Chapter 12

INCENTIVE MODELS OF THE DEFENSE PROCUREMENT PROCESS *

WILLIAM P. ROGERSON

Northwestern University

Contents

* This research was supported by the Smith Richardson Foundation.

Handbook of Defense Economics, Volume 1, Edited by K. Hartley and T. Sandler

Abstract

Economic theorists have devoted considerable attention to analyzing models of closely related incentive contracting problems that arise in the study of public procurement, private procurement, regulation, the theory of the firm, the theory of organizations, and managerial compensation. The purpose of this chapter is to provide an introduction to the incentive models literature as it applies to defense procurement.

Keywords

defense procurement, contracts, incentives, principal agent models, R&D, economies of scale, innovation, moral hazard, strategic behavior, competition, auctions

1. Introduction

Over the past twenty years, economic theorists have become increasingly aware of the fact that many economic problems can be usefully analyzed by explicitly considering the nature of actors' limited information and the role that economic institutions play in shaping outcomes through affecting actors' incentives and strategic behavior. Information economics and game theory have had a major impact on economists' view of almost all branches of economics. As part of this over-all ferment of ideas and research, theorists have devoted considerable attention to analyzing incentive contracting problems that arise in the study of public procurement, private procurement, regulation, the theory of the firm, the theory of organizations, and managerial compensation. Many of the same abstract themes and ideas arise in all of these areas and, in fact, many of these abstract topics and themes have become distinct subjects of study themselves. Even the number of theory papers analyzing defense procurement per se is quite large. However, the entire literature analyzing models relevant to defense procurement is many times larger. The purpose of this chapter is to provide an introduction to the incentive models literature that is relevant to defense procurement.

Government undeniably faces an incredibly complex and multi-faceted incentive problem in military procurement. Defense firms have private information and not all their actions can be monitored. Huge uncertainties pervade the process and complete long-term contracts are generally impossible to write and difficult to enforce. Much of the procurement process occurs in a situation of bi-lateral monopoly and both sides of the market are wary of making specific investments that will reduce their bargaining power. R&D is a key output of the process and the inherent difficulty of objectively measuring the quality of new ideas adds immeasurably to the incentive problem. Finally, on top of everything else, "government" in reality is not a single rational actor, but is itself a complex hierarchical institution, and incentive problems between actors within government are important in themselves and also impact the way that government is able to interact with defense firms.

A number of excellent surveys and overviews exist that are complementary to this one. Less technical discussions of incentive models and their role in explaining defense procurement are contained in Baron (1993), Rogerson (1994) and Sandler and Hartley (1995). Discussions of incentive models more generally, with no particular focus on defense procurement are contained in Baron (1989), Besanko and Sappington (1987), Caillaud et al. (1988), and Sappington (1991). A more thorough textbook-like treatment of many of the models discussed in this chapter is contained in Laffont and Tirole (1993). A classic discussion of incentives in procurement that predates the modern incentives literature, and is still well worth reading, is by Scherer (1964).

This chapter will rely on the American procurement system as a source for stylized facts and observations about real behavior. Since the nature of the procurement problem and the procurement system in place is very similar across the United States and most other Western countries, most of the conclusions of this chapter apply equally well to the procurement systems in other Western countries. However, there are some differences. In general, other countries have smaller domestic markets, and rely to a greater extent on joint ventures with other countries, imports, and international sales. See Sandler and Hartley (1995) for a more complete discussion of other countries' procurement systems and how they compare to the US system.

This chapter proceeds as follows. Section 2 provides an economic overview of important features of the procurement problem and the procurement process. Sections 3 and 4 describe models of a stylized one-shot procurement problem that will be called the simple procurement problem (SPP). Section 3 considers the case of a single agent and Section 4 considers the case of multiple agents. Since much of the incentives literature consists of variants of the basic models described in Section 3 these models are discussed in considerable detail. Section 5 considers R&D, and Section 6 considers multiple periods of production. All of the preceding sections focus on the incentive problem between government and defense firms. Section 7 broadens the scope of the analysis to consider incentive problems within government.

2. Background[1]

2.1. Introduction

The incentive problem between government and defense firms is shaped by four underlying economic characteristics. This section will begin by describing these four characteristics and then go on to discuss some of their consequences for procurement policy.

2.2. Characteristic #1: Research and development

A defining characteristic of weapons procurement is the constant pursuit of improved performance and capabilities through technological advance. Thus, innovation is at least as important a product of the defense sector as the physical products that embody the new ideas. As will be argued below, innovation is an inherently difficult product to purchase, and this creates the need for providing incentives for innovation.

2.3. Characteristic #2: Uncertainty

Massive uncertainties permeate the procurement process. Peck and Scherer (1962) and Scherer (1964) distinguish between internal and external uncertainty. Internal uncertainty is uncertainty due to technological unknowns and is especially high in the design phase of a new weapon. However, even after production begins, most

[1] This section draws on Rogerson (1994).

products continue to evolve in order to incorporate new technologies, fix unanticipated problems, etc. Thus, major uncertainties about cost and design typically continue into production. External uncertainty is uncertainty in the demand for a weapon due to changes in the external threat, changes in the availability of substitute weapons, or simply changes in Congress's willingness to purchase certain weapons. As events of the early 1990s make abundantly clear, external uncertainties are also enormous for most weapons systems.

A major consequence of these large uncertainties is that the Department of Defense (DoD) typically does not find it feasible or desirable to sign long-term fixed-price production contracts. In the design phase, the ultimate nature of the final weapon is not yet known. Even after production begins, the weapon will continue to evolve in unanticipated ways and DoD's demand will change in unanticipated ways. Thus long-term fixed-price contracts for the entire decade or more long production run typical of most weapons systems are thought to be infeasible[2]. DoD's failed attempt to use such contracts in the 1960s (which was referred to as the total package procurement approach) is generally thought to have conclusively demonstrated the infeasibility of this approach [Burnett and Scherer (1990, pp. 304–305)]. Rather, production contracts are signed for one annual lot of production at a time on an annual basis.

In fact, these same uncertainties typically mean that even fixed-price annual contracts are difficult to fully enforce. Unanticipated changes almost always occur and these result in substantial renegotiations during the life of the contract.

2.4. Characteristic #3: Economies of scale in production

Within most sectors of the defense industry, there are multiple firms that would be capable *ex-ante* of designing and producing a given weapons system. Therefore economies of scale do not appear to preclude the existence of multiple competitors at the beginning of a program. Furthermore, design expenditures are relatively small in the early phases of a program, and, given uncertainties at the design stage, it is often sensible to pursue multiple design strategies since it is not clear which will work best. The result is that DoD very typically funds two design approaches through to the stage where prototypes are built. Thus, economies of scale do not preclude the existence of competition through to the end of the design phase.

However, production is another matter. Given the relatively small quantities purchased of most weapons systems, it is generally thought to be completely uneconomic to have multiple firms produce the same weapon system. Furthermore, the same reasoning implies that it is uneconomic to have two or three designs enter

[2] Note that the possibility of unanticipated price inflation is not generally a major problem. This can be, and is, dealt with fairly well through using inflation adjustment formulas based on price indices for various industrial products. It is the fundamental uncertainty over the nature of the product and the demand for it that prevents the use of long-term contracts.

production that are relatively good substitutes for one another, and to buy some of each. Dramatic cost reductions could generally be achieved by purchasing larger quantities of only one design. Therefore, it is generally the case that production of almost all major weapons systems occurs in a sole source environment. Although the existence of mild substitutes may create some competitive pressures in some cases, there will not typically be a close substitute for any major system and thus the effect of competition between substitutes is limited.

The major implication of this is that prices cannot be competitively determined. As explained above, at the end of the design phase when there is still competition, pervasive uncertainties prevent the signing of a single production contract for the entire production run. Thus the bulk of all production contracts will be negotiated with a sole source.

Government's response to this has been to base prices on estimated costs. A fixed price is typically negotiated for each annual production lot. However, the fixed price is determined largely by historic and projected accounting costs, both of which are carefully and meticulously audited. A "profit" term is also added to compensate firms for the cost of capital and risk-bearing [Rogerson (1992c)]. Thus, during the production phase, the sole source producer operates much as does a regulated utility with a fairly similar type of incentive for cost efficiency. If it manages to find a new way to lower its costs, it will keep the benefit for the current production but government will eventually receive the benefit when new prices for future production are negotiated.

Even the extent to which annual fixed-price contracts are truly fixed price is open to question. Under the Truth in Negotiations Act (TINA), defense contractors must submit detailed "current accurate and complete" cost estimates when they negotiate the price of a contract with DoD. Firms that achieve large unpredicted cost reductions therefore expose themselves to a significant risk of prosecution for failing to reveal all they knew at the time of the negotiation. In this way, TINA converts a fixed-price contract into something more closely resembling a cost-reimbursement contract [Kovacic (1991, Section 3.2)].

2.5. *Characteristic #4: Government is the sole buyer*

Government is the only possible buyer of most weapons[3]. Furthermore, many of the technologies and skills required to create and produce weapons systems are relatively specific to the weapons industry. The main consequence of this is that it creates a major hold-up problem [Williamson (1985)]. At the R&D phase, firms may worry that if they invest their own funds to create ideas for weapons systems, they will never recover these sunk expenses. At the production phase, firms may worry that they will never recover their investments in physical capital which has little use outside the

[3] The government strictly regulates foreign sales so can be viewed as exercising control over these sales as well.

defense industry. More generally, one of the main assets of any defense firm is its human capital embodied in the knowledge and working relationships of its design team members. Firms may worry that expenditures to create better design teams will never be recovered since there is no good alternative use for this asset.

