receives an independent draw from $K_{possible}$ independent distributions, $G_1(\cdot), ..., G_{K_{possible}}(\cdot)$, regarding the probability that each contingency, g_k, occurs during construction. Taken together, these assumption indicate that all involved parties would agree on the different dimensions of the project along which construction could *possibly* encounter difficulties, but each contractor will possess privately-observed expectations regarding the probability, p_{ki}, that event g_k occurs.

Cost-Plus Scenario

I will now combine the baseline cost-plus contract with this parameterization of project dimensions. The composite cost-plus signal of contractor i for any procurement project can be expressed as:

$$s_{i,u}^{CP} = v_i^{CP} + c_i, \tag{4.1}$$

where v_i^{CP} is the common cost signal for the project in the cost-plus scenario. Using the defined parameters and inputs of the model, this common cost can be expressed as:

$$v_i^{CP} = \left\{ \sum_{k=1}^{K_{realized}} g_k(L+M) \right\}. \tag{4.2}$$

In this scenario, the pay-as-you-go system of cost-plus contracting and the assumption of uniformity of daily input rates, $L + M$, implies that the sum of the actual number of realized construction events will translate into the actual number of days, d_A, required to complete the project under a cost-plus contract. Furthermore, I assume that this realization of the actual common cost corresponds to a particular set of draws, $\sum_{k=1}^{K_{possible}} p_{kA}$, from distributions $G_1(\cdot), ..., G_{K_{possible}}(\cdot)$:

$$\sum_{k=1}^{K_{realized}} g_k = d_A = \sum_{k=1}^{K_{possible}} p_{kA} g_k. \tag{4.3}$$

I have specifically chosen to model the realization of construction contingencies as an additive process, $\sum g_k$, due to the fact that the contractor may face multiple contingencies with various degrees of difficulty. For example, excavation difficulties may induce $g = 3$ additional days of labor and materials, while weather conditions may require $g = 4$ additional days. In this scenario, the contractor would need to account for $g = 7$ additional days of labor and materials rather than $g_{max} = 4$ days. Combining equations (4.1) through (4.3), I can express the composite *ex ante* cost signal for the cost-plus contract, which accounts for realized contingencies, as:

$$s_{i,u}^{CP} = \left\{ \sum_{k=1}^{K_{possible}} p_{kA} g_k (L + M) \right\} + c_i = d_A(L + M) + c_i. \tag{4.4}$$

Fixed-Price Scenario

Now I consider the composite cost signal for the same contractor, i, for the identical construction project in the fixed-price environment. Note that, in the fixed-price scenario, receipt of the cost signal and bid formulation will occur prior to construction. Therefore, I am required to consider the contractor's expectation of the common cost, derived using his K independent draws from distributions

$G_1(\cdot), ..., G_K(\cdot)$, rather than the realization of actual construction contingencies. We can express the composite signal in the fixed-price environment as:

$$s_{i,u}^{FP} = E(v_i)^{FP} + c_i, \tag{4.5}$$

where $E(\cdot)$ is the expectation operator, and $E(v_i)^{FP}$ is the contractor's *ex ante* expectation of the common construction cost for the project in question. In the fixed-price scenario, the contractor must consider all of the potential construction difficulties that could arise and build those costs into the contract price in order to protect against cost growth beyond his fixed-price estimate. Given this discussion, I now express the common cost signal for the fixed-price contract as:

$$E(v_i)^{FP} = \sum_{k=1}^{K_{possible}} p_{ki} g_k (L + M), \tag{4.6}$$

where the expectation of potential construction contingencies translates to the contractor's estimated number of days to completion, $d_{T,C}$:

$$\sum_{k=1}^{K_{possible}} p_{ki} g_k = d_{T,Ci} \tag{4.7}$$

Combining equations (4.5) through (4.7), I arrive at contractor i's *ex ante* fixed-price composite signal:

$$s_{i,u}^{FP} = \sum_{k=1}^{K_{possible}} p_{ki} g_k (L + M) + c_i = d_{T,Ci}(L + M) + c_i. \tag{4.8}$$

Fixed-Price Premium

For purposes of comparison with previous literature, it may be informative to demonstrate a theoretical fixed-price premium in the context of this model. Suppose now, quite plausibly, that the procuring agency possesses a cost estimate for an identical project in which there is no exogenous uncertainty affecting the common cost of construction. In reality, for example, this estimate could be the prior cost of constructing a bridge, which is then destroyed during a natural disaster. For purposes of comparison, assume that this estimate takes the form of a known number of construction days, d_{nu}, and the common daily rates for inputs:

$$ECE_{nu} = d_{nu}(L + M).$$

If we consider the difference between this known cost and the contractor's estimated common cost, we have:

$$P_i = (d_{T,C} - d_{nu})(L + M),$$

where P_i accounts for the potential cost of contingencies, which contractor i will demand as insurance against cost growth due to construction uncertainties for the project in question. Therefore, I can express the total fixed-price cost signal for a construction project as a combination of three components: the government's baseline estimate in absence of uncertainty, an "insurance" premium associated with the fixed-price signal, and the contractor's requisite markup:

$$s_{i,u}^{FP} = d_{nu}(L + M) + P_i + c_i. \tag{4.9}$$

Comparison of Cost Signals

Without considering the competitive effects of auction mechanisms typically used in conjunction with fixed-price contracts, I can now compare the composite cost signals from the cost-plus and fixed-price scenarios. This type of comparison would be useful in the case that procurement for a project occurred through direct solicitation. Comparing equations (4.4) and (4.8), one can easily determine that the sole difference between the two competing cost signals is the mathematical difference between the actual number of days required for construction and the contractor's *ex ante* estimate of the number of required days.[4] Therefore, in the case where the government uses direct solicitation rather than a competitive award mechanism, the model suggests that the relevant consideration is the government's expectation of the magnitude of the difference between the contractor's anticipated common cost of construction and the actual cost of construction: $(d_{T,C} - d_A)$. Larger expected values of this statistic indicate greater possible cost-savings through the use of the cost-plus format, while smaller or negative values may justify the use of standard fixed-price procedures.

Although this result certainly hinges upon the underlying assumptions of the model, it captures a key consideration that influences real world procurement officials. The value of the cost-plus contract is primarily due to its flexibility in accommodating contingencies. Whereas a fixed-price contract requires *ex ante* compensation for potential adverse outcomes, which may or may not occur, the cost-plus contracting environment allows the government to pay for contingencies as they appear. On the other hand, the low-powered incentive structure of the

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[4] Note that, in the case of direct solicitation, the private cost required in the two scenarios would also likely differ if the government intended to make the contractor indifferent between the two types of contracts. However, if the objective is to induce cost savings by choosing the most efficient contract type, causing the contractor to be indifferent between the two types is likely not the government's goal.

cost-plus contract provides little motivation for cost saving behavior on the part of the contractor. In practice, this comparison is also likely complicated by information asymmetry on the part of the construction firm. The firm possesses greater knowledge of the construction process, particularly after the project has commenced. The cost-plus contract may, consequently, allow the contractor to submit false or misleading claims for additional compensation as part of routine administrative procedures. As a result of these concerns, it may be prudent to also consider the relative magnitude of the cost-reducing effects of competitive award mechanisms typically used with fixed-price contracts in standard procurement procedures.

4.4.2 Effects of a Competitive Award Mechanism

The total gain to society for the procurement of an infrastructure project is represented by Π_G:

$$\Pi_G = V - c_f(c_i, v_i, g_k) - C_s, \tag{4.10}$$

where V represents the social value of the project, c_f represents the payment to the firm, and C_s is the social cost of the project. The primary consideration in this paper is the difference in the magnitude of $c_f(\cdot)$ produced under standard procurement procedures versus cost-plus contracting in the presence of uncertainty regarding the common cost of the project. To examine the possibility that competition in standard procurement produces cost-saving effects that may tip the balance in favor of the fixed-price approach, I now introduce a competitive award mechanism into the model.

