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Author(s): Patrick Bajari and Steven Tadelis
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Incentives versus transaction costs: a theory of procurement contracts

Patrick Bajari*

and

Steven Tadelis*

Inspired by facts from the private-sector construction industry, we develop a model that explains many stylized facts of procurement contracts. The buyer in our model incurs a cost of providing a comprehensive design and is faced with a tradeoff between providing incentives and reducing ex post *transaction costs due to costly renegotiation. We show that cost-plus contracts are preferred to fixed-price contracts when a project is more complex. We briefly discuss how fixed-price or cost-plus contracts might be preferred to other incentive contracts. Finally, our model provides some microfoundations for ideas from Transaction Cost Economics.*

1. Introduction

■ The procurement problem has attracted much attention in the economics literature. The main focus of this literature has been on procurement by the public sector, in part because of its sheer importance to the economy: procurement by federal, state, and local government accounts for at least 10% of gross domestic product in the United States. (Recent books are Laffont and Tirole (1993) and McAfee and McMillan (1987), which include references to many other studies of government procurement.) Many private-sector transactions are also governed by procurement contracts. Prominent examples include electronics components, custom software, automobile production, and building construction.

Modern economic theories of procurement use mechanism design to model the procurement problem as one of *ex ante* asymmetric information coupled with moral hazard. (See Laffont and Tirole (1993) for a summary of this literature.) Namely, the seller has information about production costs that the buyer does not have. The buyer *screens* the seller by offering a *menu of contracts* from which the seller selects a particular contract, thus revealing his private information.

* Stanford University; bajari@stanford.edu, stadelis@stanford.edu.

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This literature is normative and attempts to prescribe how the procurement problem *should* be addressed under the assumption that *ex ante* asymmetric information is the main concern.

By contrast, the descriptive engineering and construction management literature (summarized in Section 2) suggests that menus of contracts are not used. Instead, the vast majority of contracts are variants of simple fixed-price (FP) and cost-plus (C+) contracts. (In fixed-price contracts, the buyer offers the seller a prespecified price for completing the project. A cost-plus contract does not specify a price, but rather reimburses the contractor for costs plus a stipulated fee.) While carefully examining the literature and speaking with industry participants, we have found little evidence that either the contractor or the buyer has private information at the onset of a procurement project. They both, however, share uncertainty about many important design changes that occur *after* the contract is signed and production begins, such as design failures, unanticipated site and environmental conditions, and changes in regulatory requirements.

An illustrative example of the significance of *ex post* adaptation is the building of the Getty Center Art Museum in Los Angeles, which is a 24-acre, $1 billion facility that took over 8 years to construct. (See *Engineering News-Record*, 1994 and 1997.) The project design had to be changed due to site conditions that were hard to anticipate. The geology of the project included canyons, slide planes, and earthquake fault lines, which posed numerous challenges for the team of architects and contractors. For instance, contractors "hit a slide" and unexpectedly moved 75,000 cubic yards of earth. More severely, in 1994 an earthquake struck. Cracks in the steel welds of the building's frame caused the contractors to reassess the adequacy of the seismic design standards that were used. The project design also had to be altered due to the regulatory environment—107 items had to be added to the building's conditional use permit. These problems were very hard to predict, both for the buyer and the contractor. However, it seems reasonable that once problems arose, the contractor had superior information about the costs and methods to implement changes.

These observations suggest that the procurement problem is primarily one of *ex post adaptations* rather than *ex ante screening*. While it is probably true that there is some asymmetric information about costs before the contract is signed, the choice of contract may not be the mechanism that deals with such asymmetries. Other mechanisms seem to be important in solving the adverse-selection problem. These include competitive bidding, reputation, and bonding companies that insure the buyer against default by the contractor. Accordingly, this article tries to shed light on the economic forces that determine the choice of procurement contracts, and it is motivated by two specific questions. First, if one restricts attention to FP and C+ contracts, when should each type of contract be used? Second, what can explain the widespread use of these two simple contracts?

To answer these questions we develop a simple model (Section 3) that formalizes the procurement problem and is helpful for organizing thoughts. We ignore *ex ante* hidden information and concentrate on problems of adaptation when the initial design is *endogenously incomplete*. Our buyer wishes to procure a product from a seller, where the latter can exert cost-reducing effort that is not contractible. The buyer provides the seller with an *ex ante* design of the product. The more complete the design, the lower the likelihood that both parties will need to renegotiate changes *ex post*. A more complete *ex ante* design, however, imposes higher *ex ante* costs on the buyer. When renegotiation occurs, the seller has private information about the costs of changes to the original design.

Our central analysis in Section 4 compares FP with C+ contracts. We show that simple projects (which are cheap to design) will be procured using FP contracts and will be accompanied by high levels of design completeness (that is, a low probability that adaptations are needed). More complex projects will be procured using C+ contracts and will be accompanied by low levels of design completeness (that is, a high probability that adaptations are needed). This is consistent with the stylized facts that we have found in the construction industry and with facts from other industries as well. We then offer some insight as to why FP and C+ contracts are so prevalent. We point at possible discontinuities (or nonconvexities) in procurement that are plausible explanations for the prevalence of extreme and simple compensation schemes.

The intuition for our central result stems from a tension between providing *ex ante* incentives and avoiding *ex post* transaction costs due to costly renegotiation. Clearly, high incentives (FP) reduce costs, but we show that these same incentives dissipate *ex post* surplus due to renegotiation under asymmetric information. Low incentives (C+), however, do not erode *ex post* surplus but obviously discourage cost-saving efforts. Thus, our model demonstrates a link between *ex ante* incentives and *ex post* renegotiation costs. This is consistent with the documented facts that demonstrate a significant difference in disputes under these two contracts.

Our model is novel in that it treats the choice both of incentives and of design (contractual) incompleteness as *endogenous* variables in the procurement problem. Our analysis demonstrates how the empirical regularities in which these contracting components seem to move together are consistent with the complexity of the project being procured. In Section 5 we discuss how our analysis may shed light on another procurement problem, the celebrated "make-or-buy" decision. Our insights resonate with themes that are central to Transaction Cost Economics (TCE), pioneered by Williamson (1975, 1985). In fact, Williamson expresses the idea that low incentives are good to accommodate *ex post* adaptations and writes (1985, p. 140) that "low powered incentives have well-known adaptability advantages. That, after all, is what commends cost-plus contracting. But, such advantages are not had without cost—which explains why cost-plus contracting is embraced reluctantly." We contribute to the TCE literature by providing a microfoundation for the different transaction/governance costs associated with weak incentives (internal production) and those with strong incentives (market procurement). By focusing on the effect of design-intensive attributes of the product (complexity), our model implies testable predictions that are consistent with several empirical investigations that evaluate TCE.

All proofs are in Appendix A.

2. The building construction industry

■ **Overview.** In 1992, there were 2 million establishments in the U.S. construction industry that completed \$528 billion of work. These firms directly employed 4.7 million workers and had a payroll of \$118 billion (U.S. Department of Commerce, 1992a, 1992b, 1992c). In 1997, the construction industry comprised 8% of U.S. GDP, and worldwide the construction industry was a \$3.2 trillion market (*Engineering News-Record*, 1998).

In general contracting, there is a division of labor between creating the technical specifications, drawings, and designs for the project and the actual construction. The buyer typically first hires an architectural firm to design the project, and the architect often helps the buyer to monitor the contractor's performance while the project is being completed.[1]

Since every construction project is unique, the coordination and management of change are important aspects of successful project management. For example, coordinating construction work at the Getty Center was an extremely complex task. There were over 240 subcontractors and between 900 and 1,200 workers at any given time performing approximately \$100 million per year of construction. The general contractor created a special division of 75 managers and supervisors to oversee construction. The general contractor was brought into the contract four years before construction even began, to help in project planning. Access to the project site posed a major and costly coordination problem. Since there was only one road to the site, a traffic coordinator scheduled access. Traffic was described as a "logistical nightmare." Long backlogs of ready-mix trucks were not uncommon since, in addition to deliveries to specialty contractors, 260,000 cubic yards of concrete were poured. (See *Engineering News-Record*, 1994, 1997.)