Government has responded to firms' fears to invest in specific assets in three ways. First, it has become a purchaser of the intermediate product "R&D", as well as the final product, "functioning weapons systems". That is, government directly funds a large portion of defense-related R&D. In most purely commercial markets, consumers of course do not purchase R&D. Rather they only purchase final products if they value the results of the R&D as embodied in the product. One reason for this is that the direct purchase of R&D is complicated by difficult incentive problems. Thus, by responding to the hold-up problem and directly funding R&D, government has created a new incentive problem for itself. How can it induce defense firms to perform good R&D?

Second, it has become the purchaser of many specific physical assets for defense firms. Physical assets that cannot be easily adapted to other weapons programs are termed "special tools and test equipment" and these are purchased directly by government. Although statistics are very difficult to come by, I am told by informed industry and government sources that the dollar value of such government funded capital is often very large and is comparable to the dollar value of firm funded capital. As well, the government sometimes provides contractual guarantees that capital will be paid for if a program is canceled (e.g., the B1 and B2) or literally builds and owns the entire physical plant (e.g., the F16). However, these latter practices are more rare.

Third, through a massive set of regulations and policies, DoD has established an extra-contractual administrative relationship with firms that provides them with a range of guarantees that their specific investments will not be appropriated [Crocker and Reynolds (1993), Goldberg (1976)]. Perhaps the major such regulatory guarantee is the regulatory directive that prices will be cost-based when negotiations occur with a sole source. That is, procurement regulations specifically instruct contracting officers negotiating with a sole source that their job is *not* to obtain the lowest price. Rather, regulations instruct them in great detail how to calculate a fair price based on estimated costs and instruct them to obtain this price. The fair price also includes a "profit" term which is meant to reimburse firms for the cost of capital, the cost of risk-bearing and other economic costs not recognized as costs by the accounting system [Rogerson (1992c)]. Many of the cost elements that the regulations instruct contracting officers to pay for are likely to be sunk at the time of negotiation.

There is a distinct element of reputational enforcement inherent in this relationship. Some of the DoD behavior that provides investment guarantees is simply DoD practice and not mandated by any regulation. Even behavior mandated by regulations cannot be completely relied on because regulations can be changed. Of course, it can be difficult to change regulations, especially when defense firms can directly lobby Congress to intervene, etc. This difficulty in changing regulations works to DoD's advantage in convincing firms that they can rely on the regulations. Nonetheless, there is also an element of reputational enforcement. Namely, DoD would often benefit in the short run from reneging on all of its commitments and negotiating the lowest possible prices for the current period's prices. However, in the long run, DoD would be harmed because it would no longer be able to convince firms to engage in specific investments. Thus, it may well be rational for DoD to honor its implicit commitments as codified in its regulations.

2.6. *The program life cycle*

Based on the above discussion, we can view the life cycle of a program as being divided into three phases. First is the design phase, during which multiple firms pursue competing designs. In early portions of the design phase there may be five or more firms; however, by the end of this phase, DoD is usually left with two competing firms, each with its own design. DoD directly funds most of this research through cost-reimbursement contracts. However, competition for the production franchise is often intense and thus firms often augment DoD funding with their own private funds.

The second phase is the sole source selection phase, in which firms submit prototypes, final design plans, etc. to DoD so it can evaluate the relative merits of the designs. They also typically bid on the next increment of work, which consists of finalizing the design, establishing the production line, and producing the first few items. DoD selects a winner based on its evaluation of the competing designs (their likely performance, production cost, maintainability, etc.) and the bids on the next increment of work. A single winner is chosen because of economies of scale.

The third phase is the production phase, during which the winner of the source selection phase produces the product. This phase may last a decade or more. An important point is that almost all of the production contracts are signed in a sole source environment after the winner has been chosen, because of cost uncertainties, demand uncertainties, and the evolving nature of the product. Prices in the production phase are highly cost based. Although production occurs under a series of annually signed fixed-price contracts, each contract's price is largely determined by audited historic and audited projected accounting costs. Furthermore, strict application of TINA probably even makes each annual fixed-price contract more cost-based than a true fixed-price contract.

2.7. *Discussion*

An interesting perspective on the role of the above four characteristics in generating the regulatory problem of defense procurement can be obtained by considering how the regulatory problem would change if only some were true. In particular, it is illuminating to consider the first two features as one group (R&D is important; large uncertainties) and the second two as a separate group (large economies of scale in production imply the absence of close substitutes; government is sole purchaser).

Suppose that only the first group of features was true. This would be an industry where technological advance is rapid and important and where large uncertainties exist, especially at the R&D phase. However, government is not the only buyer and economies of scale are not so large as to preclude competition between substitutes. The obvious example of such an industry is the computer industry. Computer procurement works in a completely different fashion than weapons procurement [Kelman (1990)]. The government does not directly buy R&D; rather, it buys final products much as occurs in any normal commercial market. Furthermore, it does not directly fund facilities capital investments. Finally, procurement is usually accomplished through competitive bidding with no element of cost based pricing.

Now suppose that only the second group of features was true. This would be an industry where technological advance is not particularly important and thus efficient production is the only real issue. However, there are large economies of scale so there is room in the market for only one firm. This is, of course, the description of a traditional public utility regulation problem. Thus, in some sense, the production phase of a procurement problem can be viewed as a typical public utility problem. What makes defense procurement special, is that each franchise lasts only a decade or so, and firms compete for the franchise by performing R&D. Furthermore, generating the correct amounts of the correct types of R&D is a major goal of the regulatory system.

2.8. Theory of the internal organization of the firm

One feature that distinguishes defense procurement from traditional public utility regulation is that each production program can be viewed as its own franchise and thus *ex-ante* competitions for each franchise are generally possible. This feature means that the regulatory problem in defense is much more closely related to incentive issues that arise in the theory of the firm than is the standard regulatory problem. In particular, DoD's long-term relational partnerships with suppliers are similar, in some respects, to the type of relationships that large commercial firms such as General Motors, have with their major suppliers. Production of major automobile subcomponents or parts often requires specific investments in R&D or physical capital. Production often occurs by a single source. However, the relationship is nested in a larger competitive environment where GM could turn to different subcontractors for future programs if it wished. Thus, just as in defense procurement, sole source relationships with specific investments occur in the context of a larger competitive environment for future programs.

One of the major differences between the DoD problem and GM's problem regards the "make versus buy" decision. Many observers believe that government either lacks the ability to take production in-house (due to low civil service pay scales, cumbersome personnel systems, lack of flexibility for decision-making, etc.), or simply does not want to design and produce its own weapons because of an ideological preference for private enterprise[4]. If this is true, then the government's options to make instead

[4] The fact that state ownership of defense firms is fairly common in Europe perhaps suggests that the latter reason (ideological preference) may be more important than the former (technological infeasibility).

of buy are much more limited than GM's. This difference is interesting, because, as will be discussed further in the next two sections, a major problem faced by the defense regulatory system is how to provide incentives for R&D. There is some evidence that large commercial firms deal with this problem by moving production in-house. Monteverde and Teece (1982) show that large automotive firms are much more likely to produce a component in-house if it involves large amounts of R&D. This suggests that provision of incentives for R&D may be a particularly difficult problem in purchaser/supplier relationships.

2.9. *Prizes for innovation*

A recurring theme in the above discussion is the necessity for providing incentives for innovation. This part will explain how the current system provides these incentives. An important characteristic of the R&D stage is that the output of this stage is inherently difficult or impossible to measure objectively and describe for purposes of contracting. That is, it is essentially impossible to sign explicit incentive contracts at the R&D stage that specify all possible good ideas and the reward that the firm will be paid as a function of which good idea it comes up with. The obvious objectively verifiable signal of whether a firm has created a successful new weapons design is whether DoD chooses to purchase it. Thus, a regulatory system could create prizes for innovation by guaranteeing that firms which generate ideas good enough to be adopted by the government will receive prizes in the form of economic profit on the production phase of the system. Furthermore, if profit was awarded approximately as a percentage of cost, this might also tend to award larger prizes to more important innovations, at least in a rough sense.

This is, in fact, the approach that DoD appears to follow. The overall result of DoD's regulatory system is that a defense firm selected to be sole source producer of a weapons systems earns economic profit on the production phase of the program and the prospect of earning this sole source profit gives defense firms an incentive to exert their best efforts at the design phase. Two different approaches have been used to empirically estimate the size of this effect. Rogerson (1989, 1991c) uses an event study methodology to estimate the size of the prizes that winners of design contests earn and finds that it is equal to approximately 3.3% to 4.7% of revenues earned in the production phase. Lichtenberg (1988) directly estimates the effect of government business on defense firms' private R&D expenditures and finds that one dollar of production purchases may stimulate 54 cents of such expenditures.

2.10. *Inter-linked stages*

An extremely important feature of the procurement process is that firms' behavior is interconnected across the three stages of procurement: design, sole source selection, and production. This means that models of the procurement process which focus on only one of the stages may fail to capture important aspects of the problem. In general, one must approach procurement policy by simultaneously considering behavior and policy options at all three stages. For example, government might choose to influence the overall amount and quality of R&D by varying direct funding at the design phase, by taking steps to change the competitiveness of bidding at the source selection phase, or by changing the profitability allowed during sole source production. Of course, these tools will have different effects on other goals, like efficiency at the production stage. Thus, an optimal policy must be designed by identifying how different combinations of policies at different stages affect all the goals to be achieved.

