SIEPR Discussion Paper No. 99-25

Incentive versus Transaction Costs: A Theory of Procurement Contracts

by

Partick Bajari and Steven Tadelis

Stanford University

March 2000

Stanford Institute for Economic Policy Research
Stanford University
Stanford, CA 94305
(650) 725-1874

Incentives versus Transaction Costs: A Theory of Procurement Contracts*

PATRICK BAJARI AND STEVEN TADELIS
Department of Economics
Stanford University

First Version: July 16, 1999
This Version: June 23, 2000

Abstract

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 trade-off 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 also show when fixed-price or cost-plus contracts would be preferred to other incentive contracts, explaining the prevalence of these simple contracts. We then apply our model to the make-or-buy procurement decision and conclude that internal production dominates market procurement when the product is more complex, providing some micro-foundations for Transaction Cost Economics. (*JEL* D23, D82, L14, L22, L74)

*We thank Tim Bresnahan, Avner Greif, Oliver Hart, John Kennan, Eric Maskin, Antonio Rangel, Ilya Segal, Curtis Taylor and especially Paul Milgrom for insightful discussions. We have also benefitted from comments by Igal Hendel, Chad Jones, Jon Levin, Scott Masten, Preston McAfee, John McMillan, Michael Riordan, Eric Van den Steen, Oliver Williamson, Jeff Zwiebel and many seminar participants. This paper stemmed out of a previous working paper titled "Procurement Contracts: Fixed Price vs. Cost plus."

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 percent of Gross Domestic Product in the United States.[1] 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 started in the early 1980's. This literature developed following the introduction of information economics and mechanism design and depicts the problem of procurement as a problem 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. Following the mechanism design methodology, the buyer screens the seller by offering a *menu of contracts* from which the seller selects a particular contract, thus revealing his private information. 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 issue at hand.

By contrast, the engineering and construction management literature that is described in section 2 suggests that menus of contracts are not commonly used. Instead, the vast majority of contracts are variants of simple fixed-price and cost-plus contracts.[2] While carefully examining the literature and speaking with industry participants, we have found little evidence that either the contractor or the buyer have private information at the onset of a procurement project. They both, however, share uncertainty about many important design changes that occur *after* the procurement contract is signed, such as design failures, unanticipated site and environmental conditions, and the changes in regulation regarding building code 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 dollar facility that took over 8 years to construct. (See Engineering New-Record 1994, 1997.) The project design had to be changed due to site conditions that were hard to

[1] Recent books include Laffont and Tirole (1993) and McAfee and McMillan (1987). These include references to many other studies of government procurement.

[2] In fixed price contracts, the buyer offers the seller a pre-specified fixed 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.

anticipate. The geology of the project included canyons, slide planes and earthquake fault lines, conditions that 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 had to be altered also 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 regarding the costs and methods to implement changes.

These observations suggest that the procurement problem is concerned with *ex post adaptations* rather than with *ex ante screening*. Accordingly, this paper tries to shed light on the economic forces that determine the choice of procurement contracts, and attempts to answer three specific questions. First, if one restricts attention to fixed-price and cost-plus contracts, when should each type of contract be used? Second, what can explain the widespread use of these two simple contracts, and the lack of other more elaborate incentive contracts which are prescribed by the existing procurement literature? Third, we illustrate the connection between our analysis and a different procurement question known as the "make-or-buy" decision: should a firm produce an intermediate product internally or should it be procured across the market? To answer these questions we develop a model that ignores ex ante hidden information and concentrates on problems of adaptation when the initial design is endogenously incomplete.

Section 3 lays out our formal model. It consists of a buyer who wishes to procure a product from a seller, where the latter can exert cost reducing effort that is not contractible. This standard moral hazard component is accompanied by two non-standard additions. First, the buyer must provide the seller with an ex ante design, where more design effort implies a lower likelihood that the parties will need to renegotiate ex post. Design is costly in the sense that more ex ante design imposes more costs on the buyer. Second, ex post renegotiation occurs under incomplete information – the seller has private information about the costs of changes compared to the initial design.