An important cost of change is the disruption of the schedule between the general contractor, subcontractors, and suppliers. The general contractor must carefully coordinate the work of many

[1] Other possible organizational forms include design-and-build contracts, force accounting, and construction management, among others. For general descriptions of the building industry, contracting practices and project management, see Bartholomew (1998), Clough and Sears (1994), Finkel (1997), Hinze (1993), and U.S. Department of Commerce (1992a, 1992b, and 1992c).

subcontractors and the deliveries of material suppliers. Schedules are highly interrelated because building construction needs to proceed sequentially—a delay on the part of one subcontractor or supplier can have a domino effect throughout the project. It is our understanding that the costs of coordination are better known to the contractor, which motivates our modelling approach of the renegotiation stage (Section 3).

□ **Construction contracts.** There is a surprising amount of standardization in the contracts used in building construction. The American Institute of Architects (AIA) and the Associated General Contractors (AGC) provide standard forms of contract that are used by many buyers as general conditions for private-sector building. These documents have the advantage that the central clauses are well understood in the industry, and there exists a significant body of case law on the interpretation of the contract conditions. While there are many forms of alternative contractual arrangements used in the industry, cost-plus and fixed-price contracting appear to be the most commonly used.[2] Fixed-price contracts in the private sector tend to be awarded through competitive bidding, while cost-plus contracts are frequently negotiated between a buyer and contractor. Occasionally there are cost incentives in cost-plus contracts that reward (or penalize) contractors for having actual costs below (or above) a cost target that is set at the start of the contract. Cost-incentive contracts are not the industry standard because of difficulties with implementing incentives in the face of changes. A leading problem is the difficulty in establishing fair and equitable cost targets. Any changes due to design failure, buyer priorities, goals, or other factors beyond the contractor's control will require a renegotiation of incentive provisions and cost targets. As a consequence, the working relationship between the buyer and contractor can be spoiled. Ashley and Workman (1986) claim that at a minimum, project engineering must be 40–60% complete to establish reasonable cost and schedule targets. In a survey of contractors and buyers, Ashley and Workman report that only 12% of the respondents use contracts with cost incentives. They also report that incentives on time-to-completion, commonly referred to as liquidated damages, appear to be more commonly used than incentives on costs. A typical set of documents in the contract includes, but is not limited to, bidding documents, general conditions of the contract, specifications, drawings, and reports of investigations of physical site conditions. The general conditions define the roles of the buyer, architect, and engineer, describe the warranty, provide provisions for dispute resolution, outline procedures for adjusting the design and how the payment will be changed, among other provisions. The drawings are also considered a part of the contract documents. The drawings should be sufficiently clear and accurate so that if the contractor conforms to them, a well-constructed product will arise.

□ **Change orders.** The courts have recognized that contractors are entitled to fair compensation for changes to the plans and specifications in a fixed-price contract. For example, Sweet (1994) discusses the case of *Watson Lumber Company* v. *Guennewig* argued in the Appellate Court of Illinois. Watson Lumber Company, a building contractor, was awarded compensation for extras in a building contract for William and Mary Guennewig. In its decision the court stated:

> In a building and construction situation, both the owner and the contractor have interests that must be kept in mind and protected. The contractor should not be required to furnish items that were clearly beyond and outside of what the parties originally agreed that he would furnish. The owner has a right to full and good faith performance of the contractor's promise, but has no right to expand the nature and extent of the contractor's obligation. On the other hand, the owner has a right to know the nature and extent of his promise, and a right to know the extent of his liabilities before they are incurred.

Therefore, in a fixed-price contract, the general contractor will not be willing to perform duties beyond those to which he is contractually bound without additional compensation. Two contractual procedures used to adjust compensation in fixed-price contracts are called *change orders* and *change directives.*

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[2] A commonly used fixed-price contract is AIA Document A101, and a commonly used cost-plus contract is AIA Document A111. Variants of fixed-price contracts occasionally used are unit-price contracts, a series of fixed-price contracts and fixed-price with escalation. (See Business Roundtable (1987), Bartholomew (1998), Clough and Sears (1994), Hinze (1993), and Sweet (1994) for an overview).

A change order is a written amendment to the contract that describes additional work the contractor must undertake and the compensation he will receive. AIA document A201 defines a change order as a

> written instrument prepared by the Architect and signed by the Owner, Contractor and Architect, stating their agreement upon all of the following: (1) a change in the work; (2) the amount of the adjustment in the Contract sum, if any; and (3) the extent of the adjustment in the contract time, if any.

The work and the conditions in a change order are generally determined by bargaining between the buyer, contractor, and architect.

If the parties are unable to reach an agreement, in many contracts the architect has the power to issue a change directive. A change directive is described as

> a written order prepared by the Architect and signed by the Owner and Architect, directing a change in the Work and Stating a proposed basis for adjustment... A construction Change Directive shall be used in the absence of total agreement on the terms of a Change order.

If the contract amount cannot be agreed to by bargaining between the parties, the contractor may be paid by what is called *force accounting*, which is described as follows:

> If the contractor does not respond promptly or disagrees with the method for adjustment in the Contract sum, the method and the adjustment shall be determined by the Architect on the basis of reasonable expenditures and savings of those performing the Work attributable to the change, including, in the case of an increase in the Contract Sum, a reasonable allowance for overhead and profit.

(For more details on change orders, directives, and force accounting, see AIA document A201.)

Change directives give the buyer significant bargaining power in the case of a dispute, and they may be viewed as the threat point in the bargaining process over compensation for changes. This clause gives the buyer the right to reimburse the contractor at cost for all change orders (although in many cases, allowances for profit and overhead are included). In practice, however, the buyer may not choose to do this because of the costs involved. First, writing construction change directives is time consuming and requires considerable administrative effort. Second, excessive changes may lead to indirect costs, such as scheduling problems between the general contractor and subcontractors. Such time delays may be a source of liability for the buyer. Last, a buyer may acquire a reputation for being difficult to work with, causing higher construction costs for future projects. All this implies that under fixed-price contracting, performing changes is accompanied by frictions between the contractor and the buyer, which is a central motivation for our model of renegotiation.

□ **Empirical evidences on contractual arrangements.** There is ample evidence that *ex post* changes are the rule rather than the exception. Hester, Kuprenas, and Chang (1991) study change orders and other forms of disputes in construction projects and document the value of changes as a percentage of the total contract price, as well as the sources of change across several studies of fixed-price contracting. Defective plans and specifications, changes in scope, and unpredictable site conditions account for many of the necessary changes to the original design. In many cases these changes have significant effects on the total costs of the project.

Ibbs et al. (1986) quantify the impact of 96 different contractual clauses on project performance in building construction. The study consisted of a survey of buyers and contractors for 36 building construction projects. The study claimed to verify the conventional wisdoms about cost-plus and fixed-price contracting that are summarized in Table 1.[3]

The first two facts should be no surprise to economists: the allocation of risk is trivial, and a simple multitask model can explain how cost-reducing incentives adversely affect quality (see Holmström and Milgrom, 1991). The other points, however, have not, to the best of our knowledge, been analyzed in the economics literature. Namely, changes are more easily agreed upon under

[3] The dataset collected by the researchers was quite unique, but the usefulness of the analysis is limited by two major factors. First, the hypothesis testing used by these researchers does not explicitly account for the fact that the choice of contractual form is endogenous. Second, in collecting the data, the researchers signed confidentiality arrangements with the firms. These arrangements prohibit us from viewing the survey responses tabulated by survey respondents.

TABLE 1 Comparing FP with C+ Contracts in Construction

	Fixed Price	Cost Plus
Risk allocation mainly on	Contractor	Buyer
Incentives for quality	Less	More
Buyer administration	Less	More
Good to minimize	Costs	Schedule
Documentation efforts	More	Less
Flexibility for change	Less	More
Adversarial relationship	More	Less

C+ contracting, while FP contracts require the buyer to invest more in design and specification. This leads to an advantage of C+ contracting in that the design of the project and the construction of the project can take place simultaneously. This generally reduces total time to project completion but requires more administrative costs. (This is sometimes referred to as "fast-tracking" of the project.)