Assume a first price, sealed-bid auction for a project successfully attracts $n \geq 2$ risk neutral bidders. Furthermore, assume that these firms receive independent draws for the private cost component (c_i) of the project from distribution $H(\cdot)$. In the standard procurement scenario, this private cost component does not include the contractor's mark-up, which is determined via a competitive award mechanism. The private cost distribution is assumed to be independent of the distributions, $G_k(\cdot)\forall k = [1, .., K]$, from which each bidding firm receives K independent draws regarding the probability of K possible construction contingencies. Additionally, I assume that all associated density functions for these distributions are twice continuously differentiable and log-concave on the supported range.[5] The log-concavity assumption is essential in addressing issues of multidimensionality. See Goeree and Offerman (2003), De Silva, et al., (2009), and Caplin and Nabluff (1991) for additional applications of this assumption.[6] Given these signals and pertinent parameters, the firm is able to construct a composite cost signal for the project, s_i:

$$s_i = s_{i,u}^{FP} = \sum_{k=1}^{K_{possible}} p_{ki} g_k(L+M) + c_i. \tag{4.11}$$

The independence of the distributions for the private and common cost signals allow this additive construction, creating an independent joint distribution for the total cost signals, $F(\cdot)$.

Define $B(\cdot)$ as a bidding function, which is strictly increasing in the

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[5] The log-concavity assumption holds for many commonly used empirical distributions. For example, the Uniform, Normal, Exponential, Logistic, Extreme Value, Weibull, Gamma, and Chi-squared distributions all possess log-concave density functions. See Bagnoli and Bergstrom (2005) for a thorough summary of this property and its applications.

[6] This assumption ensures the existence of equilibrium in the presence of the multidimensional signal. Additionally, it ensures that the expected values of both the private cost and common cost signals are non-decreasing in the value of the composite signal. This ensures that the award mechanism will not select an inefficient bidder who has grossly understated his expectation of the common cost. In other words, the lowest bid should be indicative, on average, of a firm that has both a low estimate for the common cost and a relatively efficient private cost signal.

construction firm's total cost signal. For example, a firm with total cost signal s_i would have a corresponding bid of $B(s_i) = b_i$.[7] Given that I have assumed the government will award the project to the contractor with the lowest of n total bids, we can express the expected profit for a contractor with total cost signal s_i as:

$$E(\Pi(b_i)) = [b_i - s_i][1 - F(B^{-1}(b_i))]^{n-1}. \tag{4.12}$$

Setting $b_i = B(x)$ and differentiating equation (4.12) with respect to b_i, we have the following first order condition:

$$\frac{\partial E[\Pi(b_i)]}{\partial b_i} = [1 - F(x)]^{n-1} - \frac{n-1}{B'(x)} \frac{f(x)}{[1 - F(x)]^{-n+2}} [B(x) - s_i] = 0.$$

Simplifying this equation and solving for $B(x)$, we have the optimal choice of bid for contractor i on project j:

$$B(x)^* = b_i^* = s_i + \frac{B'(x)}{n-1} \frac{1 - F(x)}{f(x)}$$

$$\Rightarrow b_i^{*FP} = \sum_{k=1}^{K_{possible}} p_{ki} g_k (L + M) + c_i + \frac{B'(s_i)}{n-1} \frac{1 - F(s_i)}{f(s_i)}, \tag{4.13}$$

indicating that the contractor's bid will shade his estimate of the total cost to account for the winner's curse in the presence of competition. It is important to note the unique nature of this bidding strategy in a common value auction. As in the standard auction result, the bidder will shade his bid less as more competitors enter the auction. However, there is no offsetting effect of increased competition on uncertainty regarding the common cost component. Each contractor has a privately observed estimate of the common cost, based on his own independent

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[7] Note that this implies $B^{-1}(b_i) = s_i$.

draws from the $G_k(\cdot)$ distributions concerning each event, g_k. This structure and the sealed-bid format of the auction do not allow for revision of the contractor's common cost based on observed competition. Therefore, this bidding strategy suggests that increased competition will only result in decreasing bid amounts. Using this optimal bidding strategy in conjunction with equation (4.12), I can solve for the contractor's expected profit from using his optimal bidding strategy in competition for the project:

$$E(\Pi(b_i^*)) = [b_i^* - s_i][1 - F(s_i)]^{n-1} = \left[\frac{B'(s_i)}{n-1}\frac{1 - F(s_i)}{f(s_i)}\right][1 - F(s_i)]^{n-1}.$$

At this point, I again introduce the cost-plus signal from the previous section. However, I will now model contractor i's daily profit rate, π_i, separately from the contractor's private cost signal, c_i. This indicates the separate specification or negotiation of the contractor's markup (the "plus" portion of cost-plus), which is standard practice in many uses of the cost-plus format. Accounting for this adjustment, I can express the total cost of hiring contractor i to conduct the project under a cost-plus contracting format as:

$$b_i^{CP} = \left\{ \sum_{k=1}^{K_{possible}} p_{kA} g_k (L + M) \right\} + c_i + \pi_i. \tag{4.14}$$

Comparing equations (4.13) and (4.14), one can ascertain the key differences between the two contracting approaches. As mentioned in the previous section, the cost-plus contract is attractive due to its flexibility in accommodating only *realized* construction contingencies, whereas the fixed-price contract requires the government to reimburse the contractor based on *ex ante* expectations of *potential* contingencies, which could be inaccurate. Relying on the alternative signals in equations (4.4) and (4.8), the contractor in the fixed price scenario stands to gain (lose) $[d_{T,C} - d_A]\,(L+M)$ in the event that his bid overestimates (underestimates) the common cost of construction. However, the fixed-price approach ensures that the contractor's markup is subject to competitive pressures, which are not present to affect profit in the cost-plus scenario.

There are at least two compelling reasons why awarding a cost-plus contract using an auction may be suboptimal. First, the selection of a cost-plus contract is an admission by the procurer that the costs are unknown or incomplete at the award date, complicating bid evaluation. Second, according to Tadelis (2012), more cost effective and competent contractors will likely charge a higher profit rate. Since this is the critical dimension along which firms differ in the cost-plus environment, the competitive selection of a bidder with the lowest cost-plus signal leads to adverse selection, as the lowest bidder will likely be less desirable (p. 299). While competition may not be beneficial in cost-plus contracting, the introduction of the auction mechanism in the case of the fixed-price approach provides another key dimension along which the government may evaluate the alternative contract types: contractor markup.

Consider the contractor's economic profit under each contract type:

$$b_i^{CP} - s_i^{CP} = \pi_i^{CP},$$

$$b_i^{*FP} - s_i^{FP} = \frac{B'(s_i)}{n-1}\frac{1-F(s_i)}{f(s_i)} = \pi_i^{FP}. \tag{4.15}$$

Notice that the profit term in the cost-plus contract is set at a daily rate or percentage of the daily cost.[8] However, the total profit for the same contractor in

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[8] While this assumption may seem questionable, given the likely aversion to providing guaranteed economic profit for contractors, this inclusion of a profit "rate" is a common feature of cost reimbursement contracts in defense contracting and is considered essential

the fixed-price scenario now depends directly on the number of active competitors in the auction. Specifically, as $n \to \infty$, the middle expression in equation (4.15) approaches zero. While this effect should never drive the profits for the contractor into negative territory within the model, the discerning government must consider whether the profit-reducing effects of competition in the fixed-price scenario outweigh the potential benefits of the cost-plus contract's flexible payment structure.