For some important questions, it is necessary to expand the scope of analysis even further, to include multiple programs. This is because economies of scope exist across products [Rogerson (1992a,b)] and because award decisions made today will influence the nature of the industrial structure that exists tomorrow, and thus affect the range of options open to government in the future.

Therefore, links between stages of a program and links between programs often have critically important effects, and this must be kept in mind when interpreting the results of models that limit themselves to a single stage of the process or a single program.

3. The simple procurement problem with a single agent

3.1. Introduction

Sections 3 and 4 will consider a particularly simple stylized procurement problem which will be called the simple procurement problem (SPP). In the SPP, a principal (government) must hire an agent (the firm) to produce a single unit of a commodity with well-defined characteristics that can be objectively specified. Government is uncertain about the cost of producing the commodity. Although it cannot predict the eventual cost of production with certainty, it is able to audit and thus measure the ex-post cost of production. Government can sign a contract with a firm that makes government's payment to the firm a function of the measured *ex-post* cost of production. There are a fixed number of firms, n, capable of producing the commodity. This section will consider the case where n equals one and the next section will consider the case where n is greater than one. The firms may or may not have private information about their likely production costs. Government needs to hire a single firm. Government's goal is to minimize its expected costs of procurement *on this procurement considered in isolation.* That is, there are no considerations about the effects of this procurement on future procurements for the same or related products. Nor are there any concerns about the effects of the procurement on industry structure or capability.

Thus far, most of the major advances in theoretical incentive models that are potentially applicable to procurement have been derived in the context of the SPP. This limits their usefulness to some extent. As argued in the previous section, these models fail to shed light on many of the most interesting questions in defense procurement, because a defining feature of the process is that in fact it *cannot* be viewed as a series of isolated procurements. Individual programs are carried out through a series of interlinked stages and investments made for one program often have spill-over effects on other programs. However, the SPP does capture many important incentive issues in procurement and, in many instances, understanding the SPP is a necessary precursor to understanding more complex issues not captured by this model.

3.2. The general model

This part will introduce notation to formally describe the general SPP when there is a single firm from which government can purchase the commodity. Then subsequent parts will show how particular models considered in the literature can be viewed as special cases of this general model.

Let c denote the cost of production if the principal hires the agent. Although the principal cannot necessarily predict c with certainty, he can measure c after production occurs. Therefore contracts can be signed based on measured production costs. Let $p(c)$ denote a contract. Under the contract $p(c)$, the agent promises to deliver the product to the principal, and the principal promises to pay the agent $p(c)$ if its measured production cost is c.

The agent must choose a level of effort, $e \in [0, \infty)$ if hired by the principal. This effort variable has the property that it both lowers production costs and induces a level of disutility in the agent. The critical assumption (and the reason that effort is distinguished from cost) is that neither the agent's level of effort nor the disutility it induces in the agent can be contracted upon. The most obvious example of such a variable is managerial effort – hence the name. However, this is not the only or necessarily the most important example of an effort variable. It is quite generally the case that accounting measures of cost do not measure all of the relevant opportunity costs to a firm. For example, a firm may have the choice of using its best engineers on a government contract or on a commercial contract. Suppose that the best engineers will achieve extra cost reductions on whatever contract they are used. To the firm, an opportunity cost of using the best engineers on the government contract is the foregone profits that could have been earned on the commercial contract. This cost is not measured by accounting numbers. Therefore it can be modelled as an effort variable.

To capture the fact that the relationship between effort and cost may be stochastic and that the agent may be better informed than the principal about this relationship, assume the cost is determined by

$$c = \Gamma(e, \varepsilon, \theta), \tag{1}$$

where ε and θ are random variables drawn by nature before the start of the relationship according to the distribution $G(\varepsilon,\theta)$ over $[\varepsilon_{\min}, \varepsilon_{\max}] \times [\theta_{\min}, \theta_{\max}]$ with density $g(\varepsilon, \theta)$. Assume that $\Gamma_e < 0$, so that increased effort decreases cost. Assume that $\Gamma_\varepsilon > 0$ and $\Gamma_\theta > 0$, so that higher draws of the random variables correspond to "worse" situations in the sense that costs will be higher. The distinction between ε and θ concerns their observability. Assume that both actors know the function Γ and the distribution G. However, neither actor can observe ε and only the agent can observe θ. Thus ε represents symmetric uncertainty about costs in the sense that both actors are uncertain about its value. However, θ represents asymmetric uncertainty about costs in the sense that only the principal is uncertain about its value. The parameter θ will often be referred to as the agent's "type". Higher values of θ will be spoken of as being worse types since $\Gamma_\theta > 0$.

The agent's income, I, will be given by the price he receives from the principal minus the production cost. Assume that the agent's utility over income, I, and effort, e, is given by the separable function[5]

$$u(I) - \phi(e). \tag{2}$$

Assume that $u(0) = 0$, $\phi(0) = 0$, and that the agent's reservation level of utility is zero. This means that the agent is completely indifferent between accepting a cost-reimbursement contract and not participating at all[6]. Thus the principal would always have the option of hiring the agent under a cost-reimbursement contract, if he wished. This assumption is not necessary for the results but helps make the model intuitively clear. Assume that the agent evaluates income lotteries by calculating expected utilities and comparing them and that $u' > 0$ and $u'' \leqslant 0$, so that the agent prefers more income to less, and is risk neutral or risk averse. Assume that $\phi'(e) > 0$ and $\phi''(e) \geqslant 0$, so that the agent dislikes effort and the marginal disutility of effort is weakly increasing.

Although it is not necessary for the analysis, it will be convenient to assume that the principal is risk neutral and places an infinite value on consuming the good. Thus the principal's goal is to procure the good at minimum expected cost.

The relationship can be viewed as unfolding in three steps. At the first step, nature chooses ε and θ. At the second step, the principal offers a contract $p(c)$ to the agent and the agent decides whether or not to accept it. At the third step, if the agent has accepted the contract, he chooses an effort level, e, that results in a production cost, c. Government receives the good and pays the firm $p(c)$.

With respect to actors' information, assume that both actors know the entire structure of the relationship given by the functions G, Γ, ϕ, and u. Thus the only information asymmetry at the time of contracting is that the agent has observed θ and the principal has not.

[5] The separability assumption is basically for expositional convenience. The same basic qualitative insights apply to the nonseparable case, only the analysis is more complicated because the agent's attitudes towards risk and preferences over income are potentially affected by his effort choice.

[6] Under a cost reimbursement contract, $p(c) = c$, so that I always equals zero. The agent will choose the lowest possible effort, i.e., $e = 0$, under this contract. Thus the agent's expected level of utility equals zero.

3.3. Pure moral hazard: The model

The pure moral hazard model is created by assuming that there is no asymmetric cost uncertainty. Formally, assume that θ assumes some particular value with probability one. Since θ does not vary, one can simplify notation by suppressing θ entirely. Let $G(\varepsilon)$ and $g(\varepsilon)$ denote the distribution and density of ε, and let $\Gamma(e, \varepsilon)$ denote the function that determines cost as a function of e and ε.

Suppose that the principal offers the agent a cost-reimbursement contract[7]. From the agent's standpoint, there is no benefit from lowering production costs. Therefore, he will reduce his effort to a minimum. Since effort levels cannot be contractually specified, the only way to induce the agent to exert effort to lower costs is to give him a financial incentive to lower costs. That is, the agent must be told that if he succeeds in lowering costs by one dollar, the price that he is paid will not decline by a full dollar. Of course, the extreme case would be to offer the agent a fixed-price contract. In this case, the agent would receive all the benefits from exerting effort, so would have no incentive at all to shirk. However, a fixed-price contract creates another potential problem. Under a fixed-price contract, the agent bears all of the risk of cost overruns and underruns. If the agent is risk averse (recall that, by assumption, the principal is risk neutral), the optimal contract from an insurance perspective would be a cost-reimbursement contract, where the principal bore all the risk.

This, then, is the fundamental contracting issue in the pure moral hazard model. From an incentive perspective, the ideal contract is a fixed-price contract. From an insurance perspective, however, this contract places all of the risk on the agent. If the agent is risk neutral, this poses no problem and the optimal contract is a fixed-price contract. However, if the agent is risk averse, the ideal contract from an insurance perspective is a cost-reimbursement contract. Therefore, we cannot simultaneously accomplish both goals of creating ideal incentives and ideal insurance. Not surprisingly, the optimal contract in general turns out to be a cost sharing contract, which tries to achieve an optimal trade-off between the two competing goals.

The outlines of a formal analysis to this problem will now be sketched [see Grossman and Hart (1983), Holmstrom (1979), Rogerson (1985), and Shavell (1979) for more complete treatments]. It turns out that the analysis of this model is somewhat more convenient if we work directly with the distribution of cost induced by effort. Let $F(c, e)$ denote the distribution function of c given that the agent exerts the effort level e. This is defined by

$$F(c, e) = \Pr\{\Gamma(e, \varepsilon) \leqslant c\}. \tag{3}$$

Let $f(c, e)$ denote the density function. The principal calculates the optimal contract to offer the agent by choosing a contract to minimize his expected payments subject to

[7] The term cost-reimbursement contract will be used to describe the contract given by $p(c) = c$. The term fixed-price contract will be used to describe a contract of the form $p(c) = \mathrm{k}$, where k is a constant.

the constraint that the agent is willing to accept the contract. In reality, the principal chooses only the contract and predicts the agent's effort choice. However, as is typical in this sort of problem, the simplest way of formally describing the problem is to view the principal as choosing both the contract and effort subject to the extra constraint that the agent is actually willing to choose the effort that the principal specifies. The optimal contract is therefore the solution to the following program:

$$\underset{p(\,),\, e}{\text{Minimize}} \int p(c) f(c, e)\, \mathrm{d}c \qquad \text{subject to :} \tag{4}$$

$$\int u(p(c) - c) f(c, e)\, \mathrm{d}c - \phi(e) \geqslant 0 \tag{5}$$

$$e \in \underset{\hat{e}}{\operatorname{argmax}} \int u(p(c) - c) f(c, \hat{e})\, \mathrm{d}c - \phi(\hat{e}). \tag{6}$$

Equation (4) is the principal's payment to the agent. The principal chooses a contract p and effort level e subject to the constraints that the agent receives his reservation level of expected utility [Equation (5)], and that the agent will actually choose the level of effort specified by the principal [Equation (6)].