We begin our analysis in Section 4 by comparing fixed price (FP) contracts with cost plus (C+) contracts. We show that simple projects will be procured using FP contracts, and will be accompanied by high levels of design completeness (that is, a high probability that adaptations *are not* needed). More complex products (in the sense of design intensity) or projects that need to be finished fast 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 (Section 2.4) and with facts from other industries as well (Section 7.2). The benefit of using a fixed price contract is that cost reducing incentives are provided to the seller, but there is a cost: bargaining under ex post asymmetric information dissipates ex post surplus. If, however, a cost-plus contract is used, then no surplus is dissipated during to ex post bargaining, but there are no cost-saving incentives either.

The analysis thus demonstrates that the ex ante contract has direct implications on how ex post renegotiation proceeds. This is consistent with the documented facts that demonstrate a significant difference in disputes under these two contracts (Section 2.4). Our analysis also demonstrates that the choice of ex ante incentives, and of design incompleteness , should both be modelled as endogenous variables in the procurement problem. Our model 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 address the question of why FP and C+ contracts are so prevalent. We argue that in order to implement *any* cost-sharing contract, the buyer must engage in the task of cost measurement. If this task imposes a lumpy cost, as evidence suggests, then a FP contract will dominate many incentive contracts simply because the former does not require costs to be measured. We then argue that changing the model to accommodate multiple contractor tasks, such as cost reduction and quality provision, will imply that *any* incentive contract will cause the seller to compromise on quality provision. This follows the same logic as Holmstrom and Milgrom (1991) who showed that in multi-task settings incentive contracts will be dominated by a contract with no cost incentives, in our case a C+ contract. Thus, we uncover discontinuities (or nonconvexities) in procurement that are plausible explanations for the prevalence of extreme and simple compensation schemes.

In Section 6 we argue that a straightforward variation of our model can shed light on the celebrated "make-or-buy" decision, a procurement problem concerned with the choice between producing a component internally or purchasing it through the market. The insights we obtain from analyzing the choice between FP and C+ contracts 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 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." (1985 p.140)

Williamson then uses this theme to argue that the make-or-buy decision is concerned with problems of adaptation and renegotiation, as well as incentive problems arising from relationship specific attributes (1985, ch. 6). He does not, however, spell out the fundamental forces and micro-foundations that would explain this assertion.

This paper contributes to the TCE literature by providing a foundation for the different transaction costs associated with internal production (weak incentives) and with market procurement (strong incentives). On one hand, market procurement reduces transaction costs due to the moral hazard problem by providing incentives that motivate cost savings, while internal production does not provide these incentives. On the other hand, market procurement dissipates ex post surplus due to bargaining under asymmetric information when changes to the original specification are needed. Internal production alleviates the problems associated with adaptation because ex post asymmetric information does dissipate ex post resources when incentives are not provided.

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 which evaluate the predictions of TCE. This focus on complexity, adaptation, and ex post asymmetric information, complements the more developed literature on asset specificity and incomplete contracts, most prominently the Property Rights literature pioneered by Grossman and Hart (1986) and Hart and Moore (1990).

2 The Building Construction Industry

2.1 Overview

In 1992, there were 2 million establishments in the United States construction industry that completed $528 billion dollars of work. These firms directly employed 4.7 million workers and had a payroll of $118 billion dollars (Census 1992a,b,c). In 1997, the construction industry comprised 8 percent of U.S. GDP and worldwide the construction industry is a 3.2 trillion dollar market (Engineering News-Record 1998).

This paper is motivated by commonly used contractual arrangements in the private sector building construction industry. 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.[3]

Since every construction project is unique, the coordination and management of change are important aspects of successful project management. The Getty Center example in the introduction illustrates this point. 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 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.[4] It is our understanding that the costs of coordination are better known to the contractor, which motivates our modeling approach of the renegotiation stage (Section 4 and Appendix A).