4.4.3 Exogenous Uncertainty and A Decision Rule

In this section, I will introduce the key difference between this model and previous models of contract design in the literature: exogenous uncertainty regarding the common value of the procurement project. Suppose the government forms its expectations for the actual value of the contract based on the following relationship:

$$E(d_A) = \tilde{d_A} = \frac{1}{n}\sum_{i=1}^{N} E(d_{T,C_i}). \tag{4.16}$$

Consider the entire distribution of common cost signals, $V(\cdot)$, with variance σ^2. The exogenous uncertainty surrounding the project manifests itself in terms of the expected variance of this distribution. Specifically, I assume that the government's expectation of the variance is an increasing function of the exogenously-determined number of dimensions, $K_{possible}$, along which the project can possibly vary:

$$E[\sigma^2] = \Phi(K_{possible}),$$

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to continued innovation in the face of uncertainty. See Rogerson (1994) for more on the importance of profitability in the defense industrial base.

where

$$\frac{\partial \Phi}{\partial K_{possible}} > 0.$$

Therefore, as the number of dimensions, $K_{possible}$, increases, the variance of the distribution $V(\cdot)$ increases, and each expected individual estimate bears a greater amount of risk.[9] In other words, the probability that any one draw from the common value distribution will be the actual common value is a decreasing function of this variance. Combining these assumptions with the profit comparison in section 4.4.2, the procurement official chooses the cost-plus contract instead of the fixed-price contract in the case that:

$$E[\tilde{d_A} - d_A] > E[\pi_i^{CP} - \pi_i^{FP}] \tag{4.17}$$

The inequality in equation (4.17) is more likely to hold in the event that the expected variance of $V(\cdot)$ is high, which corresponds to higher values of $K_{possible}$. However, in the case that $K_{possible}$ is small and, therefore, $Prob(\tilde{d_A} = d_A)$ is high, the government is perhaps better off to implement the standard procurement procedure. To see this, consider the fact that the winning bidder from the auction process is assured by the assumptions of the model to have at most the lowest common cost signal of the participating contractors. However, the government forms its expectations of the actual cost using the expected mean of this distribution. By definition, with at least two bidders, the auction will select a bidder with a common cost component that is less than or equal to the

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[9] Based on the Transportation Research Board's 2012 report (Gransberg and Loulakis, 2012), one of the major factors in emergency procurement success stories was rapid response time by agency officials. Therefore, one could also consider the possibility that the natural disaster does not directly add increased dimensions to the project relative to a non-emergency scenario but, instead, restricts the time available for officials to "trim" the possible dimensions to achieved a more reasonable assessment.

average of all participating common cost signals. Therefore, the expectation for the common cost of the lowest bidder will be less than the expected average common cost of all bidders. This result and the competitive pressures on the contractor's markup from the bidding process suggest that the expected results from the fixed-price contract design should be most efficient in the case of limited or zero uncertainty.

At this point, it is critical to mention the importance of commitment power to the results of this model. In the case of the standard procurement procedure, the above comparison of the two contract types only holds true if the government is able to commit to the result of the fixed-price procedure. If this is not the case, one can easily make a case for an adverse selection problem via the competitive mechanism. Due to the fact that the government awards the contract to the lowest bidder, the contractor with the lowest expected value of the common cost of construction will win the auction. If the procuring agency allows for the possibility of renegotiation of the contract at a later date, each contractor can understate his estimate of the common cost of construction and earns profit when contingencies are added as they occur. Alternatively, the ability to accurately estimate construction costs is likely related to the firm's experience in the industry. Therefore, one might expect inexperienced firms dealing with a large amount of uncertainty to inadvertently understate associated construction costs, actually increasing their chances of winning and receiving profits due to the realization of unspecified contingencies. Neither of these results is ideal for the procuring agency. If commitment power holds, the agency can expect offsetting effects of this strategic behavior on the part of contractors. Overstating the costs of construction contingencies may increase profit, but it also decreases the chances of winning the project, while understating the expectation of common cost risks decreased profit in exchange for increased chances of winning.

4.5 Modular Incentive Structures

Following Lewis and Bajari (2011), I now consider additional incentive structures, which provide the government with the ability to motivate contractors to internalize or reduce a portion of the total cost of the project. While these mechanisms are often used by transportation officials to account for the effect of a project on traffic patterns and delays for commuters, the US Department of Defense applies these mechanisms for a somewhat different purpose. According to the US Federal Acquisition Regulation, additional incentive mechanisms can serve to slow unwarranted cost growth in flexible procurement environments by "(i) motivat[ing] contractor efforts that might not otherwise be emphasized; and (ii) discourag[ing] contractor inefficiency and waste (FAR, 16.401)." Therefore, in addition to the internalization of social costs, I also consider the possibility that these incentive structures can be tailored to offset some of the effects of uncertainty modeled in this paper.

4.5.1 Use of Contract Incentives to Offset Social Costs

If one recalls equation (4.10), the primary purpose of the incentive/disincentive design introduced by Lewis and Bajari (2011) is to motivate the contractor to internalize a portion of the social cost of the project, C_s. In calculating bonus and penalty rates which are functions of the cost of delays to consumers, the government is essentially able to motivate the contractor to complete the project in a socially optimal amount of time.

Cost-Plus Contract with Social Incentives

Suppose that the government's estimate of the project with uncertainty surrounding the common cost takes the following form:

$$ECE_u = d_E(L + M).$$

The government can then set its estimated number of construction days as the socially optimal timeline for construction. This in turn implies that the optimal value of the social cost of the project, C_s, is $d_E c_s$, where c_s is the daily social cost of construction (e.g., the daily cost of traffic delays to commuting wage earners). In order to deter the contractor from exceeding this target, the procuring agency can then establish incentive and disincentive rates, which cause the contractor to internalize the cost of commuters in the case of delays. Due to the fact that the contractor in the cost-plus environment does not provide an estimate of the time required for construction and instead receives only a daily rate, the price of the cost-plus contract with social incentives takes the following form:

$$CP_u = d_A(L+M)+c_i+\pi_i^{CP}(d_A)+1\{d_A < d_E\}(d_E-d_A)c_I-1\{d_A > d_E\}(d_A-d_E)c_D, \tag{4.18}$$

where c_I and c_D are incentive and disincentive rates, respectively. Bajari and Lewis (2011) demonstrate that the sufficient condition to achieve *ex post* efficiency in this scenario is to set the payment structure such that $c_I \leq c_s \leq c_D$(p. 1183). By defining this incentive structure, the government is able to ensure that, in the event the contractor exceeds the engineer's estimate for the socially optimal number of construction days, he does so only by subtracting the additional social costs of construction directly from his overall payment.

Fixed-Price Contract with Social Incentives

In the fixed-price scenario, the contractor submits his bid for the project in question via a competitive award process. In this paper, the common cost component of this bid takes the form of an estimated number of construction days, multiplied by uniform daily rates for required labor and materials. As a result, the model does not explicitly provide a standard A+B bidding result but an $A = B(L + M)$ result. However, the assumptions of the model (primarily log-concavity) imply that the winner of the standard fixed-price contract should have an estimate of the required construction time that is at most equal to the lowest of all other bidders. Realizing that this is the case, the government sets the optimal value of social cost equal to the winning contractor's estimated number of construction days multiplied by the daily social cost: $C_s = d_{T,C}c_s$. Incorporating this modification, the final cost of the fixed-price contract with social incentives is:

$$FP_u^{SP} = d_{T,C}(L+M)+c_i+\pi_i^{FP}+1\{d_{T,C} < d_A\}(d_A-d_{T,C})c_I-1\{d_{T,C} > d_A\}(d_{T,C}-d_A)c_D, \tag{4.19}$$

Note that the incentive payments in the fixed-price incentive contract are based on the contractor's estimated time for completion relative to the actual number of days until completion. The government is able to force the contractor to internalize the social cost of any delays beyond his estimated timeline by again setting $c_I \leq c_s \leq c_D$.

4.5.2 Use of Incentives to Moderate Contract Cost Growth

In this section, I examine the ability of the government to implement a bonus/penalty structure to limit expenses in an uncertain procurement environment. In contrast to the previous section, the goal is now to limit or reduce $c_f(\cdot)$ in equation (4.10) instead of C_s. As previously mentioned, these types of incentive structures are routinely incorporated into contracts for major weapons systems in an attempt to slow or moderate potentially explosive cost growth.[10] In these contracts, it is common for the DoD to directly tie contract incentives to a target or ceiling price. For example, an incentive payment in a Cost-Plus-Incentive-Fee (CPIF) contract is determined using a formula that relates actual cost to a target cost (FAR, 16.405-1). The use of these types of contracts follows directly from the presence of uncertainty regarding the cost of the project and the government's assessment that accurate estimation of project costs may be incredibly difficult.