3. The model

■ **Project design.** Consider a buyer who wishes to procure an exogenously given project for her use, such as a production plant. This requires her to hire a contractor (or seller) who will perform the work according to the buyer's specifications. The buyer's value of the project is $v > 0$ (which is common knowledge) if the project is completed, and zero if not. The time horizon consists of three stages: In the first stage there is uncertainty about how to build the project given realizations that occur during construction. The buyer must supply the seller with a design, which is a specification of instructions that inform and guide the seller on how to proceed with production under different scenarios. Examples of contingencies in design can be (1) what type of foundations are needed given the type of soil, (2) what to do if the prices of alternative building materials change, (3) what air-conditioning system should be installed in case the current choice is discontinued, and (4) how to change plans in case a regulator passes restrictions such as "historic sites" or height limits. In the second stage a contractor is hired and construction begins. In the third stage the actual needs of the buyer are revealed, and the contractor proceeds with construction. In the event that the plans do not account for the realized needs, the parties can renegotiate from the specified status quo. This renegotiation process is modelled in a subsection below.

We proceed by developing a simple model of project complexity and design uncertainty that will motivate an operational reduced form. Let T be the number of states of nature that can occur *ex post*, and let $\pi_t > 0$ be the probability that state $t \in \{1, \dots, T\}$ occurs (states that occur with zero probability are ignored). For example, a state of nature would include the type of foundation needed given the actual soil type, or the specifications of the air-conditioning system given the type of machinery that will be used in the completed building.

Each state must be *ex ante* specified to completely design the project, and we assume that the cost of specifying a state of nature is $k > 0$ regardless of the state of nature. We also assume that $\pi_t > \pi_{t+1}$ for all $t \in \{1, \dots, T-1\}$. These two assumptions imply that from a cost-benefit analysis it is better to first specify a design for state 1, then for 2, and so on. Keeping v fixed, a project is characterized by the pair $\langle T, \{\pi_t\}_{t=1}^T \rangle$.

Definition. Project $\langle T, \{\pi_t\}_{t=1}^T \rangle$ is *more complex* than project $\langle T', \{\pi_t'\}_{t=1}^T \rangle$ if

(i) $T > T'$,

(ii) $\sum_{t=1}^{S} \pi_t < \sum_{t=1}^{S} \pi_t'$ for all $1 \leq S \leq T'$, and
(iii) $\forall S' < T', \exists S < T$ such that $\sum_{t=1}^{S'} \pi_t' = \sum_{t=1}^{S} \pi_t$.

Parts (i) and (ii) imply first-order stochastic dominance. Part (iii) captures the idea that a more complex project is a finer partition of the probabilities over states. This definition is a simple operational way of ordering projects along some scale of complexity, but it provides only a partial ordering over the possible space of projects. We restrict attention to a subset of this space for which condition (i) in the definition above implies conditions (ii) and (iii) and vice versa. This restriction implies that a project can be characterized only by the number of states, so that project T is more complex than project T' if and only if $T > T'$. Alternatively, if the project space is not restricted, our comparative statics will be defined over the relevant subset of ordered projects.

Consider a buyer who wishes to provide a design for project T to guarantee that the project is well specified with probability at least $\tau \in [0, 1]$. The cost of design can be written as the following value:

$$d(\tau, T) = \min_{S \in \{1,\dots,T\}} Sk \qquad \text{subject to } \sum_{t=1}^{S} \pi_t \geq \tau .$$

Lemma 1. $d(\tau, T)$ is nondecreasing in τ and T and exhibits increasing differences in (τ, T).

Proof. All proofs are found in the Appendix.

The economic implications are straightforward: First, for a given level of complexity, design costs are increasing in the probability that the project is well specified *ex post*. Second, the cost of guaranteeing a fixed probability of *ex post* specification is increasing in complexity. Finally, the more complex a project, the higher the marginal cost of increasing the probability of specification.

Using Lemma 1, we continue our analysis with a reduced-form model of project design as follows. Given the project complexity $T > 0$, the buyer chooses a design that is well specified with probability $\tau \in [0, 1]$. The cost of design is given by the function $d(\tau, T)$ that is increasing in T and τ and supermodular in T and τ. Thus, we hereafter treat T as a primitive exogenous parameter, τ as an endogenous choice variable, and $d(\tau, T)$ as the (derived) cost of design.

With probability τ the original design accurately describes the project, and if followed, it gives the buyer a value of v. With probability $1 - \tau$, however, the design fails and modifications are needed to obtain the full value of v. We make the extreme assumption that if the original design fails, and no design changes are made, then the buyer's valuation of the product built *per original design* is zero. This assumption simplifies the analysis and sets simple threat points for the renegotiation stage that follows.

Remark 1. This setup is easily generalized to projects that are given as distributions over a countable number of states, or a continuum. For a continuum, let $G_A(\cdot)$ and $G_B(\cdot)$ be two such distributions for projects A and B respectively. We say that project A is more complex than project B if and only if $G_A(\cdot)$ first-order stochastically dominates $G_B(\cdot)$, and the density is everywhere lower over the support where *both densities are positive*. Indeed, this will mean that $G_A(\cdot)$ has a "fatter" upper tail, and that more states need to be specified in order to achieve the same level of completeness.

Remark 2. Notice that due to our assumption that $\pi_t > \pi_{t+1}$, the increments in design costs are increasing in τ, which seems sensible from an engineering perspective. This is not convexity, since our derived $d(\tau, T)$ is a step function of τ. We will, however, treat this function as continuous in (τ, T) and convex in τ. Convexity is not needed for our comparative statics results, for which only increasing differences are required. Without convexity in τ we will have corner ("bang-bang") solutions, but the qualitative comparative statics will still hold.

Remark 3. A more realistic model of complexity and design uncertainty would account for realizations for which the original design is "close" to the actual needs. For example, without changes the original design will result in a payoff of $\gamma(\tau, T) \cdot v$, where $\gamma(\tau, T) < 1$ reflects the loss from not implementing changes. The gross benefit from renegotiation will then be $[1 - \gamma(\tau, T)]v$, which can easily be incorporated into the analysis. The shape of $\gamma(\tau, T)$ will have bearing on the meaning of complexity, which itself would have to be revisited to ensure a condition of increasing differences for $d(\tau, T)$. It is extremely interesting to fully characterize a general and more realistic model of project complexity and design uncertainty, but this is beyond the scope of the current article and is left for future research.

□ **Construction and change orders.** Following design, a contractor is hired to build the project. We assume that the contractor engages in cost-reducing effort denoted by $e \geq 0$ that is not contractible. The technology is given by the product's cost function $c(e) \geq 0$, which is assumed to be decreasing and strictly convex in e (i.e., $c'(e) < 0$, $c''(e) > 0$). Given effort e, the cost of production *per original design* is perfectly known, but design changes will add noise, as described below. Effort imposes a private cost on the contractor denoted by $g(e) \geq 0$, which is assumed to be increasing and convex (i.e., $g'(e) > 0$, $g''(e) \geq 0$), and we assume that $g(0) = 0$. This specification leads to a standard moral hazard problem.

Design changes are implemented during construction if both parties agree to depart from the original design during renegotiation. (The renegotiation game is fully specified in a subsection below.) Recall that a change is needed if the initial design was inadequate, i.e., the realized state of nature was not specified in the design, which occurs with probability $1 - \tau$. In this case, "filling in" the design should be equivalent to specifying what to do for this particular state, at a cost of k. Aside from the cost of completing the design, the change itself entails production costs. We assume that the cost of change is *ex post* private information for the contractor and is equal to some value $m \in [0, v - k]$ that is distributed according to the cumulative distribution function $F(\cdot)$ (with density $f(\cdot) > 0$), which is common knowledge. Together with the assumption that the whole value v is lost unless renegotiation occurs, $m \leq v - k$ implies that it is always first-best optimal to describe and implement the change.

□ **Contracting.** Following the discussion in Section 2, a contract includes two elements. The first is the *specifications, drawings, and reports*, which are summarized by τ. The second is a *compensation scheme, $p(c)$*, which defines a transfer from the buyer to the seller upon completion of the project. Since costs are verifiable in our model, we allow the compensation scheme to depend on c.

Note that if changes are not required, then contracting on costs c is equivalent to contracting on effort e, since there is a one-to-one correspondence between $c(e)$ and e. The problem is not trivial, however, since the possibility of design changes provides noise and generates tradeoffs. This requires the following assumption about cost-based compensation:

Assumption 1. The product's total costs are verifiable, but the costs of modifications cannot be independently measured.