2.2 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.[5] Fixed

---

[3]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), Heinze (1993), and U.S. Department of Commerce Census (1992a,b,c).

[4]For example, coordinating construction work at the Getty was an extremely complex task. There were over 240 subcontractors and between 900 and 1200 workers at any given time performing approximately $100 million dollars 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 4 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 project site, a traffic coordinator scheduled access to the site. 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.)

[5]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 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 incentives in cost-plus contracts are not the industry standard because of difficulties with implementing incentives in the face of changes. According to Ashley and Workman (1986) 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 (1986) report that only 12 percent of the respondents use contracts with cost incentives.[6]

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.

2.3 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.[7] Therefore, in a

---

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).

[6]Incentives on time, commonly referred to as liquidated damages, appear to be more commonly used than incentives on costs however. See Ashley and Workman (1986).

[7]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

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*.

A change order is a written amendment to the contract that describes additional work the contractor must undertake, and the compensation he will receive.[8] The work and the conditions in a change order are generally determined by bargaining between the buyer, contractor and architect. If they are unable to reach an agreement, in many contracts the architect has the power to issue a change directive.[9] If the contract amount cannot be agreed to by bargaining between the parties, the contractor may be paid by what is called force account.[10]

---

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."

[8] A change order is defined in AIA document A201 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."

[9]In AIA document A201 this 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, if any, in the Contract Sum or Contract Time, or both. The Owner may by Constructive Change Directive, without invalidating the Contract, order changes in the Work within the general scope of the Contract consisting of additions, deletions or other revisions, the Contract Sum and Contract Time being adjusted accordingly." " A construction Change Directive shall be used in the absence of total agreement on the terms of a Change order."

[10]This is described in AIA document A201 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. Unless otherwise provided in the Contract Documents, costs for the purposes of this subparagraph 7.3.6 shall be limited to the following: (1)costs of labor, including social security, old age and unemployment insurance, fringe benefits required by agreement or custom, and workers' or workmen's compensation insurance; (2) costs of materials, supplies and equipment, including cost of transportation, whether incorporated or consumed; (3)rental costs of machinery and equipment, exclusive of hand tools, whether rented from the Contractor or others; (4) costs of premiums for all bonds and insurance, permit fees and sale, use or similar taxes related to the Work; and (5) additional costs of supervision and field office personal directly attributable to the change."

Change directives give the buyer significant bargaining power in the case of a dispute, and 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 due to 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.

2.4 Empirical Evidence on Contractual Arrangements

To the best of our knowledge, there has been no empirical work in the economics literature to assess the costs and benefits of cost plus and fixed price contracting in building construction. We will provide an overview of some relevant studies from the engineering management literature.

First, there is ample evidence that ex post changes are the rule rather than the exception. Hester et al. (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, and 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.

Second, 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 was claimed to verify the following conventional wisdoms about cost plus and fixed price contracting:[11]

[11] The data set 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 respondent.

	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

Table 2.1: Comparing FP with C+ contracts in Construction

The first two facts should be no surprise to economists: the allocation of risk is trivial, and a simple multi-task model can explain how cost reducing incentives adversely affect quality (see Holmstrom and Milgrom, 1991). The other points, however, have not, to the best of our knowledge, been analyzed in the economics literature. Changes in fixed price contracts will lead to costly renegotiation of the contractor's compensation, namely the friction depends on the compensation scheme. Furthermore, if the buyer wishes to implement a fixed price contract without a large number of change orders, the project drawings, plans and specifications must be substantially complete (which is costly) before the contract can be awarded through competitive bidding. An advantage of cost-plus contracting is that the design of the project and the construction of the project can take place simultaneously and therefore total time to project completion is reduced, but this requires more administrative costs. This is sometimes referred to as "fast-tracking" of the project.