In order to support implementation of cost-limiting incentives, the government can establish an upper bound for the contract price. This allows the government to identify situations in which additional contractual incentives may actually motivate the contractor to reduce the overall cost of the contract. Consider the following scenario. The government wishes to procure a more advanced version of an existing aircraft, complete with new avionics and targeting mechanisms. While some production aspects of this aircraft will be clearly defined based on the procurement of the existing version, the development process and incorporation

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[10] The incentives I include here embody the idea behind the FAR incentive contracts but do not explicity follow a formula from the FAR. An explicit formula is actually not listed in the FAR, and the details of these formulae are negotiated between the DoD and contractors.

of the new components may be quite complex and difficult to describe. In this scenario, the government can acknowledge the possibility of error in its estimate and limit its cost exposure by setting a price ceiling as a percentage increase over its estimate for the new aircraft. One can imagine a similar scenario in highway or road procurement. Suppose a bridge is destroyed by flooding in a natural disaster, and the actual extent of the damage to the surrounding terrain and bridge footings is unknown. In this scenario, the government could again establish a price ceiling, using a percentage increase over its own estimate. In order to provide concrete guidance for acquisition officials, it is important that the guidelines for establishing price limits for decision-making purposes are codified in regulation or policy.

The goal for the remainder of this section is to demonstrate how the inclusion of contract incentives may assist in limiting the government's total cost in the procurement of complex or uncertain projects. In order to focus my analysis, I will momentarily assume that the government is only interested in using the incentives to reduce procurement costs due to uncertainty and ignores social costs: $C_s = 0$ in equation (4.10).[11]

For purposes of clarity, I will now consider only the relevant range of contract cost outcomes over which the government would be willing to incentivize faster completion by the contractor. The government would likely not want to provide additional compensation to the contractor in the case that the actual number of construction days fell below the government's estimate. However, in the case that the actual timeline exceeds the government's estimate, it may be possible

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[11] In defense contracting, this is not an outlandish assumption. Consider, for example, the acquisition program for the F-35, whose procurement timeline already exceeds fifteen years. The obvious conclusion from this sort of lengthy timeline is that, in certain projects, the need of the user may not be immediate and production may be relatively non-intrusive for society.

for additional contract incentives to "put the brakes" on additional cost growth. In light of this discussion, I now amend the definition of the actual number of construction days to reflect the following relationship:

$$d_A = d_E + d_u, \tag{4.20}$$

where d_E represents the government's estimate of the number of days of construction, and d_u is the number of additional construction days due to unforeseen contingencies.[12] The purpose of this additional definition is to incorporate the intuition that the government is procuring an item or task whose exact common cost is *ex ante* uncertain and may exceed the government's estimate.[13]

Cost-Plus Contract with Moderation Incentives

First, I consider the price of a cost-plus contract, augmented with an incentive payment function. I can express the total price of the cost-plus contract as:

$$CP_u = d_A(L + M) + c_i + \pi_i^{CP}(d_A) + 1\{d_A \leq d_C\}(d_C - d_A)c_I, \tag{4.21}$$

where $c_I > 0$ and is a daily incentive rate for completing the project by a target date, d_C.[14] This target date is associated with the government's price ceiling for

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[12] This definition is primarily intended to define the value of d_u and does not conflict with the assumptions regarding d_A from previous sections.

[13] This framework implies that the uncertainty surrounding the project may leave the government and contractors with large amounts of error in their estimates in comparison with the eventual cost of the project. One can think of the upper bound as a theoretical confidence interval above the government's estimate. Given the method by which uncertainty is built into the theoretical model, this consideration of potentially positive estimation error seems to be a natural extension of the underlying theoretical issues with contract formalization.

[14] Note that this expression implicitly assumes that wasted time and resources naturally occur in the construction process, and the incentive structure works through the elimination of this

the project. For the purposes of this paper, I will assume that the government determines its ceiling price using a uniform percentage increase above its own engineering cost estimate, d_E. Specifically, I assume that the government chooses a percentage α, leading to:

$$d_C = d_E + \alpha d_E.$$

This continuum of possible cost outcomes is depicted in Figure 4.1, along with a hypothetical realization of the actual number of construction days, d_A. Due to the government's imposition of a price ceiling, I assume that the government will offer no compensation beyond the ceiling date. In the cost-plus scenario, the contracting firm only receives an incentive payment if it completes the project in less time than the procurer's ceiling date, as in Figure 4.1. Therefore, the incentive structure in equation (4.21) implies that the government may be able to use contract savings relative to the ceiling price in order to limit the overall payment to the contractor.

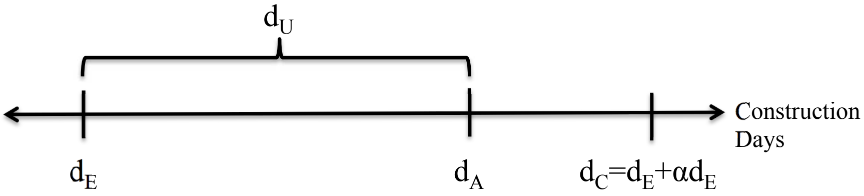

Figure 4.1: Cost Plus Incentive Scenario

Based on the details of this scenario, the government's optimal "rule" for setting the incentive rate, c_I, should satisfy:

$$(d_C - d_A)(L + M) \geq d_u(L + M) + (d_C - d_A)c_I. \tag{4.22}$$

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waste. If this were not the case, the goverment might incur additional costs as the contractor increased amounts of labor and material to speed completion of the project.

Equation (4.22) indicates that the government should set its incentive rate so that the savings on labor and material costs due to the reduction in the overall number of construction days meets or exceeds the combined cost of the unforeseen construction contingencies and the incentive payment. In order for this condition to be possible, the daily rates for labor and materials, $(L + M)$, must be greater than or equal to the daily incentive rate, c_I, which should be a relatively palatable condition for the government to satisfy.[15] If one considers the incentive contract from the firm's perspective, the contractor will choose to accept the incentive payment in the case that:

$$(d_C - d_A - d_u)(L + M) \geq (d_C - d_A)(\pi_i^{CP}/d). \tag{4.23}$$

In order for this expression to hold, the daily rates for labor and materials must meet or exceed the contractor's daily markup. Again, this is certainly a feasible scenario, as this condition would only be violated if the contractor's markups on labor and materials were greater than one hundred percent.

In the case that equation (4.22) holds with equality, we can solve for the break-even incentive rate:

$$c_I = \frac{(d_C - d_A - d_u)}{(d_C - d_A)}(L + M). \tag{4.24}$$

Substituting this expression back into equation (4.21) and simplifying, I can

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[15] To demonstrate this condition, note that equation (4.22) can be simplified to the following expression:

$$(d_C - d_A - d_u)(L + M) \geq (d_C - d_A)c_I.$$

Given that all of the measures of construction days are positive, the only way that equation (4.22) can hold is if $(L + M) > C_I$.

express the final break-even cost for the cost-plus contract as:

$$CP_u = (d_C - d_u)(L + M) + c_i + \pi_i^{CP}(d_A). \tag{4.25}$$

Given this result, the government can make a decision regarding the usefulness of the incentive structure in the contract through comparison with the initial cost-plus result. Notice that implementation of this incentive structure means that the government strictly pays less than the actual value for the cost-plus contract when:

$$(d_E + d_u) = d_A > (d_C - d_u) > d_E.$$

This corresponds to the situation when:

$$d_A > d_E + \frac{\alpha}{2} d_E > d_E.$$

Conversely, the government strictly pays more under the incentive contract when

$$d_E < d_A < d_E + \frac{\alpha}{2} d_E,$$

and the two contracts are equivalent at

$$d_A = d_E + \frac{\alpha}{2} d_E.$$

Note that in the event the contractor reaches the ceiling date the cost-plus payment becomes:

$$CP_{Ceiling} = (d_C - \alpha d_E)(L + M) + c_i + \pi_i^{FP},$$

which reverts the contract back to the government's estimate. The effect of this payment structure is pictured in Figure 4.2. Taken together, this analysis demonstrates that the contractor, once incentive payments are enacted, should do everything in his power to complete the project prior to the halfway point between the government's estimate and the target date associated with the price ceiling.