This assumption implies that when modifications are needed, the original costs $c(e)$ and the added costs m cannot be disentangled. For example, in the middle of construction the buyer might ask to raise the height of the first floor. This would entail additional labor and material that is used *in parallel* to the original plan's specifications, and it would be impossible to accurately measure the incremental costs associated with the modification. Another way to view this is that the costs of counterfactuals (the abandoned original design) cannot be measured, so incremental costs due to changes in the original design likewise cannot be measured. Clearly, monitoring technologies that would undermine this assumption would cause different optimal contracts to arise, as discussed below. In summary, Assumption 1 rules out compensation schemes that are based on the costs of modification, which is important in our analysis and is discussed further at the end of this section.

We assume that there is a competitive market of potential sellers, so that *ex ante* the buyer can offer a contract that guarantees the seller zero expected profits. This zero-profit condition will be useful for our analysis, but allowing the seller to capture some positive *ex ante* surplus will not alter our qualitative results.

Finally, we will restrict attention to linear contracts of the form $P(c) = \alpha + \beta c$, where $\beta \in \{0, 1\}$ can take on only two extreme values. Notice that $\beta = 0$ is a fixed-price contract with a price of α, whereas $\beta = 1$ is a cost-plus contract that reimburses the contractor for costs and gives him an additional compensation of α. In our framework the restriction to linear contracts is without loss, as shown in Appendix B. The restriction to the two extreme values is arbitrary, but in Section 4 we shall offer some plausible explanations for the prevalence of these extreme contracts.

□ **Renegotiation.** With probability $1 - \tau > 0$ the parties will have to renegotiate the contract for the buyer to receive the value v. From the setup above, the disagreement payoffs are well defined. Regardless of the realized state of nature, the contractor can complete the project per original design and receive his payment of $\alpha + \beta c$, paid for by the buyer. The buyer's benefit, however, does depend on the state of nature; she receives the benefit v when the design covers the particular state, while she receives zero otherwise, unless the parties agree to modify the design.

We model the renegotiation stage as a reduced-form game: with probability $\lambda > 0$ the buyer makes the seller a take-it-or-leave-it (TIOLI) offer, and with probability $1 - \lambda > 0$ the seller makes the buyer a TIOLI offer. Clearly, the party making the offer will capture all the surplus from renegotiation. However, given that the seller has private information, there is scope for *ex post* inefficiencies, as will indeed be demonstrated shortly.[4] For analytical convenience both parties are assumed to be risk neutral.

Renegotiating fixed-price contracts. If a FP contract is chosen, then when the buyer makes a TIOLI offer she chooses a payment w to maximize her expected *ex post* payoff given by

$$F(w) \cdot (v - w) - k,$$

which yields the first-order condition with respect to w, $f(w) \cdot (v - w) - F(w) = 0$, or

$$w^* = v - \frac{F(w^*)}{f(w^*)} < v. \tag{1}$$

Thus, we get the standard distortion of a monopoly facing a downward-sloping demand curve, where this demand curve is generated from the private information of the seller. If $F(w)/f(w)$ is increasing in w (satisfied by any log-concave distribution of m, such as uniform), then there is a unique solution to (1), and $w^* < v$ implies that there is a positive probability that renegotiation breaks down.

If the seller is making the TIOLI offer he will clearly ask for v, since this is what the buyer has to gain, and this leaves the buyer with the sunk cost of additional design k and the seller with the *ex post* profits $v - m$. Therefore, if the status quo contract is a FP contract, then we can summarize the expected utility of the buyer and the expected profits of the seller from renegotiation as

$$Eu_{RNG}^{FP} = \lambda F(w^*)(v - w^*) - k,$$
$$E\pi_{RNG}^{FP} = \lambda \left(F(w^*)w^* - \int_0^{w^*} m dF(m) \right) + (1 - \lambda) \left(v - \int_0^{v-k} m dF(m) \right).$$

Renegotiating cost-plus contracts. Now imagine that the relationship is governed by a C+ contract. When the buyer makes a TIOLI offer, she can do no better than to offer the contractor to do the change *without amending* the C+ contract. The added costs due to the change, m, are less or equal to the benefit $v - k$, and thus following the original C+ contract gives the buyer all the surplus. When the seller makes the TIOLI offer he can extract no more than the buyer's expected benefit, which is $v - E[m]$ (where E is the expectations operator). Therefore, when the status quo contract

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[4] We thus assume full commitment for the party making the offer, so that rejection causes loss of all surplus. This is a simplifying assumption. The conclusion that incomplete information causes bargaining inefficiencies is consistent with a wide class of bargaining models.

is a C+ contract, we can summarize the expected utility of the buyer and the expected profits of the seller from renegotiation as

$$Eu_{RNG}^{C+} = \lambda\left(v - \int_0^{v-k} m dF(m)\right) - k,$$
$$E\pi_{RNG}^{C+} = (1-\lambda)\left(v - \int_0^{v-k} m dF(m)\right).$$

Notice that the right to *demand* changes is *not* part of the C+ contract. Instead, the complete flexibility is achieved by the fact that a C+ contract is a well-defined compensation scheme that guarantees the seller his outside option of zero. When the seller makes a TIOLI offer in our model, he extracts the buyer's surplus and α increases as a result (*ex ante* individual rationality). When the buyer makes the TIOLI offer, the seller is set to his outside option, which is zero, and the C+ contract does not change. It is interesting to note that in our model, the seller is offered an initial compensation that does not cover his expected costs. This follows from the fact that the seller expects to get positive expected *ex post* surplus when changes are required. This is a rather realistic aspect of the model. (In reality, bigger changes include both more costs and more time to implement them. If the contractor's outside opportunity is not zero, as reality suggests, then bigger changes would require more compensation. Choosing $\beta > 1$, which is common but cost inefficient (it gives incentives to increase costs), may be a response to reduce haggling over the contractor's willingness to continue under C+ contracts.)

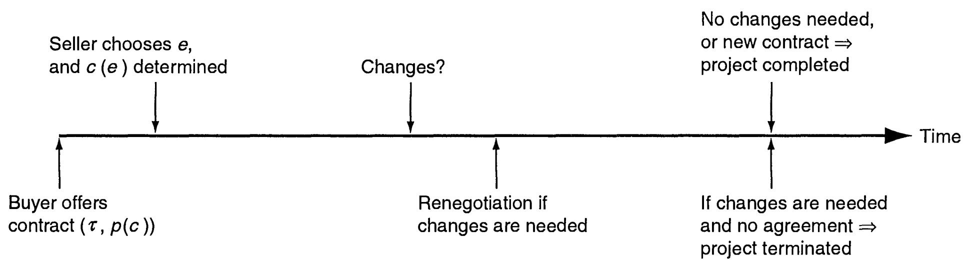
Several points are warranted given the stark and crude structure of our renegotiation game. First, if the seller had all the bargaining power, then no inefficiency would arise at the renegotiation stage. In fact, if the parties can commit in the *ex ante* contract that the seller has all the bargaining power in case of design failure, then they can circumvent this inefficiency. This scheme, however, would undermine our reduced-form bargaining game. Thus, it is implicitly assumed by our reduced-form game that design failure is not verifiable. With nonverifiable design failures the seller would hold up the buyer's design investment and always claim that failure occurred. Indeed, nonverifiability of design failure and the potential for seller holdup would be a good reason to grant the buyer the bargaining power. This is consistent with the practice of change directives as described in Section 2.

Second, after renegotiation the parties continue with the same type of contract they began with, either FP or C+. This implicitly assumes that the parties can't measure total cost after renegotiation accurately unless they chose a C+ contract *ex ante*. If we allow for such shifts at the renegotiation stage from a FP to a C+ contract, then the optimal contract is to start with FP and renegotiate to C+, which reduces incentives (through the seller's correct foresight of renegotiation) but eliminates renegotiation costs. To restore *ex ante* selection of C+ contracts, we would need to add noise to the construction costs $c(e)$, as is standard in moral hazard models. This would restore the bargaining inefficiencies because inefficiencies arise either from unknown postbargaining payoffs (our case in FP) or from unknown disagreement points (the result of a random $c(e)$).

Third, in reality one would expect that the buyer too has some private information at the renegotiation stage with respect to her value from the change. It is easy to extend the model in this way so that when the seller makes his TIOLI offer then an inefficiency will arise for both types of contract, while the buyer's TIOLI offer still has no inefficiencies when a C+ contract is in place. (For example, if the value from the change is $v \in [\underline{v}, \overline{v}]$ and $m \in [0, \underline{v} - k]$.) This would cause more bargaining inefficiencies under FP contracts, which would preserve the nature of our analysis.