The standard method of solving this program is to replace constraint (6) by the first-order condition for the agent's effort choice problem,

$$\int u(p(c) - c) f_e(c, e)\, \mathrm{d}c - \phi'(e) = 0. \tag{7}$$

It is straightforward to use control theory to characterize the solution to the resulting program. Readers unfamiliar with control theory can derive the same result using standard Lagrangian techniques by assuming that c takes on n possible values, $\{c_1, \ldots, c_n\}$.

In general the optimal contract is neither a fixed-price contract nor a cost-reimbursement contract. Rather, price depends on cost in a complex way.

3.4. Pure moral hazard: Discussion

What light does this model shed on procurement problems and practices? At the level of logical foundations, it obviously makes a significant contribution. It clearly and explicitly describes the basic idea that incentive contracting may involve a trade-off between effort inducement and risk allocation and thus supplies a theory of incentive contracting. In order to be useful for normative or positive analysis, however, a theory of optimal contracts must describe how measurable features of a contract ought to vary with measurable features of the contracting environment.

It turns out that this theory has been less successful on this front. Although the problem itself is very simple to state, formal derivation of optimal contracts is surprisingly complex and delicate. Furthermore, other than the statement that the optimal contract will, in general, be neither a fixed-price nor a cost-reimbursement contract, almost no general statements can be made. The nature of the optimal contract varies tremendously depending upon the precise functional forms of the utility function and distribution function for ε. For normative purposes, the problem this creates is that the precise nature of the optimal contract is highly dependent on features of the contracting environment that government may be unsure about. For positive purposes, the problem is that the theory does not generate testable predictions.

Therefore, it is probably fair to say that the major value of this model to date has been to help clarify the underlying incentive issues rather than to explain specific contracting phenomena.

In reality, most contracts used by DoD are linear in cost. That is, they are of the form

$$p = \alpha + \beta c, \tag{8}$$

where α is a positive constant and β is a constant between 0 and 1. If β equals 0, it is a fixed-price contract. If β equals 1, it is a cost-reimbursement contract. If β is between 0 and 1, the contract is a cost-sharing contract, and β is usually spoken of as the share of the risk borne by DoD. Similarly, $(1-\beta)$ is usually spoken of as the share of the risk borne by the firm.

It is difficult to find simple examples where the optimal contract in the formal model is linear. This is unfortunate, but not a critical problem. In all likelihood, linear contracts are used because they are simple and information does not exist to support more finely-tuned calculations. By exogenously restricting oneself to linear contracts (or, by restricting oneself to a two-outcome case, where costs can be "low" or "high"[8]), fairly well-behaved solutions can be calculated. In particular, it is possible to demonstrate a very intuitive result that will be referred to as testable result #1 (TR #1).

Testable Result #1: Suppose that contracts are linear. Then under the optimal contract, the share of risk borne by government, β, is always between zero and one. The share of risk borne by government grows larger as cost uncertainty increases.

Government, does, of course, always choose β between zero and one. The interesting question is whether it can be shown that β increases with cost uncertainty. Even attempting to relate this simple prediction to real behavior turns out to be problematic. It is a well-accepted stylized fact of the procurement process, that DoD bears successively lower fractions of risk as a program matures. At the early R&D phase, cost-reimbursement contracts are typically used. In development, the firm may accept a small share of the risk. In initial production, the firm will accept a large share of the risk and then, after initial production, fixed-price contracts will typically be used. A natural

[8] In this case, the change in price divided by the change in cost as costs go from low to high can be viewed as the slope, β.

hypothesis is that this behavior is explained by the simple moral hazard model. Namely, cost uncertainty declines over the life of the program and this is reflected by decreases in the value of β.

However, there may be another, more important, factor explaining this behavior. In the formal moral hazard model, the product is completely well-defined. Thus the government and the firm are able to sign a contract at the outset that completely specifies the nature of the product that will be delivered in an objectively verifiable fashion. The extent to which this assumption is satisfied varies enormously and systematically over the life of a program. In the R&D phase, government may be completely unable to specify many important aspects of what it wants. By the time of the third or fourth annual production lot, government may be able to describe quite precisely what it expects. Therefore, government's use of cost type contracts for R&D may be largely due to the fact that no product can be objectively defined at the date of contract signing. Fixed-price contracts would simply create an incentive to reduce the quality of the R&D supplied.

In summary, in order to argue that the simple moral hazard model explains why β varies across a group of contracts, it would be important to be able to control for the extent to which the product can be objectively described at the date of contract signing. This has not been done.

3.5. *Pure self selection: The model*

Economic analyses of defense procurement dating back to Scherer (1964) have emphasized the fact that information about cost is asymmetric at the contracting stage and that this fact plays a key role in shaping the procurement process. That is, at the time of contract signing the firm is often much better informed than government about the likely cost of performing the contract.

The pure self selection model focusses attention on this factor by assuming that the only cost uncertainty in the model is asymmetric cost uncertainty. That is, it is assumed that ε equals some fixed value with probability one. Since ε is now constant, we can simplify notation by suppressing it entirely. Let $G(\theta)$ and $g(\theta)$ denote the distribution and density of θ and let $\Gamma(e, \theta)$ denote the function determining cost as a function of e and θ. From the agent's perspective, there is no uncertainty in this model. Therefore without loss of generality, assume that $u(I) = I$.

In the pure moral hazard model, the basic contracting issue was the trade-off between effort inducement and risk allocation. In the pure self selection model, the basic contracting issue is different. The principal is constrained to offer a contract that all types will accept[9]. One way of doing this is to offer a cost-reimbursement contract. By construction, every type is just willing to accept such a contract; however, the problem

[9] If we relaxed this assumption, the same logic applies given whatever fraction of types the principal wishes to attract.

with this contract is that no effort is induced. Under a cost-reimbursement contract, all types will exert zero effort. The other extreme would be to offer a fixed-price contract. In this case, every type would choose the efficient level of effort. However, the problem with this contract is that, in order to guarantee that every type will accept the contract, the principal must offer a fixed price that is high enough that the highest type, $\theta_{\max}$, (i.e., the highest-cost type), will accept it. Thus all other types are left with a positive surplus. Therefore, a cost-reimbursement contract enables the principal to extract all of the joint surplus generated by the relationship, but the level of joint surplus generated is low because no effort is induced. A fixed-price contract generates a high level of joint surplus because effort is induced, but the principal extracts only a small share of the joint surplus. Therefore, the optimal contract will in general be some form of cost sharing contract that trades off between these two factors.

In the pure moral hazard model, the trade-off was between effort inducement (which is best accomplished by a fixed-price contract) and risk allocation (which is best accomplished by a cost-reimbursement contract.) The optimal contract is in general some sort of cost-sharing contract that seeks an optimal compromise between these two competing concerns. In the pure self selection model, rent extraction takes the place of risk allocation. Therefore in both cases, the basic intuition flowing from the models is quite similar. When cost uncertainty is high, government should choose contracts which have government bear more of the risk. In the pure moral hazard model, this is because extra symmetric uncertainty creates greater risk that the principal can more easily bear. In the pure self selection model, this is because extra asymmetric uncertainty makes it harder for the principal to capture rent through offering a fixed price, so cost sharing become more desirable.

Although the basic "bottom line" qualitative insight is fairly similar, the method of formal analysis for the pure self selection model is actually quite different. This is because the principal does not know the agent's type. Therefore when the principal considers a contract, he must calculate whether each type will participate and what effort level each type will choose. Thus each type "self selects" into a price/cost pair from the contract. In general, each type will choose a different price/cost pair, and thus keeping track of and analyzing how different types self select creates an extra level of complexity in these models.

It turns out that essentially the same mathematical structure applies to self selection models of a wide variety of phenomena, including models of price discrimination and quality choice by a monopolist, models of taxation and its incentive effects, principal agent models where the output of the agent is units of some physical commodity such as wheat, and principal agent models where the output of the agent is units of cost reduction. Of course this last interpretation is the one considered by this chapter. The basic mathematical structure of this model was developed by authors considering other interpretations [Guesnerie and Laffont (1984), Mirrlees (1985), Musa and Rosen (1978), Baron and Myerson (1982), Sappington (1983)]. Laffont and Tirole (1986) and McAfee and McMillan (1987a) were the first to apply this type of model to the case considered by this chapter.