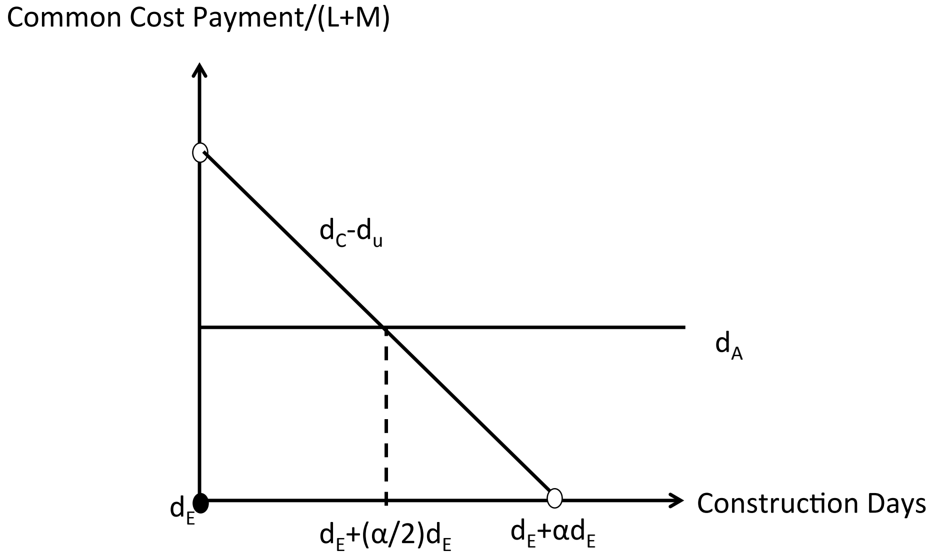

Figure 4.2: Effect of Cost-Plus Incentive Structure

From these results, I can list at least two conclusions regarding the cost-plus incentive contract: 1) the government must retain its own estimate as private information to prevent manipulation if the estimate is to be used as the trigger for incentive payments, and 2) it is in the contractor's best interests to complete the project as soon as possible after the incentive payments begin. Additionally, one can see that the policies governing calculation of the price limits and the actual momentum of cost growth in the cost-plus environment will largely determine the efficiency of the incentive payment program. The flexible compensation structure of the cost-plus contract supports this as a possible course of action, and I have modeled the incentive decision in terms of actual values rather than expectations to reflect the unique ability to collect information in the cost-plus environment. It is also important to realize that this incentive structure prevents the government's cost liability for the common cost of the project from exceeding the estimated price ceiling (the common cost never exceeds $(d_C - 1)(L + M)$) but does not eliminate costs beyond the government's estimate.

Fixed-Price Contract with Moderation Incentives

In the fixed price scenario, the procuring agency acquires additional information regarding the common cost of construction via the competitive bidding process. As in previous sections of the paper, the government's expectation of the actual number of construction days, $E(d_A)$, is the sample average of the submitted bids for common cost, defined in equation (4.16). As a result of the competitive award process, the government expects that the estimate of the winning contractor is less than or equal to $E(d_A)$. Therefore, the government's *ex ante* expectations do not indicate that the situation described for the cost-plus contract should occur under the fixed-price contract. In other words, the contractor should exceed its own fixed-price bid and, thus, the government's estimate at its own risk. However, it may be possible, after receiving bids and awarding the contract to the lowest bidder, that the government observes a sizable difference between the average bid and the winning bid, as depicted in Figure 4.3. In this scenario, the government may suspect the potential for unforeseen cost growth beyond the contractor's initial estimate. In this case, the government could implement the following type of incentive contract, which pays the contractor for days worked beyond its estimate but penalizes the contractor for exceeding the government's expectation of the actual number of days of construction:

$$FP_u = d_A(L+M) + c_i + \pi_i^{FP} - 1\left\{d_A > E(d_A)\right\}(d_A - E(d_A))c_D \tag{4.26}$$

As this essentially sets a price ceiling for the contract, the disincentive rate equals the contractor's daily cost of continuing the project: $c_D = (L+M) + \frac{c_i}{d_A - E(d_A)}$. By implementing this type of incentive, the government retains use of the competitive pressure on the contractor's markup but also allows for flexibility in allowing a defined amount of cost growth. Additionally, this incentive structure still caps the cost of the contract from the government's standpoint, although at a point higher than the contractor's initial estimate.

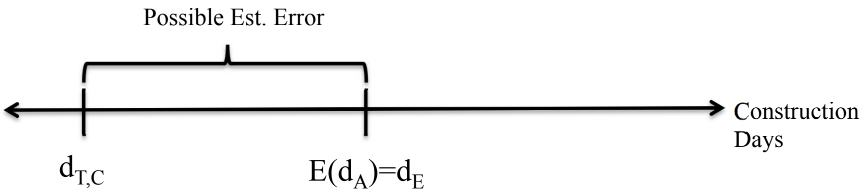

Figure 4.3: Fixed-Price Incentive Scenario

The results of this section are intended to address a different issue and, therefore, do not conflict with the findings of Lewis and Bajari (2011). Due to the demonstrated success of these types of incentive contracts in reducing overall government expenditure in highway contracts(see Lewis and Bajari, 2011) and their presence in the Federal Acquisition Regulation's menu of contracts, it seems that strong consideration should also be given to implementing incentive payments aimed at limiting the cost of particularly complex or uncertain highway projects. A decision tree which summarizes the paper's preceding results up to this point is presented in Figure 4.4.[16]

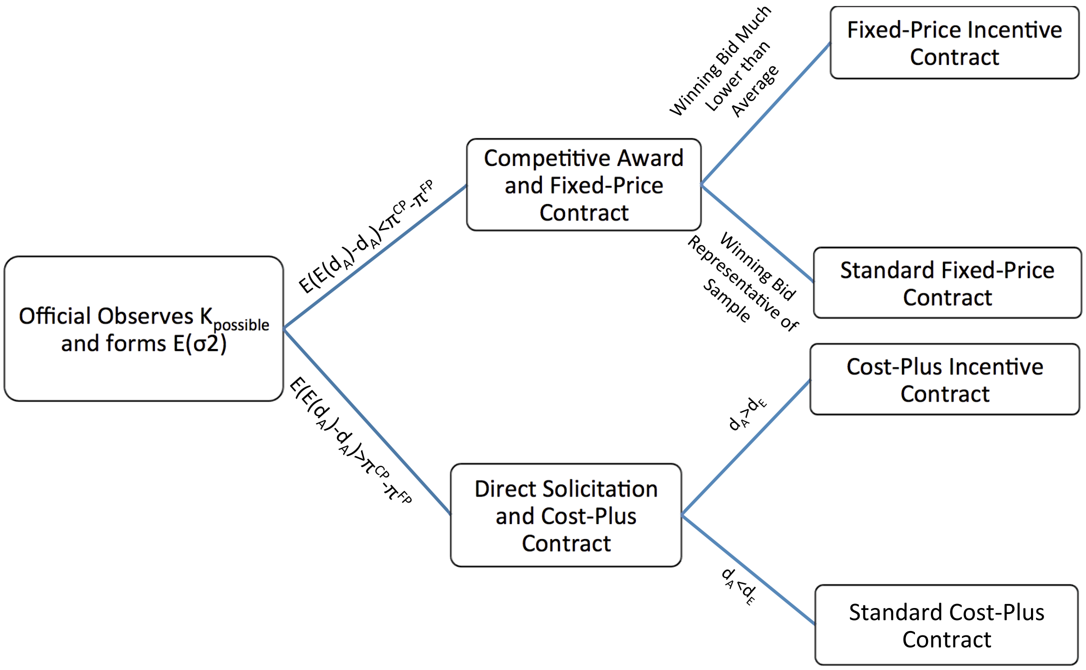

Figure 4.4: Summary Decision Chart

4.6 Additional Considerations

4.6.1 Costs of Contract Administration

The model of contract design presented in the preceding sections of this paper suggests that the selection of one contract type over another should be based only on the relative size of the payment to the contractor. However, as previously mentioned, the contractor enjoys many more opportunities to revise his cost