In summary, there is a fundamental difference between having a FP or C+ contract governing the relationship. A C+ contract is a *well-defined compensation scheme* for both the initial design and any modifications that are requested, as long as compensation is based on total costs. If a FP contract was initially chosen, then the compensation scheme is a *specific performance*

FIGURE 1
SEQUENCE OF EVENTS



compensation scheme and cannot account for modifications, resulting in *ex post* inefficient bargaining. The time line in Figure 1 is provided to clarify the sequence of events.

Remark. Asymmetric information at the renegotiation stage implies that a menu of contracts should be offered by the uninformed principal. This is indeed the case with FP contracts: the TIOLI offer explicitly states two continuations, perform or quit. With C+ a menu would not improve utilities. This all follows from our all-or-nothing assumption on the buyer's value. If there are several potential changes with different costs and benefits, more elaborate menus should be used, but our qualitative results on selective friction would not change. It would be reasonable to argue that the role of negotiations is to nail down the choice from such a menu.

4. Fixed price or cost plus?

■ We turn to our first question: If the buyer was restricted to choose between a FP and a C+ contract, when should each be chosen? We begin by examining the *ex ante* expected payoffs under the two extreme contractual arrangements we consider here.

□ ***Exante* payoffs: FP.** A FP contract has $\alpha > 0$ and $\beta = 0$, so that the seller's *ex ante* expected profit is

$$\begin{aligned} E\pi^{FP} &= \alpha - c(e) - g(e) + (1-\tau)E\pi^{FP}_{RNG} \\ &= \alpha - c(e) - g(e) \\ &\quad + (1-\tau)\left[\lambda\left(F(w^*)w^* - \int_0^{w^*} m dF(m)\right) + (1-\lambda)\left(v - \int_0^{v-k} m dF(m)\right)\right]. \end{aligned} \tag{2}$$

The seller maximizes (2) to obtain his optimal effort choice under a fixed-price contract, e^{FP}. Notice that the seller bears all the construction costs, $c(e)$, and the private costs of effort, $g(e)$, implying that his choice of effort will be first-best optimal. The buyer's expected utility is given by

$$\begin{aligned} Eu^{FP} &= \tau v - \alpha - d(\tau, T) + (1-\tau)Eu^{FP}_{RNG} \\ &= \tau v - \alpha - d(\tau, T) + (1-\tau)\left[\lambda F(w^*)(v - w^*) - k\right], \end{aligned}$$

which she maximizes taking the seller's effort e^{FP} as given. Recall that by assumption the seller earns zero expected profits, so we can substitute α from equating (2) above with zero, and simple algebra yields the following representation for the buyer's utility:

$$\begin{aligned} Eu^{FP} &= v - c(e^{FP}) - g(e^{FP}) - d(\tau, T) \\ &\quad - (1-\tau)\lambda(1 - F(w^*))v \end{aligned}$$

$$- (1-\tau)\left[\int_0^{v-k} mdF(m) - \lambda \int_{w^*}^{v-k} mdF(m) + k\right]. \tag{3}$$

The first line captures the value from having the project completed, less the costs of construction, effort, and design. The second line represents the loss of efficiency due to bargaining under asymmetric information: with probability $(1-\tau)\lambda(1-F(w^*))$ the buyer will make a TIOLI offer that is rejected, and lose the gross value v. The third line represents the expected cost of modifications.

In other words, the buyer gets the benefits v, bears all the costs of construction, effort, and design, and finally will bear a *friction* in case the design fails due to inefficient *ex post* bargaining under asymmetric information. This friction is the loss of gains from renegotiation, which is equal to

$$(1-\tau)\lambda(1-F(w^*))v - (1-\tau)\lambda \int_{w^*}^{v-k} mdF(m). \tag{4}$$

Notice also that w^* is not a function of τ, so the gross loss (the first part of (4)) can be rewritten as $(1-\tau)\sigma v$, where $\sigma \equiv \lambda(1-F(w^*))$ is the *endogenous friction* arising from inefficient *ex post* bargaining. We can now rewrite (3) as

$$Eu^{FP} = v - c(e^{FP}) - g(e^{FP}) - d(\tau, T) - (1-\tau)\sigma v - (1-\tau)K_1, \tag{5}$$

where $K_1 \equiv \int_0^{v-k} mdF(m) - \lambda \int_{w^*}^{v-k} mdF(m) + k$ is the expected costs of modifications following renegotiation. Thus, (5) represents a reduced form for the derived expected utility of the buyer from a FP contract.

□ ***Exante*** **payoffs: C+.** A C+ contract has $\beta = 1$, and α derived to guarantee the seller expected zero profits *ex ante*. The seller's *ex ante* expected profit is

$$\begin{aligned} E\pi^{C+} &= \alpha - c(0)g(e) + (1-\tau)E\pi_{RNG}^{C+} \\ &= \alpha - c(0)g(e) + (1-\tau)(1-\lambda)\left(v - \int_0^{v-k} mdF(m)\right). \end{aligned} \tag{6}$$

This problem clearly implies that the seller will choose no effort, $e^{C+} = 0$, which is suboptimal. As before, this is not affected by the buyer's choice of design, τ.

Turning to the buyer, her expected utility is given by

$$\begin{aligned} Eu^{C+} &= \tau v - \alpha - d(\tau, T) + (1-\tau)Eu_{RNG}^{C+} \\ &= \tau v - \alpha - d(\tau, T) + (1-\tau)\left[\lambda(v - \int_0^{v-k} mdF(m)) - k\right], \end{aligned}$$

which she maximizes over τ taking the seller's effort $e = 0$ as given. As before, substitute α from equating (6) above with zero, and simple algebra yields the following representation for the buyer's utility:

$$Eu^{C+} = v - c(0) - g(0) - d(\tau, T) - (1-\tau)K_2, \tag{7}$$

where $K_2 \equiv \int_0^{v-k} mdF(m) + k$. That is, the buyer gets the benefits, v, and bears all the costs of construction, effort, design, and the expected cost of modifications. Notice that with C+ contracts the value of design is not reducing friction, just reducing the expected costs from modifications.

□ **Comparative analysis.** Notice the differences between the C+ problem, (7), and the FP problem, (5). C+ contracting has no friction, since the inefficiencies due to asymmetric information do not arise, even though there is still asymmetric information. Thus, our model demonstrates that the efficiency of *ex post* renegotiation is affected by the *ex ante* contract that the parties sign, which implies that renegotiation costs, or transaction costs, are endogenous. This plays a key role in the costs and benefits of the two contracting arrangements.

Benchmark: exogenous design. We describe two benchmark cases to illustrate the simple economic forces that describe the tradeoff between FP and C+ contracts in the model. First, consider the extreme case in which the buyer is given a product that comes with a complete specification and requires no initial resources for design. That is, $\tau = 1$ is given exogenously, and the cost of design, $d(\cdot)$, is zero. Following the analysis described in Section 4, if a FP contract is chosen, then the contractor will choose effort e^{FP}, and from (5), the buyer's expected utility from a FP contract is given by

$$Eu^{FP} = v - c(e^{FP}) - g(e^{FP}),$$

since there will be no renegotiation given the complete design ($\tau = 1$). If, however, a C+ contract is chosen, then $e^{C+} = 0$ and the buyer's expected utility is given by

$$Eu^{C+} = v - c(0).$$

In this benchmark case, we obtain the following result:

Lemma 2. If $\tau = 1$ is exogenously given, then FP contracts dominate C+ contracts.

The intuition for this result is quite straightforward. If there is no cost to complete the design, then FP contracting gives the contractor an incentive to invest optimally in cost reduction, and *ex ante* competition transfers these cost savings directly to the buyer. Since no costly renegotiation occurs, a FP contract induces (first-best) cost reduction without introducing renegotiation costs.

Now consider the opposite extreme case, in which the buyer has a project T, but $\tau = 0$ is exogenously set. In this case the buyer's expected utility from a FP contract is given by

$$Eu^{FP} = -c(e^{FP}) - g(e^{FP}) + (1 - \sigma)v - K_1, \tag{8}$$

since renegotiation will occur with probability one when no *ex ante* design is provided. If a C+ contract is chosen, then $e = 0$, and the buyer's expected utility is

$$Eu^{C+} = v - c(0) - K_2. \tag{9}$$

In this benchmark case of $\tau = 0$, comparing (8) with (9) shows that a C+ contract dominates a FP contract if and only if

$$\sigma v + g(e^{FP}) \geq c(0) - c(e^{FP}) + K_2 - K_1.$$

The intuition is again straightforward. If $\tau = 0$ is exogenously set, then the gains from choosing a FP contract over a C+ contract are the incentives for cost-reducing effort, $c(0) - c(e^{FP})$, and saving modification costs when renegotiation breaks down, $K_2 - K_1$. The costs of a FP contract are that first, the contractor needs to be compensated for his effort by the amount $g(e^{FP})$, and second, a proportion σ of the remaining surplus will be dissipated through inefficient renegotiation. When the costs outweigh the benefits, then choosing a C+ contract is optimal.