The formal analysis of this model will now be outlined. Readers interested in further details should consult the references listed above or Laffont and Tirole (1993). It is convenient to reformulate the model slightly in order to analyze it. Because the agent faces no uncertainty, the agent can be viewed as choosing c directly instead of choosing effort. Let $z(c, \theta)$ denote the amount of effort needed to produce cost c when the agent's type is θ. (This is simply the inverse of Γ.) Then define $\delta(c, \theta)$ to be the disutility of choosing c which is given by

$$\delta(c, \theta) = \phi(z(c, \theta)). \tag{9}$$

Rather than work directly with effort, it is more convenient to simply view the agent as choosing c at a disutility cost of $\delta(c, \theta)$. Thus the effort variable is suppressed entirely[10].

Assumptions made previously that effort decreases cost and effort induces disutility ($\Gamma_e < 0$, $\phi' > 0$), and that higher values of θ mean that costs are higher ($\Gamma_\theta > 0$) immediately imply that disutility both decreases in cost and increases in θ, i.e.,

$$\delta_c < 0 \qquad \text{and} \qquad \delta_\theta > 0. \tag{10}$$

The regularity assumption will be made that

$$\delta_{c\theta} < 0. \tag{11}$$

This means that the marginal disutility from lowering costs becomes greater as θ increases. Thus increases in θ mean that both the disutility from lowering costs and the marginal disutility from lowering costs increase. This is equivalent to the property that the efficient or first-best cost level increases in θ, which is also equivalent to the property that if the agent was given a fixed-price contract, the agent would choose a higher cost if his type was higher. This is of course a very intuitive requirement. We interpret higher values of θ as meaning that the type is "worse". The assumption in Equation (11) states that as θ becomes higher, we would observe the same contract resulting in higher costs. Therefore, Equation (11) simply formalizes what we intuitively mean by a worse-cost situation, and is a very natural assumption.

This is an important point, because the main qualitative results depend on this assumption. For example, if δ was additively separable in c and θ, this would imply that all types would choose the same cost. In this case, a fixed-price contract would

[10] All of the early analyses of the pure self selection problem followed this practice of suppressing the effort variable. This led to the inaccurate impression that the distinction between the pure moral hazard and pure self selection models is whether an effort variable exists. This is not true. In the pure self selection model, the agent makes a decision that affects his unobservable utility and this can always be thought of as an effort choice. The distinction between the two models is whether the uncertainty over cost is symmetric or asymmetric.

extract all the rent from every type and this would be the optimal contract for the principal to offer. If $\delta_{c\theta} < 0$, then worse (i.e., higher) types choose higher costs. Thus, offering a price high enough to attract the high types leaves the low types earning rent. Recall from the above discussion of the intuition of the pure self selection problem, that this was the reason that a non-trivial contracting problem exists.

One more regularity assumption will be made. For any type θ, the total disutility of the agent is given by the sum of production cost, c, and the disutility of effort, $\delta(c, \theta)$,

$$c + \delta(c, \theta). \tag{12}$$

It will be assumed that

$$\delta_{cc} > 0 \tag{13}$$

and that for every θ there exists a unique value of c, $c^{\mathrm{F}}(\theta)$, which satisfies the first-order condition

$$1 + \delta_c(c^{\mathrm{F}}(\theta), \theta) = 0. \tag{14}$$

Therefore $c^{\mathrm{F}}(\theta)$ is the unique first-best or efficient-cost choice for type θ, in the sense that it minimizes total disutility of c. Total differentiation of Equation (14) yields

$$c^{\mathrm{F}\prime}(\theta) = -\frac{\delta_{c\theta}}{\delta_{cc}}. \tag{15}$$

By Equations (11) and (13), this is positive, i.e., higher types should optimally produce at higher cost.

Laffont and Tirole (1986) consider an example satisfying properties (10)–(14). The exampie is created by assuming that

$$\Gamma(e, \theta) = \theta - e \tag{16}$$

and that $\phi(e)$ is strictly increasing and strictly convex. The agent's type is therefore the value of cost if no effort is exerted. Exertion of effort results in cost reductions below θ. If Γ is defined by Eqation (16), then,

$$\delta(c, \theta) = \phi(\theta - c). \tag{17}$$

It is easy to verify that δ satisfies the assumptions stated in Equations (10)–(14).

The principal's contractual design problem can now be formally described. Government considers a contract, $p(c)$. Given this contract, the principal predicts for each type of firm, θ, whether that type will participate, and what cost that type will choose to produce at, if it does participate. Among the contracts that cause all types to participate[11], the principal picks the one that minimizes his expected cost. Let $c(\theta)$ denote the cost chosen by type θ. Then, formally, the principal can be viewed as solving the following program:

$$\underset{c(\,),\,p(\,)}{\text{Minimize}} \quad \int p(c(\theta))\, g(\theta)\, \mathrm{d}\theta \qquad \text{subject to} \tag{18}$$

$$c(\theta) \in \underset{\hat{c}}{\operatorname{argmax}}\{p(\hat{c}) - \hat{c} - \delta(\hat{c}, \theta)\} \quad \text{for every } \theta, \tag{19}$$

$$p(c(\theta)) - c(\theta) - \delta(c(\theta), \theta) \geqslant 0 \quad \text{for every } \theta. \tag{20}$$

This problem can be transformed into a well-behaved optimal control problem under various regularity assumptions. The main result is to show that a unique solution $c^*(\theta)$ and $p^*(\theta)$ exists with the following three characteristics:

(i) Higher types choose strictly higher costs,

$$c^{*\prime}(\theta) > 0. \tag{21}$$

(ii) The lowest type, $\theta_{\min}$, chooses the first-best cost. All other types choose a cost strictly greater than the first best,

$$c^*(\theta_{\min}) = c^{\mathrm{F}}(\theta_{\min}) \tag{22}$$

$$c^*(\theta) > c^{\mathrm{F}}(\theta) \quad \text{for every } \theta \in (\theta_{\min}, \theta_{\max}]. \tag{23}$$

(iii) The highest type, $\theta_{\max}$, earns zero expected utility. All other types earn positive expected utility and expected utility is strictly decreasing in type:

$$\upsilon^*(\theta_{\max}) = 0, \qquad \upsilon^{*\prime}(\theta) < 0, \tag{24,25}$$

where $\upsilon^*(\theta)$ is defined by

$$\upsilon^*(\theta) = p^*(c^*(\theta)) - c^*(\theta) - \delta(c^*(\theta), \theta). \tag{26}$$

None of these characteristics directly describe the nature of $p^*(c)$. However, based on these characteristics, it is straightforward to do so. When a type θ chooses c, it solves the problem of maximizing

$$p(c) - c - \delta(c, \theta). \tag{27}$$

The first-order condition for this problem is

$$p'(c) - 1 - \delta_c(c, \theta) = 0. \tag{28}$$

By comparing Equations (28) and (14), it is immediately apparent that the slope of $p(c)$ at the c chosen by type θ is sufficient to tell us whether the cost chosen by type

[11] Recall that, to simplify the exposition, it is assumed that the principal places infinite value on the good and therefore definitely wants to consume it. If we relax this assumption, then in general the principal would rationally plan to make offers that would be rejected some of the time. However, nothing significant changes in the analysis.

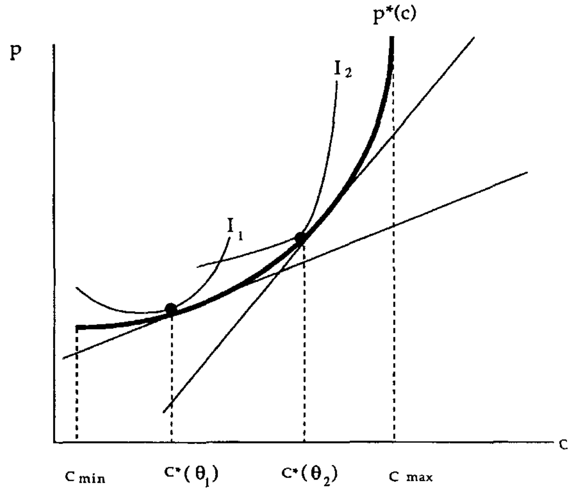

Figure 1.

θ is less than, equal to, or greater than the first best. In particular, $c^*(\theta)$ is greater than the first best iff $p'(c^*(\theta)) > 0$ and equal to the first best iff $p'(c^*(\theta)) = 0$. That is,

$$c^*(\theta) \gtreqless c^{\mathrm{F}}(\theta) \Leftrightarrow p'(c^*(\theta)) \gtreqless 0. \tag{29}$$

Let $[c_{\min}, c_{\max}]$ be the interval of costs over which $p^*(c)$ is defined. The cost $c_{\min}$ is chosen by type $\theta_{\min}$ and the cost $c_{\max}$ is chosen by $\theta_{\max}$. Then it follows immediately that

$$p'(c_{\min}) = 0 \tag{30}$$

$$p'(c) > 0 \quad \text{for } c \in (c_{\min}, c_{\max}]. \tag{31}$$

That is, the slope of $p(c)$ equals 0 at $c_{\min}$ and is strictly positive elsewhere. This is the only property of the function $p(c)$ that follows from the general analysis.

A fixed-price contract is one where $p'(c)$ is identically equal to zero. Therefore, the general result is that it is optimal for the principal to offer a cost-sharing contract, in the sense that prices increase with cost.

Since $p^{*\prime}(c)$ equals zero at $c_{\min}$ and is strictly positive for larger values of c, the function $p^*(c)$ cannot be globally concave. However, it is possible that it may be globally convex. This possibility is illustrated in Figure 1. The contract $p^*(c)$ is the convex function defined over $[c_{\min}, c_{\max}]$. Each type of agent chooses a (p, c) combination off this curve to maximize his expected utility. Utility is increasing in price and decreasing in cost. Let θ_1 and θ_2 be two types with $\theta_1 < \theta_2$. The best indifference curve which can be achieved by each type is drawn in. The key geometric property illustrated by this graph is that higher types have flatter indifference curves [12]. This follows from assumption (11) and is often referred to as the single crossing condition. This property is why higher types locate a tangency at a higher cost.