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[16] Note that in the case of either contract type, the additional incentive to hurry construction ahead of the target completion date may adversely effect the quality of the finished project. Based on discussions with VTrans officials, this seems to be a legitimate concern regarding post-Irene construction projects. Specifically, required time limits for "compaction" of paved surfaces may have been ignored in order to complete the projects as soon as possible, perhaps leading to decreased durability.

estimates in the cost-plus environment and perhaps has a greater opportunity to extract contractual surplus from the government. Due to the fact that the cost-plus contract is essentially paid on a daily basis until completion of the project, the contractor has limited incentives to control cost growth. In practice, the potential for this behavior from the contractor often leads the procuring entity to employ cost monitoring systems and personnel in addition to layers of incentives (e.g., the incentive/disincentive structure), which are intended to limit cost growth.

One can find examples of these cost oversight measures in DoD procurement and offshore petroleum drilling contracts. The US Department of Defense often utilizes some of the more flexible cost reimbursement contracts from the FAR in the procurement of major weapons systems.[17] One of the primary considerations for DoD acquisition officials in choosing a cost reimbursement contract is the ability of the government to fund implementation of its project management technique, known as Earned Value Management, for the project in question. The FAR states that, as part of required documentation, each contract must include a discussion of any additional "burden of managing the contractor's costs" in the selected contract type, including an assessment of "the adequacy of Government resources" required to mitigate expected cost risk (FAR, 16.103). In DoD procurement of major weapons systems, this additional "burden" includes ensuring the contractor's adherence to standard ANSI/EIA-748, Earned Value Management Systems.[18] In the DoD's largest projects, this often involves the assignment of a project manager or management team, consisting of a group of military officials whose sole responsibility is to administer the associated

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[17] See Crocker and Reynolds (1993) for more on the DoD's use of the FAR menu of contracts.

[18] ANSI/EIA=American National Standards Institute/Electronic Industries Alliance, DoD Earned Value Management Guide

contracts.

In Corts and Singh (2004), the authors empirically analyze the choice of fixed-price versus cost-plus contracts in offshore petroleum drilling. In this industrial setting, petroleum exploration and production companies utilize a cost-plus structure in the form of “day-rate” contracts, where the drilling contractor provides a fully-staffed drilling rig in exchange for a daily payment (p. 234). To monitor the operation’s progress and protect company interests in a day-rate contract, a representative from the petroleum company is located on the drilling rig and has direct input in decisions regarding the technical aspects of the operation (p. 234). The presence of this representative allows the petroleum company to directly observe “the timeliness of well completion, the occurrence of worker and environmental accidents, [and] the ease of working with the particular driller.”(p. 235) Therefore, one can observe at least two examples of additional administrative requirements for cost-plus contracts in relevant and important industries.

The magnitude of the additional administrative burden in cost-plus contracting will certainly vary by the regulatory environment in which procurement occurs and by the magnitude of the potential surplus extraction. Whereas the multi-billion dollar contracts that collectively form a DoD weapons project may require an entire team of administrators and a mandated set of project guidelines, petroleum companies seem content to protect their interests by placing a single, although influential, representative at day-rate drilling sites. While the intent behind these two practices is quite similar, the difference in the magnitude of the associated costs is likely substantial across the two industries.

In terms of the model used in this paper, the additional administrative costs used in cost-plus contracting would appear as an additional procurement cost to the government. If I assume that the government is solely responsible for this expense, I can amend equation (4.10) to depict this additional consideration:

$$\Pi_{G,j} = V - c_f(c_i, v_i, g_k) - c_A(type, size) - c_u, \tag{4.27}$$

where $c_A(type, size)$ is the cost of administering the contract in question and is a function of both the contract type and overall cost of the contract. Notice that I have not assumed the costs of fixed-price administration to be zero. In some cases, particularly in urgent circumstances, the solicitation of bids and coordination required to conduct standard procurement procedures may outweigh the costs of administering the contract in a cost-plus environment. Additionally, as prominently featured in Crocker and Reynolds (1993) and Bajari and Tadelis (2001), the costs of formulating a high-powered, complete contract can be prohibitive if the project is difficult to define. Clearly, this is a situation in which the regulatory details surrounding the contract and characteristics of the project itself will be of paramount importance in the acquisition official's choice of contract type. Any empirical application of this theoretical contract choice model will require the investigator to identify these regulatory parameters and ensure that the empirical model accurately reflects their impact on the contracting outcome.

4.6.2 Extension: Contractor Risk Aversion

Due to heterogeneity between firms in terms of capacity, existing backlog, proximity to the construction site, and experience, among other considerations, it is possible that contractors will have differing risk attitudes regarding their involvement in a competitive award process for construction projects. For some contractors, losing the bid on a contract may result in severe consequences such as layoffs, repossession of equipment, or even complete exclusion from a geographical portion of the market. One might infer that these idiosyncratic risk preferences would then directly affect the contractor's bidding strategy. To incorporate this possibility into the current model of contract design, I will now introduce an assumption of constant absolute risk aversion, where the coefficient of absolute risk aversion is a function of the contractor's current status in the procurement marketplace. For example, firms with relatively higher capacity and larger market shares should be relatively less risk averse, on average, than smaller firms with fewer existing contracts.

A utility function, $U(x)$, exhibiting Constant Absolute Risk Aversion(CARA) preferences satisfies the following condition:

$$CARA \Rightarrow \frac{U''(x)}{U'(x)} = \lambda,$$

where λ is the coefficient of absolute risk aversion and $0 \leq \lambda \leq 1$.[19] To satisfy this condition, I will assume that all participating construction firms receive utility from expected profit in accordance with the following functional form:

$$U[\Pi(b_i)] = \frac{-1}{\lambda_i} e^{-\lambda_i \Pi(b_i)} + r,$$

where

$$\Pi(b_i) = [b_i - s_i], \tag{4.28}$$

and r is a constant value that ensures the bidder receives zero utility in the event his bid does not win.

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[19] See Babcock, et al. (1993) for a survey of research aimed at empirically estimating the CARA coefficient. The authors report an estimated range of 0.005 to 0.49.

The contractor's expected utility from participating in the auction is then:

$$E(U[\Pi(b_i)]) = U[\Pi(b_i)][1 - F(B^{-1}(b_i))]^{n-1},$$

where $B(s_i) = b_i$ is again defined as a bidding function, which converts the contractor's composite cost signal (s_i) into an actual bid (b_i). Taking the derivative of this expression with respect to b_i and simplifying, I have the following first order condition:

$$\frac{B'(s_i)}{n-1}\frac{[1 - F(s_i)]}{f(s_i)}e^{-\lambda_i(b_i - s_i)} + \frac{1}{\lambda_i}e^{-\lambda_i(b_i - s_i)} - r = 0.$$

I can then solve this equation for the optimal bidding strategy in the case of the bidder with CARA utility preferences:[20]

$$b_i^{*RA} = s_i - \frac{1}{\lambda_i}log(r) + \frac{1}{\lambda_i}log\left[\frac{B'(s_i)}{n-1}\frac{[1 - F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right] \tag{4.29}$$

Through this expression, it is apparent that increasing levels of risk aversion (increases in λ) will result in a smaller shade for the bidder. Given the previous discussion regarding factors that could possibly influence a contractor's risk attitude, this result seem quite intuitive. As bidders become more risk averse, they are increasingly sensitive to losing the contract to another bidder, and the contractor lowers his shade on the bid to reflect his risk preference. As a result of this prediction, the government can expect greater overall savings in an auction with risk averse bidders. See Krishna (2010) and Miller (2008) for similar examples of this effect of risk aversion on bid levels.