This subsection demonstrated that FP contracts create strong cost-reducing incentives, which benefit the buyer through the *ex ante* competition between potential contractors. But if the design fails, then some surplus will be eroded by the frictions of *ex post* renegotiation The next subsection completes the analysis by endogenizing the choice of design completeness and then demonstrating the comparative analysis between the two contractual arrangements.

Endogenous design. To proceed, let $x \in \{0, 1\}$ denote the contractual compensation choice of the buyer, where $x = 1$ is a FP contract and $x = 0$ is a C+ contract. The buyer then maximizes

$$\max_{\substack{x \in \{0,1\} \\ \tau \in [0,1]}} x \left[v - c(e^{FP}) - g(e^{FP}) - (1 - \tau)(\sigma v + K_1) \right] + (1 - x) \left[v - c(0) - (1 - \tau) K_2 \right] - d(\tau, T).$$

Proposition 1. The buyer's optimal choices $x(T)$ and $\tau(T)$ are monotone nonincreasing in T.

To put the proposition in words, more complex products have a less complete design and are more likely to be procured using C+ contracts. The intuition is almost identical to that described in the previous subsection, in which the design was considered exogenous. The effect of complexity on endogenous design is linked to the choice of the compensation scheme by the complementarity characteristics of the derived function $d(\tau, T)$. When a C+ contract is chosen, then savings on design costs (lower τ) are warranted because renegotiation friction is eliminated. When a FP contract is chosen, then to reduce inefficient *ex post* renegotiation there is a need to have a more complete design (higher τ). As described earlier, when design is fairly complete the gains from cost incentives outweigh the losses from inefficient renegotiation. When the design is fairly incomplete the losses from inefficient renegotiation outweigh the benefits from cost incentives. Notice that $\tau(T)$ nonincreasing does not mean that as complexity increases then the buyer specifies fewer states if, for example, the contractual choice does not change from FP to C+. What this means is that even if more states are specified, the design is (weakly) less complete and τ is (weakly) smaller.

This conclusion is consistent with the stylized facts described in Table 1. Our result explains why more design documentation is linked to the choice of FP contracts, and it can shed light on the tradeoff between cost reduction and time to completion. Namely, if one considers T to be a combined measure of complexity per unit of time invested in design, then saving time is equivalent to less design in our model. Thus, a buyer who wishes to engage in "fast tracking" is indeed better off choosing a C+ contract as observed in the stylized facts (Section 2).

Remark. Notice that Assumption 1 (total costs are measurable but modification costs are not) prevents the buyer from writing an initial FP contract and later requesting changes using a C+ contract. If such a contract is feasible, it clearly is optimal: it provides efficient incentives and has no *ex post* inefficient bargaining. Though the intuition of the tradeoff between incentives and bargaining costs is rather straightforward, without this assumption the tradeoff would not be generated by our model. In a sense, this observation is due to the model, and discussions with practitioners verify the validity of this assumption.

□ **The comparative statics of friction.** In the reduced-form representation of the buyer's maximization problem, the friction is characterized by $\sigma > 0$. It is interesting to ask the following question: If renegotiation friction increases due to more severe asymmetric information (or other sources of friction), what will the effects on the contractual arrangement be? The following result answers this question.

Proposition 2. The buyer's optimal choice $x(\sigma)$ is monotone nonincreasing in σ, and her optimal choice $\tau(\sigma)$ is nonmonotonic in σ.

The intuition is simple. As friction increases, the loss from inefficient renegotiation of a FP contract increases, making it less desirable. As for the completeness of design, this depends on the choice of the compensation scheme. If parameters are such that a FP contract is chosen ($x = 1$), and friction increases without changing the optimal choice of x, then it will be beneficial to provide more design to mitigate the loss from renegotiation of a FP contract. If the optimal regime is a C+ contract, and friction increases, then the optimal contract will still remain a C+ contract, and design completeness will be unchanged. The difficulty arises when an increase in friction causes the regime to change from FP to C+. In this case there will be a discontinuous reduction in τ because of the shift to frictionless renegotiation due to the C+ contract.

This suggests that reducing friction is beneficial for three reasons. First, it trivially reduces the *ex post* inefficiencies from costly renegotiation. Second, it may allow the buyer to save on design costs and face a higher probability of renegotiation. Finally, it increases the use of FP contracts, which generate cost incentives and lower construction costs. The interesting question is how buyers and sellers can cause frictions to be lower. One answer may be by using third parties as arbitrators, which seems to be a common practice in the construction industry. Clearly, this finding begs for more careful analysis of how costly renegotiation can be reduced in different procurement settings.

□ **Optimality of extreme contracts.** Consider the more general problem in which all linear contracts $\beta \in [0, 1]$ are considered. Under the continuity conditions we have assumed, the objective function over the domain $\beta \in (0, 1)$ is continuous in β. Thus, we can find functional forms and parameter values to support any $\beta \in (0, 1)$ as a solution, and in this more general problem the analogy to Proposition 1 is that $\beta(T)$ and $\tau(T)$ are monotone nonincreasing in T. Why then are most observed contracts either FP or C+? Two simple observations seem to make the procurement problem "nonconvex" at these extreme contracts, and this subsection will outline two simple ways to modify our model and address these issues. We refrain from performing the actual analysis, since it seems quite predictable, and further algebra would add very little.

First, we argue that there is a fundamental difference between a FP contract ($\beta = 0$) and any other cost-sharing contract with $\beta \in (0, 1]$. This follows because a FP contract *does not require the measurement of construction costs*, whereas any cost-sharing contract requires such measurement. This obvious fact, which is documented in the engineering-management literature, leads to a clear nonconvexity in the cost of measuring and monitoring product costs. An immediate implication of introducing measurement costs is that FP contracts will dominate contracts that are "close" to FP, and as it becomes costlier to measure costs, FP contracts will dominate a larger set of incentive contracts.

Second, we argue that there may be a fundamental difference between a C+ contract with $\beta = 1$ and other incentive contracts with $\beta < 1$. Consider a richer model in which the seller engages in two tasks, as introduced by Holmström and Milgrom (1991). For example, the seller can exert effort in cost reduction, e_c, and effort in quality enhancement, e_q. Holmström and Milgrom impose two extreme assumptions: (1) the tasks are perfect substitutes in the seller's private cost function, $g(e_c + e_q)$, and (2) costs are verifiable but quality is not. With these extreme assumptions Holmström and Milgrom show that giving the seller incentives to reduce costs will cause him to ignore quality considerations completely and engage only in cost reductions.[5] Thus, in our simple model that ignores quality considerations, there exist solutions β close to 1 (close to C+) that are no longer optimal once quality concerns are introduced.

McAfee and McMillan (1986) analyze a model in which risk-averse agents (contractors) bid and the buyer is faced with both adverse selection and moral hazard. In their model the tradeoff between risk sharing, incentives, and information revelation cause incentive contracts that lie between FP and C+ to be generally desirable. In fact, C+ contracts are never optimal in their model because they give the contractor no incentive to bid aggressively. McAfee and McMillan acknowledge that most government contracts are FP, and some are C+, and they use their results to encourage more use of incentive contracts. Our arguments shift the focus of attention and try to rationalize the use of these extreme contracts.

It is hard to assess the magnitude of such nonconvexities, though their existence is suggested by the stylized facts. Furthermore, our stylized model cannot address the relative performance of these extreme contracts compared to intermediate ones, since it is hard to imagine that these nonconvexities are so extreme as to eliminate all intermediate contracts. Clearly, other sources of monitoring costs would affect the choice of contracts, such as the ability to monitor quality and performance *ex post*. Trying to understand the prevalence of these extreme contracts is very much still an open question, and we can only offer limited insights at this stage. Note that these nonconvexities, together with the need for design specification, are related to the problem of measurement introduced by Barzel (1982).