An interesting result of Laffont and Tirole (1986) and McAfee and McMillan (1987a) is that if $p^*(c)$ is convex as drawn, it would be possible to replace the contract $p^*(c)$ with a menu of linear contracts. Consider the menu of linear contracts formed by all tangent lines to $p^*(c)$ over the interval $[c_{\min}, c_{\max}]$. Suppose the principal initially offered the agent this menu. It is geometrically clear that each type θ would choose the tangent line at $c^*(\theta)$ and would then choose the cost $c^*(\theta)$. Thus, the nonlinear contract $p^*(c)$ could be implemented by offering a menu of linear contracts. Furthermore, it is straightforward to show that one can add back some symmetric additive noise to the model, ε, and the menu of linear contracts continues to be optimal [13].

This result is interesting for three reasons. First, it provides a formal theoretical model consistent with the observation of only linear contracts. Second, it extends the pure self selection model to cases including a symmetric noise term, ε. Third, it suggests the general idea that government should structure bargaining so that firms claiming to be lower cost select themselves into contracts where they bear a higher share of the risk. This qualitative insight is potentially quite applicable in a wide variety of situations.

It turns out that it is difficult to identify broad classes of cases where $p^*(c)$ can be shown to be globally convex. In the case considered by Laffont and Tirole (1986), for example, one must assume that the third derivative of the disutility function is positive in order to guarantee that $p^*(c)$ is globally convex [Rogerson (1987)]. However, while this is unfortunate, it is not a "fatal flaw" of the model. In some over-all sense, $p^*(c)$ must be "generally convex" in the sense that its slope equals zero at $c_{\min}$ and is positive elsewhere. Thus in many practical applications, the intuition that lower cost types should self select themselves into contracts where they bear a greater responsibility for cost overruns and underruns may turn out to be correct. More research is required on this point.

Another interesting line of research explores how auditing should optimally be used in the pure self selection model [Baron and Besanko (1984)].

3.6. Pure self selection: Discussion

Just as for the pure moral hazard model, the pure self selection model obviously makes a significant contribution at the level of logical foundations. It clearly and

[12] In Figure 1, I_1 (I_2) is an indifference curve belonging to a low (high) type. The single crossing property means that I_2 is flatter than I_1 at the point where they intersect. If this property holds for all indifference curves, the tangency for type 1 must occur to the left of the tangency for type 2.

[13] See Rogerson (1987) for a thorough discussion of this geometric interpretation of the menu of linear contracts result.

explicitly describes the basic idea that incentive contracting may involve a trade-off between effort inducement and rent extraction, and thus supplies a theory of incentive contracting.

Unfortunately, the same basic criticism also applies to this model. Namely, the technical analysis is surprisingly delicate and complex, and the general nature of the optimal contract varies tremendously depending upon the precise functional forms one assumes. Just as for the pure moral hazard model, it is possible to derive various versions of TR #1. Once again, the problem is that it is difficult to actually test this result. Furthermore, since both theories predict the same result, it does not help distinguish between them.

Five additional remarks should be noted about the pure self selection model. First, the basic idea underlying the pure self selection model is more complex and subtle than the basic idea underlying the moral hazard model. Thus, it is probably fair to say that the basic idea was not well understood by economists even on an intuitive basis prior to the creation of the formal models.

Second, it may be that the pure self selection model is focussing on the more fundamental or important phenomenon. Asymmetric information at the time of contracting may turn out to be a more important explanation for various contracting practices than risk aversion. If all firms were risk neutral, it is not clear that contracting practices and institutions would necessarily be much different. However, if no firms had private information, there would be clearly be large differences.

Third, the "linear menus" result for the pure self selection model possibly creates another testable result which will be called testable result number two (TR #2). Under the optimal menu, higher-type firms select a linear contract with a higher value of β and earn lower rents. The term "rent" refers to the agent's *total* utility including the unobservable part. Therefore, if we observed the same contracting problem played out n times, where nature drew an independent identically distributed (iid) value of θ each time, we would observe a negative correlation between β and total utility. This is TR #2.

Testable Result #2: Firms operating under linear contracts with higher values of β should earn lower rents.

It is a well-accepted stylized fact that the measured *ex-post* rate of accounting profit earned by firms on fixed-price contracts is greater than the measure *ex-post* rate of accounting profit earned by firms on cost-reimbursement contracts. One might interpret this as supporting TR #2; however, this argument is problematic. The model predicts a correlation between *unmeasurable* total utility, $p(c)-c-\delta(c,\theta)$, and β; it does not predict a relationship between *measured* profit, $p(c)-c$, and β. Since the key feature of the model that generates all of the results is that there is *unmeasurable* utility, abstracting away from this for the purposes of creating testable predictions is clearly inappropriate. This stylized fact is most straightforwardly explained by some sort of risk/expected return relationship. Therefore, although testable results may flow from the linear menus analysis, TR #2 is not such a result.

Fourth, it may be that the linear menus analysis may help government to create better negotiation strategies with firms by explicitly offering them menu choices [see Reichelstein (1992) for a very interesting analysis along these lines].

Fifth, the SPP proceeds under the relatively artificial bargaining structure that government makes a single take-it-or-leave-it offer. In the moral hazard model, where information is symmetric at the time of contracting, this assumption is no great cause for concern; but, in the pure self selection model, where information is asymmetric, this assumption is much less palatable. Institutions that affect negotiations and the government's ability to commit may play a much more important role in determining contracting outcomes in this case. In support of this point, it is interesting to note that the pure self selection model has had its greatest success in explaining behavior, precisely in situations where commitment is not an issue. This is in models of a monopoly practicing price discrimination in a market with large number of anonymous consumers. A firm facing a large anonymous market of consumers truly does make a take-it-or-leave-it offer when it publishes a price schedule[14].

3.7. The general model

A general model would allow both types of cost uncertainty to exist simultaneously, and would allow the agent to be risk averse. This model would contain elements of both the pure moral hazard and pure self selection model, but has not yet been extensively analyzed [see Baron and Besanko (1987b, 1988) and McAfee and McMillan (1986)]. One way that some of these papers make progress is by exogenously restricting themselves to linear contracts and making other simplifying assumptions. This is a good strategy given the complexities of the general model.

4. The simple procurement problem with multiple agents

A natural way to generalize the SPP of the preceding section would be to assume that there are initially n agents capable of producing the commodity, where n is greater than one. The principal only needs to hire one agent.

If there is no asymmetric information, nothing fundamental changes. The principal would face n different pure moral hazard problems. He would calculate the optimal contract for each problem and the resulting expected payment. He would then simply choose the agent to minimize his expected wage payment.

If there is asymmetric information, however, the introduction of multiple potential agents creates a fundamental change. In this case, the principal can conduct some type of auction in an attempt to extract more rent from the agents. Thus the question of how the principal should design auctions to produce the lowest expected payment arises.

[14] The extra structure created by observable demand curves also make the models potentially more empirically relevant.

The auctions literature has concentrated on the case where it is assumed that the principal does not measure any production costs at all, so only fixed-price contracts are possible. Of course, if there is a single agent this problem is trivial from an analytic point of view [15]. The pure self selection literature in a sense creates an interesting problem out of the single-agent case by assuming that some costs can be measured and that an effort variable exists which affects both measurable and unmeasurable cost. This creates a trade-off between rent extraction and effort inducement. When there are multiple agents, a non-trivial problem exists even when costs cannot be measured. There are many different ways to run a fixed-price auction for producing a commodity. Which will minimize the principal's expected procurement cost and why?

The auctions literature has been one of the most successful literatures in information economics. A large number of sharp and interesting results have been derived. This literature is too voluminous to attempt to survey here [see the excellent survey by McAfee and McMillan (1987b)]. This literature is mentioned simply to place it in the context of the models described in this chapter. The auctions literature simplifies the SPP by assuming that costs are unobservable so that only fixed-price contracts can be signed. Thus the issue of effort becomes irrelevant and we can simply assume that each agent has an unobservable cost of production drawn from some distribution.

Anton and Yao (1989, 1992) have analyzed a number of models of "share auctions" where two firms bid prices for various shares of the total buy. This is a particularly interesting type of auction from the perspective of defense procurement because it resembles the DoD practice of dual sourcing [Anton and Yao (1990)]. One of the main insights from these models is that, in a one-period model, it would generally be highly undesirable to conduct a share auction. The principal would almost always be better off by conducting a winner-take-all auction, because it induces more competitive behavior. Therefore, the value of dual sourcing must be that it preserves competition for the future.

A number of papers have considered two-agent self selection models where extra structure is added by distinguishing between a low-cost incumbent and a higher-cost potential entrant [Anton and Yao (1987), Demski, Sappington and Spiller (1987), Stole (1994)]. The general flavor of the results is that it may be desirable for government to commit *ex-ante* to use the potential entrant in circumstances where it would be cheaper to use the incumbent, *ex-post.* This threat can force the incumbent to bid lower.