3 The Basic Model

3.1 Project Design

Consider a buyer who wishes to procure a product for her consumption. This requires her to hire a contractor (or seller) who will perform the work according to the buyer's specifications. The buyer's desired product is exogenously given, and if completed provides her with a value of $v > 0$ which is common knowledge and fixed. The time horizon consists of two distinct periods: in the first period there is uncertainty about what is the best way 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 price 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 period the uncertainty is revealed, and the contractor proceeds with the plans. In the event that the plans do not account for the realized situation, the parties will need to renegotiate from some specified status quo. This renegotiation is modeled in subsection 3.2.

Formally, let T be the number of states of nature that can occur in the second period, and let $\pi_t > 0$ be the probability that state $t \in \{1, ...T\}$ occurs (states that occur with zero probability are ignored). To fully specify the project, a design is needed for each state of nature. Assume that the cost of specifying a design for a particular state of nature is $k > 0$ regardless of the state of nature. Also assume that $\pi_t > \pi_{t+1}$ for all $t \in \{1, ...T-1\}$. 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) $T > T'$, and

(ii) $\sum_{t=1}^{S} \pi_t < \sum_{t=1}^{S} \pi'_t$ for all $1 \leqslant S \leqslant T'$

This definition is a simple way of ordering projects along some scale of complexity, and has the following implication. If project A is more complex than project B then in order to have both projects specified with (at least) probability $\tau > 0$, the cost of design for project A is (weakly) more than for B.

Notice that the definition of complexity provides only a partial ordering given our specification of a project. Our goal is to provide a framework in which comparative statics with respect to project complexity can be analyzed. For this reason we restrict attention to project spaces for which condition (i) in the definition above implies condition (ii) and vice versa.[12] This restriction implies that a project can be characterized only by the number of states it entails, so that project T is more

[12] That is, our project space is limited to projects that satisfy

$$T > T' \Longleftrightarrow \sum_{t=1}^{S} \pi_t < \sum_{t=1}^{S} \pi'_t \text{ for all } 1 \leqslant S \leqslant T' .$$

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.[13]

Now 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,

$$d(\tau, T) = \min_{S\in\{1,\ldots,T\}} \quad Sk \qquad \text{s.t.} \quad \sum_{t=1}^{S} \pi_t \geqslant \tau$$

and this function has three sensible and important characteristics as demonstrated by the following Lemma:

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

The formal proof is in Appendix A, yet 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.[14] 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 cost of marginally increasing the probability of specification.

Using Lemma 1 we can 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 $\tau \in [0,1]$. That is, with probability τ the original design accurately describes the project, and if followed 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. The cost of design is given by the function $d(\tau, T)$ that is

[13] It is interesting to note that this setup is easily generalized to projects that are given as distributions over a countable number of states. In particular, 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 $G_B(\cdot)$. Indeed, this will mean that $G_A(\cdot)$ has a "fatter" upper tail, and more states need to be specified in order to achieve the same level of completeness. In this scenario and abstract order of complexity that obeys FOSD will be used to index projects, and this index will be used to obtain monotone comparative statics.

[14] Notice that due to our assumption that $\pi_t > \pi_{t+1}$ thecost of design is convex in τ. Convexity is not needed for our comparative statics results for which only increasing differences are required. Without convexity we will have corner solutions, but the qualitative comparative statics will still hold. Note, however, that convexity in τ seems reasonable from an engineering perspective.

increasing in T and τ, convex in 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.

3.2 Construction and Change Orders

Construction is performed by a contractor, who receives the project design and uses these to supply the buyer with a product that meets the design specifications. As in many principal-agent models, we assume that the contractor can engage in cost reducing effort denoted by $e \geq 0$ that is not contractible.