5. Discussion

■ **Relation to the literature.** We depart from many of the central themes illustrated by the standard theoretical literature on procurement contracting. First, we depart from the mechanism-design approach of Laffont and Tirole (1993) by assuming no *ex ante* hidden information. While

[5] In a different context, Manelli and Vincent (1995) show that if the buyer cares a lot about quality, using an auction mechanism (which is associated with a fixed price) is not efficient.

it is probably true that there is some asymmetric information about costs before the contract is signed, the optimal choice of contract may not be the mechanism that deals with such asymmetries. Other mechanisms, like competitive bidding, reputation, and third-party bonding companies, seem to be important in solving the adverse-selection problem.

As for its positive implications, the mechanism-design methodology predicts that (i) screening of sellers should occur via menus of contracts; (ii) we should see various strengths of incentives, not primarily FP or C+; (iii) the likelihood of renegotiation is not related to types of contract;[6] (iv) the distribution of "types" should affect incentives, rents, and compensation; and (v) project complexity/design are ignored and thus not related to the choice of contract. As we describe in Section 2, the facts do not seem to support predictions (i), (ii), and (iii), and the mechanism-design approach cannot account for the strong empirical regularities that (iv) ignores. The comparative statics of (iv) on the distributions of types are not very useful, since it is possible to rationalize any choice of contracts with the right asymmetry of information. Finally, the mechanism-design approach assumes that sellers do not compete for projects, which is instrumental in deriving the results of that literature. This assumption seems to be inadequate for many industries.

Second, we depart from the standard contracting literature by making the product design and specification endogenous.[7] At one extreme, the mechanism-design literature assumes that writing contracts is costless, while at the other extreme, the incomplete-contracts literature pioneered by Grossman and Hart (1986) assumes that writing contracts is prohibitively expensive. In our model, both the form of compensation and the completeness of design are endogenous choice variables and are related in a systematic way: FP contracts feature high levels of design, strong incentives, and significant friction when changes are required. C+ contracts feature low levels of design, weak incentives, and small amounts of friction. Another contrast to the incomplete-contracts literature is that we do not assume efficient *ex post* renegotiation. We endogenously derive a relationship between *ex ante* incentives and *ex post* renegotiation that results in selective friction. The selective friction we derive seems consistent with the stylized facts on the intensity of contract disputes.

□ **Evidence from other industries.** It is evident that *ex post* adaptation is important in other industries and procurement settings. For example, change orders are common in defense procurement, as Rogerson (1994, p. 67) notes: "Significant unanticipated changes almost always occur, which leads to renegotiation where there is an inevitable tendency to ascribe all cost overruns to the changes." Our analysis suggests that if the likelihood of changes to a design is large, then the buyer should choose weak incentives, whereas strong incentives should govern purchases that are less likely to involve changes. Crocker and Reynolds (1993) find that Air Force engine procurement contracts are based more on cost reimbursements and adjustments at initial production stages. These initial stages are those where changes are expected (initial batches of production). Later production stages involve fixed-price contracts. These later stages are performed after initial production problems were resolved by change orders. This is consistent with our predictions.

A recent study by Banerjee and Duflo (2000) examines the choice of contracts in the Indian customized software industry. They construct and analyze a dataset of 236 contracts, which are either FP or C+ (time and material) contracts. Their main empirical finding is that older firms (sellers) are more likely to be engaged in cost-plus contracts compared to young firms. They interpret age as a measure of reputation and conclude that a seller's reputation affects his contract. They also show that older firms, and firms that are ISO-certified, do on average larger and more

[6] More precisely, in a dynamic mechanism-design model, contracts will be renegotiated to change the incentive structure after the buyer learns information about the seller. In reality, renegotiation seldom changes the overall compensation scheme but rather changes the product specification in return for added compensation. In C+ contracts the added compensation is well specified *ex ante*.

[7] Endogenous incomplete contracts arise in the analysis of Dye (1985), who developed a model with costly specification of contingent actions in a competitive equilibrium framework. Battigalli and Maggi (2000) offer a different, but related, approach to modelling contractual incompleteness. These articles do not link *ex post* renegotiation to the incentives of the *ex ante* contract.

complex products than younger or non-ISO-certified firms. These results are not inconsistent with our model. A software project that is simple, or small, will be easy to design, which in turn calls for a FP contract. It is reasonable to argue that in the software industry, young (small) firms will generally bid lower and more aggressively to establish themselves as capable, or because larger and more established firms have higher overhead and greater profit margins. If, however, the project is complex or large, then design is more costly, resulting in less complete design and a C+ contract. In the latter case, since competitive bidding is not an option, then the buyer needs to select a firm using other criteria. If there are concerns about a software firm's ability to carry out a complex project (ignored in our model), then we would expect the buyer to care about reputation, which indeed may be evaluated by age or, more likely, by certification. Thus, a similar correlation identified would be interpreted by a different causality: the type of product determines the contract, and the latter determines the type of firm selected.

□ **The make-or-buy decision.** Our framework may shed some light on the celebrated "make-or-buy" question that lies at the heart of what determines a firm's boundaries: which activities should be performed inside the firm, and which should be procured across the market?[8] To apply our insights to this question, consider a buyer (firm) who faces the decision of whether an input component will be produced inside the firm (make) or purchased on the market (buy). A "make" decision has the buyer bear all the costs of producing the component, and the relationship between the buyer and the "unit" that produces the good is like a C+ contract. Similarly, a "buy" decision has the seller (a different firm) bear all the cost of producing the component.

Our analysis then suggests that the complexity of the component determines the buyer's choice. Namely, a simple component that is easy to define will be bought, while a complex component will be procured internally. These insights resonate with Williamson (1975, 1985), who addressed the tradeoff between incentives and governance costs and noted that "internal organization often has attractive properties in that it permits the parties to deal with uncertainty/complexity in an adaptive, sequential fashion..." (1975, p. 25) and that "a high degree of bilateral dependency exists in those circumstances and high powered incentives impair the ease with which adaptive, sequential adjustments to disturbances are accomplished" (1985, p. 91). However, Williamson did not spell out *why* it is that *ex post* adaptation is easier in the firm compared to the market.

Riordan and Williamson (1985) extend Williamson's arguments to include neoclassical choices such as scope and scale, and their analysis of binary institutional choice is similar to our reduced-form structure. However, Riordan and Williamson "employ a reduced-form type of analysis, in that we ascribe rather than derive the basic production and governance cost competencies of firms and markets" (p. 366). Given that their reduced form is tailored to the vertical-integration decision, and the ascribed governance costs are not derived from a structural model, it is difficult to adapt their analysis to the choice of procurement contracts or to understand what might drive such results. In contrast, our model derives, rather than ascribes, the costs and benefits of different contractual forms based on specific tradeoffs between incentive provision and renegotiation costs.

Our approach contributes to the TCE literature in two ways. First, we formalize how the product's complexity affects the choice of incentives, and we highlight the endogenous transaction costs that arise from *ex post* bargaining. This, together with our agency approach, erects a comprehensive bridge between the less formal TCE literature and the more formal models of modern agency theory. Second, by focusing on product complexity as the determinant of the make-or-buy decision, our approach has clear empirical predictions. Indeed, several well-known empirical studies provide evidence that supports this conclusion. For the aerospace industry, Masten (1984) shows that both a higher degree of specialization (specificity) and a higher level of complexity will increase the probability of internal procurement. For the automobile industry,

[8] This agenda was pioneered by Coase (1937) and developed further by Williamson (1975, 1985), Klein, Crawford, and Alchian (1978), Grossman and Hart (1986), Hart and Moore (1990), and others. (See Holmström and Roberts (1998) for an excellent summary.)

Monteverde and Teece (1982) show that more complexity, identified by more engineering investment, will increase the likelihood of internal procurement. More recent work has further supported these empirical regularities. (See, for example, Novak and Eppinger (2001) and Knez and Simester (forthcoming).)

□ **Concluding remarks.** We develop a model that illustrates what we believe to be a fundamental problem of procurement contracting. An important aspect of contractual arrangements is their ability to accommodate adaptation, thus creating a tradeoff between transaction costs that are due to changes and incentives to reduce costs. On one hand, FP contracts provide the strongest incentives for cost reduction. On the other hand, if the design is left incomplete, then the cost of renegotiating FP contracts is high. When C+ contracts are used the cost-reducing incentives disappear, but the process of adaptation is far smoother because the reimbursement process is simple, well defined, and leaves little room for haggling. Evidence from procurement contracts in private construction, defense, and software acquisition are consistent with the results of our model.