In order to fully discuss the impact of risk aversion on contracting outcomes,

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[20] A full derivation of this bidding strategy can be found in Appendix C.

I will now substitute the fixed-price composite cost signal into equation (4.29):

$$b_i^{*RA} = d_{T,C}(L+M) + c_i - \frac{1}{\lambda_i} log(r) + \frac{1}{\lambda_i} log\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right] \quad (4.30)$$

As in section 4.4.2, I can now compare the results of the fixed-price award mechanism with risk averse bidders to the result from direct solicitation of the cost-plus contract. The cost-plus profit markup is identical to that defined in section 4.4.2, whereas the resulting profit from the fixed-price contract design is now:

$$b_i^{*RA} - s_i = -\frac{1}{\lambda_i} log(r) + \frac{1}{\lambda_i} log\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right] = \pi_i^{RA}$$

Given this markup from the award process and the potential for the contractor to realize a loss or gain based on the accuracy of his cost estimate, the government must again make a decision between the two contracts based on the expected magnitude of the contractor's surplus extraction. Specifically, if the government anticipates:

$$\pi_i^{CP} \geq \left[\sum_{k=1}^{K_{possible}} p_{ki} g_k - \sum_{k=1}^{K_{realized}} g_k\right](L+M) + \pi_i^{RA}, \quad (4.31)$$

the fixed-price procedure may prove to be the most cost efficient form of contract design. Note that this inequality is more likely to hold when the bidder is highly risk averse, thus including a smaller competitive markup in his bid. This result may support use of contractor training programs and promotion of policies that foster participation by small or financially disadvantaged contractors in contracts for complex or uncertain projects, as the gains from more aggressive bidding may outweigh perceived difficulties in cost estimation.

4.6.3 Feasibility Assessment: VTrans Post-Irene Procurement

In formulating the contract design model that I have presented in this chapter, I attempted to ensure that the decision structure relied on information that is routinely collected as part of either standard or post-disaster procurement procedures. However, some of the features of the model are more closely tied to practices in DoD contracting. Therefore, in order to better establish the applicability of this theoretical model in an empirical setting, it may be useful to discuss its potential application to a real-world scenario. Following my choice for background context, I will now discuss the feasibility of implementation of my contract design model in studying post-Irene emergency procurement by the Vermont Agency of Transportation (VTrans). As previous studies of Vermont highway procurement have established the availability of data from the fixed-price contracts, I will focus primarily on the unique information collected during administration of maintenance rental agreements (MRAs).

The procedural guidelines for employment of the emergency MRAs and email correspondence with VTrans officials state that the contractual terms of the MRAs were not available for renegotiation. This feature supports the *ex ante* screening approach of the contract design model presented in this paper, suggesting that the primary concern of acquisition officials in this situation is not the potential magnitude of subsequent transaction costs associated with a particular contract type.

From correspondence with VTrans officials, it is verifiable that payments for the MRA contracts were delivered via a specially-designed software program, known as the Maintenance Activity Tracking System (MATS). For each contract, the MATS entries include 1) the dimensions of the project, 2) a start and completion date, 3) the physical location of the project, and 4) a description of the contractors employed and labor, materials, and equipment used (L and M). In addition to the MATS data, each maintenance rental agreement document signed prior to commencement of work specifies a contract term (beginning and end date) and a maximum limiting amount (a ceiling for potential cost reimbursement).

Using the listed "dimensions" of projects in the MATS database, it may be possible to construct an index of project complexity based on similarities between contracts. Furthermore, this same index could then be applied to standard projects or similar projects administered via non-emergency procedures. To construct this index, one could rely on standardized definitions of tasks and materials utilized by VTrans and FEMA in bid analysis and cost accounting. For example, FEMA provides cost codes and descriptions for over 750 different tasks, materials, and equipment requirements in its cost reimbursement instructions for local officials.[21] This process could potentially allow for the construction of the $K_{possible}$ dimension and g_K task variables for each individual project.

The alternative sets of dates provided for each project in its corresponding MRA document and MATS entry may provide us with competing measures of the project timeline. If the MRA lists an estimate of the start and completion dates, which is likely due to the fact that the document is signed prior to construction, this would provide the researcher with the expected number of construction days, $d_{T,C}$ or d_E. Conversely, the MATS entry used to remit payment to the contractor

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[21] An example of these instructions, provided via VTrans to local officials, can be found at http://vtransgrants.vermont.gov.

would contain the actual start and completion dates and, thus, the actual number of construction days, d_A.

Given this discussion, I have two primary concerns regarding the feasibility of applying my model to the VTrans procurement process. First, contractors were not required to separately state their private and common costs in the MRA contract. For example, the equipment and labor rates included overhead, meals, lodging, etc. Furthermore, the contractors did not separately state their markup. However, the standardized cost accounting procedures used by FEMA and VTrans may allow the researcher to estimate these “hidden” costs. Second, some of the MRAs may have involved the solicitation of several bids from different contractors. It is unclear at this point whether these contractors knew they were in competition, and the effect of this process is unclear. Fortunately, the required documentation for these contracts should include justification for selecting the winning contractor, perhaps allowing the researcher to model the process as a scoring auction.

In addition to the standardized contract data, it may also be possible to use contractor invoices from cost-plus contracts to demonstrate the ability to implement project management techniques traditionally used by the DoD. For example, procedural guidelines for the MRA require contractors to submit invoices every two weeks. Using this information, it may be possible to construct measures of Earned Value, Planned Value, and Actual Value, which can then be used to calculate cost and schedule variance for each contract.[22] If this process is successful, the researcher could then use the Earned Value Management output to conduct policy evaluation.

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[22] An example invoice, found at http://vtransgrants.vermont.gov, shows that the contractor may calculate a “percentage complete” for each invoice, relating the current cost to the total expected cost.

The unique procurement environment during the post-Irene recovery provides several interesting possibilities for policy evaluation. First, if we compare emergency MRAs from before and after Irene, it may be possible to detect the magnitude of the competition effect on cost-plus contracting outcomes. Due to the sudden requirement for the simultaneous execution of multiple projects, transportation officials were often not able to solicit multiple bids for the MRAs during the response to Irene. Second, by comparing emergency MRAs with fixed-price contracts of similar scope, one may gain a better understanding of the impact of the contract type decision on cost outcomes. Finally, it may be possible to compare the outcomes of projects administered and funded by different levels of government to investigate the impact of coordination issues during the response to a major natural disaster.

4.7 Conclusion

The intent of this paper is to provide a theoretical foundation for the contract design process in the presence of exogenously-driven uncertainty regarding common costs of procurement. I have argued that this uncertainty is a similar characteristic in both the US DoD acquisition environment and highway procurement conducted by government officials during post-disaster recovery operations. As a result, the contracting tools used by officials in both scenarios are motivated by similar concerns regarding the potential magnitude of unforeseen project contingencies. In the event of pervasive uncertainty, officials in both scenarios typically elect to administer a more flexible cost-reimbursement contract rather than rely on standard procurement procedures.

This paper models the contract design decision as an *ex ante* screening problem: the government official must determine which contract type is appropriate based on his confidence level in the potential accuracy of contractor cost estimates. If the deciding official foresees massive estimation errors in cost estimation procedures typically conducted as part of the fixed-price process, the option to instead complete the project through direct solicitation and a cost-plus contract becomes more attractive. The theoretical model in this paper provides several decision rules regarding the contract design process. First, it suggests that the costs associated with possible estimation errors in the fixed-price contract must be weighed against the possibility of larger surplus extraction by the contractor in the cost-plus environment. Second, given the choice of contract type, the model provides suggestions for additional incentive structures that may help to offset the overall cost of procurement to society. Finally, the model incorporates the differential costs of administering each contract, which depend not only on the contract type but also the size of the project and the regulatory environment.