Recently, a number of papers have begun to generalize the general n-person auction model to consider cases where there is unobservable effort, measurable cost, unmeasurable disutility, and effort affects both measurable cost and unmeasurable disutility [Laffont and Tirole (1987), McAfee and McMillan (1987a), Riordan and

[15] In the formal model of the previous section, it was assumed that the principal places infinite value on consuming the good. Therefore the principal would offer a fixed price equal to the lowest price the agent would accept with certainty. In a more realistic case where the principal places a finite value on consuming the good, the optimal price would generally be one where the agent refuses the contract with positive probability. Calculation of the optimal price is analytically straightforward.

Sappington (1987)]. These papers generalize the pure self selection model to the case where there are n agents. The general flavor of the result is that, in cases where it would have been optimal for the principal to offer a menu of linear contracts with a single agent, it is now optimal for the principal to announce a menu of linear contracts and a preference ordering over them, and then to have agents bid a linear contract from the menu. The agent bidding the most preferred linear contract wins the auction. An interesting technical feature of these models is that there is often a sort of "separability" between the effort-inducement problem and the rent-extraction problem. Adding more agents does not change the relationship between type and effort for the winning bidder. It only changes the amount of rent extracted.

Another interesting line of research has investigated how government should run auctions where firms bid both price and quality, in situations where quality can vary and some aspects of it can be objectively measured [Che (1993)]. In such cases government announces a "scoring rule" that it uses to compare bids with different prices and qualities.

5. Research and development

As discussed in Section 2, innovation is a major product of the procurement process. Producing innovation quite clearly requires unobservable "effort" on the part of defense firms. Therefore government faces an incentive problem. A natural first approach to modeling this would be to attempt to use the models developed in Sections 3 and 4. In the SPP of Sections 3 and 4, the agent exerted unobservable effort to produce units of "output". We chose to interpret units of output as units of "cost reduction", but the same mathematics would still apply if we chose another interpretation for output. In fact, most of the incentives literature does choose other interpretations. Why then, don't the models of Sections 3 and 4 describe the government's problem of inducing firms to perform R&D?

To be more concrete, suppose that the value of consuming a weapons program to government is given by v and the cost of producing the program is given by c. Both of these are affected by R&D work at the design stage. Finding a better design increases v and finding a cheaper way to produce the same design decreases c. The net value or surplus from producing the program is $v-c$, which I will denote by s. Why can't the models of Sections 3 and 4 be applied by assuming that the agent exerts effort to produce units of s?

The answer is that the models of Sections 3 and 4 assume that units of output can be objectively measured for purposes of contracting upon. For the R&D case, this would amount to assuming that government can describe all possible designs in an objectively verifiable fashion, and specify the reward that the firm will be paid depending upon what design it comes up with. Generally speaking this is not possible. There are too many possible designs and no way of objectively measuring their surplus to government. Of course the *ex-post* cost of production can be measured to some extent, and this is one of the factors that determines s. However, so long as the performance of the weapon cannot be completely specified at the beginning of the design phase, attempting to write contracts which rewarded the firm if the *ex-post* production cost turned out to be low would create serious incentive problems. Namely, a firm could always reduce production costs by settling on a design which offered less performance. Therefore, from a modelling standpoint, the distinguishing feature of the R&D phase is that it is a principal agent problem where the agent's output cannot be objectively measured for purposes of contracting upon. Therefore the solution of signing explicit incentive contracts as modelled in Sections 3 and 4 cannot be followed.

In purely commercial markets where there are generally fairly large numbers of consumers for a product, incentives for innovation are created by the patent system. A firm which invents a new idea is allowed to be the owner of it for a number of years and charge "whatever the market will bear". Thus the prospect of earning monopoly profit at the production stage gives firms the incentive to innovate. In the case of defense procurement, the policy of telling firms to invest their own money in R&D and then to charge government "whatever the market will bear" would create severe problems. Firms would generally be unwilling to invest in any R&D because there would be no guarantee of recovering any investment at the production stage, due to the hold-up problem. At a minimum, allowing prices at the production stage to be determined by "free and unfettered" bargaining would create enormous uncertainties and bargaining costs.

As discussed in Section 2, one of government's main responses to this has been to directly fund a large share of R&D itself. That is, unlike most purely commercial markets, government directly buys the intermediate product R&D, as well as buying the products that incorporate this R&D. However, this does not create any incentives for firms to exert effort at the R&D stage.

How does government create incentives for firms to exert effort at the design phase? The method that government appears to use is a "prize" system. Suppose that multiple firms are creating different designs at the R&D phase. Although there is no objectively verifiable signal of the value of s that each firm comes up with, there is an objectively verifiable signal of which firm comes up with the highest s. That is, government will choose the design with the highest value of s to enter production. Therefore, government could create incentives for innovation by committing to a set of regulatory institutions that guaranteed that firms which generate ideas good enough to be adopted by government would receive prizes in the form of economic profit on the production phase of the system. Furthermore, if profit was awarded approximately as a percentage of cost, this might also tend to award larger prizes to more important innovations, at least in a rough sense. It appears that government has followed this strategy [see Rogerson (1989, 1994) for a more extensive discussion].

The basic idea that offering a prize to the winner of a contest will create incentives for contestants to work hard, is simple and clear enough that perhaps no formal modelling is required to elucidate it. However, three more complex and subtle issues related to this do require modelling, and have been considered in the incentives literature.

First, R&D is not simply a one-shot process where a number of firms simultaneously spend money and then each receives a design. R&D is a sequential process, where one can begin with many possible design approaches and narrow the field gradually as intermediate results become known. Taylor (1995) explicitly analyzes how a prize system should be organized in light of the fact that R&D is sequential.

Second, the main focus of the incentives literature has been on the role of asymmetric information at the sole source selection phase in allowing government to make credible commitments to give prizes for innovation. The issue is "How does government credibly commit to award prizes?" Suppose, as was done in Sections 3 and 4, that the principal has all the bargaining power at the source selection phase, in the sense that the principal can make a take-it-or-leave-it offer. If there is no asymmetric information at the source selection phase then, in the absence of any other commitments on the part of the principal, the agents know that they will earn no surplus at the source selection phase regardless of how good their design is. Working backwards, they will therefore have no incentive to perform R&D at the design phase. However, now suppose that there is asymmetric information at the source selection phase. Then agents will expect to earn positive rents at the source selection phase, and in many plausible situations agents will perceive that their expected rents are increasing in R&D effort, so this creates an incentive for R&D. Therefore asymmetric information at the source selection phase may be desirable because it creates a credible commitment on the part of government not to expropriate all the benefits of firms' R&D. This then suggests that government might be able to influence the amount and quality of R&D that firms perform by committing to institutional procedures that affect its ability to extract rent at the source selection phase. In particular, by committing to procedures that reduce competition or reduce the amount of information that government has available at the source selection phase, it may be that firms' incentives to perform R&D would increase [see Laffont and Tirole (1988b), Piccione and Tan (1993), Riordan and Sappington (1989), Tan (1992), Tirole (1986a), and Sappington (1986) for models that explore aspects of this issue].

The third subject investigated by formal models is the "franchise bidding" aspect of the problem that is created by the fact that multiple firms typically perform R&D and then a sole source is selected for production. For a moment, ignore the effects of source selection procedures and pricing procedures in the sole source phase on firms' incentives to perform R&D – this was described above. Even if firms' R&D efforts can be directly controlled by government, the fact that multiple firms bid for the sole source franchise creates some interesting questions. In particular, it is reasonable to expect that much of the profit earned at the sole source production stage will be bid away at the source selection phase. If this is true, there is no reason to necessarily insist on using regulatory institutions at the sole source production stage that extract all the rent at that stage. In particular, one could allow rents to be earned at this stage if this would create some other benefit. Two possible benefits that have been discussed are creating better incentives for the sole source to lower production costs [Riordan (1993), Rogerson (1994)] and creating incentives for more competitive bidding at the source selection phase [Bower and Osband (1991)]. Bower and Osband's argument is particularly clever. They build a model where allowing higher profit rates on sole source production contracts actually reduces over-all expected contractor profits and increases government's welfare. The intuition for their result is that the differential subsidization created by profit policy at the sole source phase (higher-cost producers receive higher markups) encourages more aggressive competition at the source selection phase. This paper very strikingly illustrates the general idea that the procurement stages are interrelated and that policy instruments applied at one stage may have quite surprising and unintended consequences for behavior at other stages. Many more insights remain to be gleaned from procurement models that explicitly model procurement as occurring over three stages – design, source selection, and production – and consider the interlinkages between stages.

6. Multiple periods of production, regulatory lag, and the ratchet effect

An important facet of many real procurement situations that the SPP abstracts away from is the fact that DoD often purchases the same product or closely related versions of the same product over a number of years. Because the design continues to evolve in difficult-to-anticipate ways, and because of uncertainty regarding future demand, long-term contracts cannot be signed. In such situations, even if the firm is initially better informed than government, we might expect much of the firm's private information to be revealed over time as costs of production for each year are observed.

One focus of the theoretical literature has been to highlight the crucial role of commitment ability in such situations. Consider the pure self selection model with a single agent from Section 3. Now, however, assume that the procurement will occur twice and that the agent's type remains the same over both procurements. Such a model has been considered by Laffont and Tirole (1988a). Let $p^*(c)$ denote the optimal contract to offer in the one-period version. It is straightforward to show that, if the principal can make a long-term commitment, the best policy for the principal is to commit to offer $p^*(c)$ both times. However, now consider what happens if the principal cannot make a binding commitment to the period-2 contact. Suppose, for the sake of argument, that the principal initially promises to offer $p^*(c)$ both periods and the agent initially believes him. Then, in period 1, the agent will choose a cost according to his type as described in Section 3. In particular, the principal will be able to precisely infer the agent's type, since higher types choose strictly higher costs. This means that, at the start of period 2, the principal knows the agent's type. Since the principal now knows the agent's type, he will of course no longer want to offer $p^*(c)$. Realizing this at stage 1, the agent will alter his selection of c to take into account the effects of this on the principal's period-2 choice. Laffont and Tirole (1988a) solve for equilibrium behavior in this model. The general flavor of the results is that the inability to commit may make the principal significantly worse off, and that the formal analysis becomes much more complicated than for the one-period case, because the incentive constraints are not as well-behaved. Laffont and Tirole (1990) and Baron and Besanko (1987a) consider the effect of allowing government certain types of commitment ability.