The implications of our analysis are relevant to both the private and public sector as to how procurement should be conducted. As the Federal Acquisition Rules (FARs) prescribe, government procurement is guided almost solely by fixed-price contracts. A common justification is that competitive bidding reduces the risk of ad hoc selection and corruption. But for complex systems, particularly in defense and aerospace, this approach may have high costs. Following the unsuccessful mission of NASA's Mars Polar Lander at the end of 1999, in an interview on PBS,[9] Liam P. Sarsfield, a senior policy analyst with the Science and Technology Policy Institute at RAND, wondered how "NASA [can] ask the contractor community—it's done this many times—to build some of these very exotic spacecraft—cutting-edge spacecraft—on really fixed-price budgets. . . the private sector that builds these spacecraft is being asked really to develop a spacecraft the way you and I would buy a car. And there is so much that is unknown up front." In response to this concern, Lori Garver, NASA's associate administrator for policy and plans, suggested that "NASA has been on the cutting edge of trying to get fixed-based cost contracting, and we may need to look at other incentives to provide commercial companies who work with NASA the ability to have more flexibility." This anecdote highlights the central theme of our article, and we believe that our analysis provides some guidance as to when relaxing stringent fixed-price rules is warranted.

Appendix A

■ Proofs of Lemmas 1–2 and Propositions 1–2 follow.

Proof of Lemma 1. The fact that $d(\tau, T)$ is increasing in τ and T follows immediately from the definition of $d(\tau, T)$. To see that $d(\tau, T)$ exhibits increasing differences, consider two projects $T > T'$, and fix some $\tau < 1$. Since project T is more complex than T', then by definition $\pi_t < \pi_t'$ for all t, and there exist integers S and S', $S \geq S'$, such that

$$\sum_{t=1}^{S-1} \pi_t < \tau \leq \sum_{t=1}^{S} \pi_t \quad \text{and} \quad \sum_{t=1}^{S'-1} \pi_t' < \tau \leq \sum_{t=1}^{S'} \pi_t',$$

and $d(\tau, T') = S'k \leq Sk = d(\tau, T)$. Now consider an increase from τ to $\tau + \varepsilon$. Since project T is more complex than T', then there exist integers $K \geq K'$ such that

$$\sum_{t=1}^{S+K-1} \pi_t < \tau + \varepsilon \leq \sum_{t=1}^{S+K} \pi_t \quad \text{and} \quad \sum_{t=1}^{S'+K'-1} \pi_t' < \tau + \varepsilon \leq \sum_{t=1}^{S'+K'} \pi_t',$$

and $d(\tau + \varepsilon, T') = (S' + K')k \leq (S + K)k = d(\tau + \varepsilon, T)$. It then follows that

[9] *The Newshour with Jim Lehrer*, December 7, 1999. Transcript available at http://www.pbs.org/newshour/bb/science/july-dec99/mars_12-7.html.

$$d(\tau + \varepsilon, T) - d(\tau, T) \geq d(\tau + \varepsilon, T') - d(\tau, T'),$$

which proves the result. *Q.E.D.*

Proof of Lemma 2. The optimal FP contract for the exogenous design case $\tau = 1$ ($\alpha = c(e^{FP}) + g(e^{FP})$ and $\beta = 0$) dominates the optimal C+ contract for this case ($\alpha = 0$ and $\beta = 1$) if and only if $Eu^{FP} \geq Eu^{C+}$, which reduces to

$$c(0) \geq c(e^{FP}) + g(e^{FP}). \tag{A1}$$

Now consider the contractor's problem with a FP contract. By revealed preference, he prefers choosing e^{FP} over $e = 0$, which implies that

$$\max_e E\pi^{FP} = \alpha - c(e^{FP}) - g(e^{FP}) \geq \alpha - c(0),$$

which is equivalent to (A1) above. *Q.E.D.*

Proof of Proposition 1. From well-known results in monotone comparative statics (see Vives (1999), and also Milgrom and Shannon (1994) and Topkis (1998)), if the buyer's objective function has increasing differences in $(x, \tau, -T)$, then the optimal response functions $x(T)$ and $\tau(T)$ are monotone decreasing. Define the buyer's objective function as $f(x, \tau, -T, \sigma)$. To show that the buyer's objective function exhibits increasing differences in $(x, \tau, -T,)$, it suffices to show that the cross partials of $f(\cdot, \cdot, \cdot, \cdot)$ with respect to these three variables are nonnegative. We first compute two of the partial derivatives:

$$\frac{\partial f}{\partial \tau} = x(\sigma v + K_1 - K_2) - \frac{\partial d(\tau, T)}{\partial \tau} \tag{A2}$$

$$\frac{\partial f}{\partial(-T)} = \frac{\partial d(\tau, T)}{\partial T}. \tag{A3}$$

Differentiating (A3) with respect to x and τ respectively gives

$$\frac{\partial^2 f}{\partial x \partial(-T)} = 0, \quad \text{and} \quad \frac{\partial^2 f}{\partial \tau \partial(-T)} = \frac{\partial^2 d(\tau, T)}{\partial \tau \partial T} > 0,$$

where the inequality follows from the supermodularity of the derived function $d(\tau, T)$. Differentiating (A2) with respect to x gives

$$\begin{aligned}\frac{\partial^2 f}{\partial x \partial \tau} &= \sigma v + K_1 - K_2 \\ &= \lambda(1 - F(w^*))v + \int_0^{v-k} m dF(m) - \lambda \int_{w^*}^{v-k} m dF(m) + k - \int_0^{v-k} m dF(m) - k \\ &= \lambda \left[(1 - F(w^*))v - \int_{w^*}^{v-k} m dF(m)\right] > 0,\end{aligned}$$

where the last inequality follows from the fact that the losses from renegotiation are positive, and this is indeed (4) from the analysis in Section 4 above. This shows that $f(\cdot, \cdot, \cdot, \cdot)$ has increasing differences in $(x, \tau, -T)$, completing our proof. *Q.E.D.*

Proof of Proposition 2. From (A2) we obtain $\partial^2 f / \partial x \partial(-\sigma) = (1 - \tau)v > 0$, while $\partial^2 f / \partial \tau \partial(-\sigma) = -xv \leq 0$. *Q.E.D.*

Appendix B: Optimality of linear contracts

■ This Appendix shows that the restriction to linear contracts is without loss of generality due to the risk neutrality of the parties. Consider general contracts of the form $p(c)$. The seller's *ex ante* expected profits are given by

$$E\pi = p(c) - c(e) - g(e) + (1 - \tau)E\pi_{RNG}.$$

Notice that the expected renegotiation payoffs of the seller do not depend on his choice of effort. This follows because the continuation gains from trade are not a function of the initial compensation scheme, or of the choice of effort. The following compensation scheme will trivially implement effort level e^*:

$$p(c) = \begin{cases} c(e^*) + g(e^*) - (1 - \tau)E\pi_{RNG} & \text{if } c = c(e^*) \text{ or if the parties renegotiate} \\ -\varepsilon & \text{otherwise.} \end{cases}$$

This works as follows: if the design is complete, and there is no renegotiation, then by choosing e^* the seller guarantees zero profit, while other levels of effort cause a loss. In the event that the parties renegotiate, the seller would maximize his expected profits by choosing the first-best effort level, which may be different from e^*. But by choosing ε large enough, this discontinuous scheme will implement e^*, thus giving the seller an expected profit of zero.

Now we show that the same effort e^* can be implemented with a linear contract, and the expected payoffs are the same as from the discontinuous contract above. With a linear contract the seller's expected utility is given by

$$E\pi = \alpha + \beta c(e) - c(e) - g(e) + (1 - \tau)E\pi_{RNG},$$

and the seller's necessary and sufficient first-order condition is

$$\beta c'(e) - c'(e) - g'(e) = 0.$$

Now let

$$\beta^* = 1 + \frac{g'(e^*)}{c'(e^*)} \leq 1,$$
$$\alpha^* = c(e^*) + g(e^*) - \beta^* c(e) - (1 - \tau)E\pi_{RNG}.$$

It is easy to see that (α^*, β^*) implement effort level e^* and give the seller zero expected profits by construction. This exercise works because the seller and buyer are assumed to be risk neutral.

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