Possible extensions of this paper include relaxation of the independence assumption. If contractor experience with similar projects increases the accuracy of cost estimation, the independence assumption regarding each contractor's draws from the cost distribution for each dimension may no longer be valid. For example, an experienced contractor may realize that a high probability of one event implies a high probability for another event. This would perhaps provide experienced contractor's with more accurate estimates under the fixed-price framework. As a result, relaxation of this assumption would also lead to asymmetric information among bidders. Another possible extension might consider the relationship between incentive power and previous contracting history with the procuring agency. For example, if the contractor's current status and future livelihood is largely dependent on government contracts, the government may be less susceptible to surplus extraction by this contractor in the cost-plus environment. The ability to punish the contractor in future contracts may naturally align the contractor's incentives with the government's. Therefore, in this scenario, typical reservations regarding the cost-plus contract may not be as severe.

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Appendices

Appendix A

Categorical Examples of Cost and Schedule Variance Explanations

Change in Manufacutring Inputs

1. Change in material costs. (CV/SV)
2. Change in required amount of materials. (CV/SV)
3. Decision to hire locally led to lower wage costs. (CV)
4. Decreased travel requirements led to lower labor costs. (CV)
5. Contractor forced to fabricate parts it originally intended to purchase. (CV)
6. Increased labor wage rates. (CV)

Supply Chain Management

1. Early delivery of components or receipt of materials from subcontractor. (CV/SV)
2. Sale of over-requisitioned materials. (CV)
3. Delay in delivery of parts or components to the production line. (CV/SV)
4. Parts shortage. (CV/SV)
5. Receipt of parts in excess of baseline requirements. (CV)
6. Over requisition of material. (CV)
7. Cost growth in subcontracted parts or components. (CV)
8. Early completion of all outside vendor tasks. (SV)
9. Delayed off-loading of work packages to subcontractors. (SV)
10. Delayed pull of materials from inventory. (SV)

11. Chain reaction/ domino effect production delay. (SV)
12. Shortage of general procurement items. (SV)

Corrective Actions in Production

1. Correction of deficiencies identified by product testing. (CV/SV)
2. Alteration of fabrication methods to improve performance. (CV/SV)
3. Implementation of “recovery” or “challenge” schedule to improve delivery performance. (CV/SV)
4. Additional testing required due to initially poor performance. (CV/SV)
5. Contractor risk mitigation efforts. (SV)
6. Realignment of prime and sub- contractor work schedules to improve delivery performance. (SV)

Fundamental Change to Contract Details

1. Change in funding scope due to incorporation of additional capabilities. (CV/SV)
2. Re-design of aircraft or major component. (CV/SV)
3. Incorporation of funds spent prior to contract definitization. (CV)
4. Cessation of cost reporting on an under-performing portion of the contract. (CV)
5. Re-baselining of contract or major subcontract established new contract price and schedule milestones. (CV/SV)
6. Re-prioritization of contract due to other operational commitments (Iraq/Afghanistan) of prime contractor. (CV/SV)
7. Extension of contractor’s oversight period for program. (CV)

Administrative Factors

1. Change in overhead, general and administrative (G&A), or burden rates by prime contractor. (CV)
2. Change in foreign exchange rates. (CV)
3. Transfer of inventory or materials to other contracts. (CV)

4. Perceived savings or additional costs due to pre-existing delays from previous iterations of the contract. (CV/SV)
5. Errors in the Earned Value Management (EVM) reporting process. (CV/SV)
6. Correction of accounting or invoicing mistakes. (CV/SV)
7. Cost reporting prior to contract definitization is recorded as negative cost growth due to lack of budget. (CV/SV)
8. Implementation of new FAA regulations changes testing requirements. (CV)
9. Staffing vacancies in vital areas of production. (CV/SV)
10. Production delays due to labor negotiations/ strikes. (SV)
11. Change in EVM reporting procedures. (SV)
12. Administrative hold on procurement funds. (SV)

Changes to Required Effort

1. Change in level of effort or work required for design and/or production of contracted item(s). (CV/SV)
2. Change in expertise or worker aptitude level required to complete a specific work package. (CV/SV)
3. Change in staffing levels to address problem areas. (CV)
4. Change in required administrative support for subcontracted efforts. (CV)
5. Change in overtime hour requirements. (CV)

Appendix B

Regression Results: Estimation of $EDRNK$

Table B.1 lists the regression results for the OLS estimation of the contract choice model. Using the resulting coefficient estimates, I then construct the expected contract type for each contract in the estimation sample as a function of its associated project and firm characteristics.

Table B.1: Regression Results for IV Estimation (Expected Contract Type)

	(1) drnk
ladjip	0.022
	(0.078)
army	1.422**
	(0.706)
navy	1.315***
	(0.447)
af	1.563***
	(0.469)
rd	-2.286**
	(1.001)
proc	0.289
	(0.994)
length	-0.001
	(0.004)
lvar	0.017
	(0.027)
duals	0.791**
	(0.375)
winage	-0.019
	(0.027)
lemp	-0.096
	(0.326)
ldrev	0.079
	(0.225)
prevcont	0.043***
	(0.012)
nsd	8.659
	(6.547)
cratio	-1.923**
	(0.783)
rdper	-0.006
	(0.513)
Constant	4.438
	(3.712)
Interaction Terms with NSD	Yes
N	149
R-Squared	0.614
F-Statistic	26.268

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix C

Derivation of Optimal Bidding Strategy: CARA Utility Preferences

An individual possesses Constant Absolute Risk Aversion(CARA) preferences when his utility function, $U(x)$, satisfies the following condition:

$$CARA \Rightarrow \frac{U''(x)}{U'(x)} = \lambda_i,$$

where λ is the coefficient of absolute risk aversion and $0 \leq \lambda \leq 1$. In this paper, I assume that all firms exhibit CARA risk preferences for profit gained during the award process. Specifically, I constrain the contractors to have an identical utility function:

$$U[\Pi(b_i)] = \frac{-1}{\lambda_i} e^{-\lambda_i \Pi(b_i)} + r,$$

where

$$\Pi(b_i) = [b_i - s_i],$$

and r is a constant value that ensures the bidder receives zero utility in the event his bid does not win and λ varies by contractor.

The contractor's expected utility from participating in the auction is then his profit times the probability that he possesses the lowest composite cost signal:

$$E(U[\Pi(b_i)]) = U[\Pi(b_i)][1 - F(B^{-1}(b_i))]^{n-1} = U(b_i - s_i)[1 - F(s_i)]^{n-1},$$

where $B(s_i) = b_i$ is again defined as a bidding function. I can then solve for the optimal bidding strategy by finding the bid that maximizes the contractor's expected utility from his auction profits:

$$\Rightarrow \frac{\partial E(U[\cdot])}{\partial b_i} = U'(b_i - s_i)[1 - F(B^{-1}(b_i))] + U(b_i - s_i)\frac{n-1}{B'(s_i)}\frac{f(s_i)}{[1-F(s_i)]^{-n+2}} = 0$$

$$\Rightarrow e^{-\lambda_i(b_i - s_i)}[1 - F(s_i)]^{n-1} - (-\frac{1}{\lambda_i}e^{-\lambda_i(b_i-s_i)} + r)\frac{n-1}{B'(s_i)}\frac{f(s_i)}{[1-F(s_i)]^{-n+2}} = 0$$

$$\Rightarrow \frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)}e^{-\lambda(b_i-s_i)} + \frac{1}{\lambda}e^{-\lambda(b_i-s_i)} - r = 0$$

$$\Rightarrow e^{-\lambda(b_i-s_i)}\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right] = r$$

$$\Rightarrow e^{-\lambda(b_i-s_i)} = r\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right]^{-1}$$

$$\Rightarrow -\lambda(b_i - s_i) = log(r) - log\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right]$$

Therefore, the optimal bidding strategy in the case of the bidder with CARA utility preferences:

$$b_i^{*RA} = s_i - \frac{1}{\lambda_i}log(r) + \frac{1}{\lambda_i}log\left[\frac{B'(s_i)}{n-1}\frac{[1-F(s_i)]}{f(s_i)} + \frac{1}{\lambda_i}\right].$$