In reality, the most overwhelming stylized fact related to the repeat nature of procurement is that a type of simple regulatory lag behavior seems to occur [Rogerson (1994)]. Each annual procurement occurs under a fixed-price procurement and this year's price is determined largely by last year's cost. This creates a distinct incentive for firms to find ways to lower costs. Namely, if they find a way to lower cost, they can "keep" the savings on the current contract.

It is not completely clear how to square this observation with the theoretical models described above. Should regulatory lag be modelled as the result of government commitment or is it what we would observe when government can make no commitments? The topic of using formal incentive models to normatively and positively analyze the observed behavior of regulatory lag is an interesting subject for future research.

7. Incentives within government[16]

7.1. Introduction

To focus attention on the incentive problem between government and defense firms, the discussion to this point has implicitly viewed government as a single rational actor. But DoD's budget is the size of a small country's GNP and decision-making must necessarily be decentralized among thousands of individuals with potentially conflicting objectives. The way that government organizes its decision-making procedures, and the incentives faced by individual acting in their own self-interest, will affect how these decisions are made. Thus, government faces a massive planning, organizational, and incentive problem of its own, independent of any problems it faces with defense firms [Baron (1993), Leitzel (1993)].

Three underlying factors characterize the defense decision-making process. First, since final decision-making authority rests with Congress and the President, there is no single rational actor with well-defined preferences in control of defense procurement. However, this chapter will set aside political aspects of the procurement process [Mayer (1990)], and instead describe the organizational problem that remains even if a single rational principal – call it "Congress" – pursued the goal of adequate defense at minimum cost. Second, the defense decision making process is enormous and complex. This means that Congress must delegate substantial decision-making authority to lower levels. Within DoD, this delegation has taken the form of individual military services

[16] This section draws from Rogerson (1994).

essentially choosing their own weapons, while the Office of the Secretary of Defense and Congress play a supervisory role. Third, many aspects of DoD's performance – like "preparedness", and whether it was accomplished at minimum cost – are very difficult to measure objectively. In the absence of convenient bottom-line measures of defense performance, it becomes harder to delegate, and more necessary for Congress to control and manage the process. Thus, while the technical complexity and sheer magnitude of the procurement process make delegation of decision-making authority necessary and desirable, the lack of objective overall performance measures limits its value.

An analogy to the organizational problem of a profit-maximizing firm is illuminating. When a board of directors of a large firm delegates authority to management, it can monitor the results by using (admittedly imperfect) objective performance measures like profits and stock-market value. But there is no analog to profit or stock-market value in the Congress/DoD relationship, which is what makes the delegation problem more difficult.

7.2. Two-level models

There are two different types of principal agent models that can be used to capture different aspects of the problem. One type of model is the normal two-level principal agent model where the principal is interpreted as Congress and the agents are interpreted to be the military services or other agencies within DoD. This type of model therefore completely abstracts away from the incentive problem between government and defense firms. One interesting conclusion that has emerged from this type of model is that the military services may derive some of their power to affect policy through strategically controlling program decisions made early in a program's life.

A theme of the literature on government decision-making dating back to Niskanen (1971) is that a goal of government bureaucrats may be to maximize the size of their own budget. It is well-accepted that military services act as though this is one of their primary goals [Fox (1988), McNaugher (1989), Stubbing (1986)].

In Niskanen's (1971) theory, bureaucrats are assumed to be able to maximize their budget by exercising a sort of monopoly power. He assumes that an individual government bureau is the only possible supplier of a particular product and is able to make Congress a take-it-or-leave-it offer. Rather than offer Congress the first-best quantity (where marginal cost equals marginal benefit), the bureau offers Congress the largest quantity that Congress would prefer to having nothing (where total cost equals total benefit). Faced with the offered quantity or nothing, Congress chooses the offered quantity. The bureau then receives a budget sufficient to produce this quantity.

A problem with this theory is explaining why bureaucrats have monopoly power. Why can't Congress simply choose the quantity it wants to? In the case of defense procurement, a different, though somewhat related, theory which does not exhibit this problem can be created to explain how bureaucrats are able to increase their budget. The key fact which this theory is based on is that defense programs are executed over many years. Congress exercises budget authority and thus decides how many units to purchase each year. However, many relatively complex and technical decisions made early in the program's life affect the marginal benefits and marginal costs that Congress will face when it makes annual quantity decisions. In many cases, these early decisions are delegated to the military services and Congress has a difficult time evaluating the technical merits or consequences of these decisions. This means the military services can strategically manipulate Congress's future decisions through their decisions made early in the program's life which affect future marginal benefits and marginal costs.

In this theory, the source of the bureau's power to influence its budget is its informational advantage. Congress can still be viewed as "moving first" or as designing the over-all mechanism that is played. At the outset, Congress has two choices. If it delegates certain decisions to the military, better decisions will be made in a variety of technical dimensions because of the military's greater technical expertise. However, the military may also purposely distort its decisions to alter future marginal benefits and marginal costs of the program and thus manipulate Congress's future decisions over quantities to procure. Congress must weigh the benefits and costs of delegation and then determine how much authority to delegate. Two examples of such decisions will now be described.

The first example concerns the trade-off between quality and quantity. Many institutional analyses of defense procurement have argued that the same expenditures would produce a more effective defense if larger numbers of less elaborate and less technically sophisticated weapons were purchased [Gansler (1980, pp. 15–21), Peck and Scherer (1962, ch. 13), Stubbing (1986, ch. 8)]. This outcome can also be seen as the result of an agency problem between Congress and the military. Rogerson (1990) describes a simple framework where the military chooses the quality of weapons, and then Congress chooses quantity. In this model, the military's goal is to maximize the benefits of military preparedness, while Congress's goal is to maximize the benefits of military preparedness *minus the costs*. The major result is that when quality and quantity are not good substitutes, that the military will purposely choose a quality higher than the efficient level. The intuition behind this result is that the military can increase military preparedness by purposely increasing quality above the efficient level because this induces a relatively small decrease in Congress's quantity choice.

An interesting feature of this model is that the military is assumed to be as good an agent as one could realistically hope for. The military agrees with Congress's definition of military preparedness and makes a good-faith effort to maximize this. If given a fixed budget, the military in this model would always choose quality and quantity to maximize military preparedness. The distortion arises because the military is able to manipulate Congress into increasing the budget by increasing quality. In this model, budget-maximizing behavior on the part of defense bureaucrats is caused by the relatively idealistic goal of maximizing the bureau's production of social benefits.

A second example concerns the decision of what scale of production facility to build. In a model related to the above quality vs. quantity model, Rogerson (1991b) shows that the military can induce Congress to increase the quantity purchased of a weapon by purposely selecting a production technology of too high a scale. The underlying insight is that higher-scale technologies exhibit higher fixed costs, but lower marginal costs. Thus, so long as Congress does not cancel the program, it will buy more when faced with a higher scale technology. This model explains the well-accepted stylized fact that weapons production systematically occurs in production facilities designed to produce at much higher rates than they are actually operated at [CBO (1987), Gansler (1989), Rogerson (1991a)].

7.3. Three-level models

The other type of model to build is a three-level model with a principal, a supervisor, and an agent. In this model, the principal is interpreted as Congress, the supervisor as the military service, and the agent as the defense contractor. The focus of this type of model is to explicitly analyze the hierarchical nature of control within defense procurement. The study of such models is in its infancy, and a large literature on such models addressing the structure of control and authority in organizations is likely to develop over the next few years.

One of the most interesting qualitative insights explored by this literature is the idea that control problems within government may affect the type of incentive arrangements that government is able to offer defense firms. In particular, Congress may limit the type of contractual arrangements that the military services have with defense contractors, because Congress is worried about being strategically manipulated by the military services. Kelman (1990) argues that this explains why Congress delegates so little discretion to DoD officials. Laffont and Tirole (1991) and Marshall, Meurer and Richard (1994a) have built formal models that exhibit this phenomenon. Marshall, Meurer and Richard (1991, 1994b) have analyzed models where the bid protest process is modelled as a device to help Congress monitor and control defense bureaucrats.

An interesting issue that arises in this type of model, is modelling the possibility of collusion between the supervisor and the agent. See Tirole (1986b) and Campbell (1994) for some approaches to this. Tirole (1986b) calculates the optimal "collusion-proof" contract in a model where collusion occurs through legally binding contracts between the supervisor and employee. Campbell (1994) expands upon this line of research by modelling collusion as occurring through non-binding agreements.

8. Conclusion

Formal models of incentive contracting have contributed to our understanding of defense procurement by forcing us to think more explicitly (and thus more clearly) about the nature of the incentive and information problems that affect defense procurement. Much of the modelling thus far has been devoted to the necessary first step of considering fairly simple stylized principal agent problems. Research that builds upon these efforts, to develop models with more institutional and empirical content and models which capture aspects of the multi-stage nature of defense procurement, will surely yield many new insights over the next decade.

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