The construction technology is given by the product's cost function $c(e) \geq 0$,which is assumed to be decreasing and strictly convex in e (that is, $c'(e) < 0$, $c''(e) > 0$). We assume, therefore, that given effort e, the cost of production is perfectly known and is constant unless design changes are required, which will be introduced shortly.[15] In addition to reducing costs, effort imposes a private cost on the contractor denoted by $g(e) \geq 0$, which is assumed to be increasing and strictly convex (that is, $g'(e) > 0$, $g''(e) \geq 0$) and assume that $g(0) = 0$. This specification leads to a standard moral hazard problem.

Design changes will be done during construction if the buyer and contractor agree to depart from the initial design during renegotiation. (The renegotiation game is fully specified in subsection 3.4 below.) Recall that a change is needed if the initial design was inadequate, or more precisely, a state of nature occurred that was not specified in the design. In this case "filling in" the design should be equivalent to specifying what to do for this particular state, and the cost of supplying a design for a particular state was denoted earlier by k. This cost will be incurred whenever the initial design fails, that is, with probability $1 - \tau$. Aside from the cost of completing the design, the change itself entails some 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.

Finally, we assume 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 0. This assumption simplifies the analysis and sets simple threat points for the renegotiation

[15] Unlike standard moral hazard models, the costs will perfectly reveal the effort of the contractor if the design was adequate. It will become clear later that we can indeed despense of the standard "noisy" cost observations to capture the essence of the procurement problem as we see it.

stage that follows.[16] This, together with the domain assumption that $m \leqslant v - k$ implies that if the design fails, then it is first best optimal to have the change performed.

3.3 Contracting

We define the procurement relationship by the contract between the buyer and the seller. Following Section 2.2, a contract includes two elements. First, the *specifications, drawings and reports*, which are summarized by τ. Second, a *compensation scheme,* $p(c)$, which defines a transfer from the buyer to the seller upon completion of the original design. Since costs are verifiable in our model, we allow the compensation scheme to depend on c. Thus, a contract includes a design, τ, and a compensation scheme, $p(c)$, that is verifiable and enforceable by the courts.

Note that contracting on costs c is equivalent to contracting on effort e since there is a one-to-one correspondence between c and e. This may make the problem seem trivial, yet it will become clear that the possibility of design changes makes the analysis interesting and generates trade-offs. For this we make the following assumption regarding cost based compensation:

Assumption A1: *The product's total costs are verifiable, but the costs of specific sub-components and modifications cannot be independently measured.*

This assumption implies that when modifications are needed, the original costs c, and the added costs m, cannot be disentangled. This guarantees that it is impossible, at the renegotiation stage, to specify a compensation scheme based solely on the costs of modification. 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 that incremental due to changes of the original design cannot be measured as well.

[16] One can justify this expected value of $\tau \cdot v + (1 - \tau) \cdot 0$ as invoking a law of large numbers. That is, assume that the project is made up of N small tasks, each having a completion value of $\frac{v}{N}$, where N is large. Assume that given design τ, each task is well defined with probability τ and completely undefined with probability $1 - \tau$. As N grows large the value of the project is almost certainly τv. It is important to note that we can define $s(\tau) \in [0, v]$ to be the value of the project when design fails with $s'(\tau) \geq 0$. This will add notation, but will not modify our qualitative results.

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, for most of the analysis 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, at this stage arbitrary, yet section 5 introduces conditions under which these extreme values are potentially optimal.

3.4 Renegotiation

If the design is incomplete then 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 $\alpha + \beta c$. The buyer's payoff, 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 follows: with probability $\lambda > 0$ the buyer makes the contractor 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.[17] For analytical convenience both parties are assumed to be risk neutral.

To specify renegotiation, notice that 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 for any modifications that are requested, as long as compensation is based on total costs. In other words, if the relationship is governed by a C+ contract, then when a change is requested there is no need for the buyer and contractor to engage in renegotiation over the compensation

[17] We thus assume full commitment for the party making the offer so that rejection causes loss of all surplus. This is a rather standard assumption in bargaining models that allows for inefficiencies due to asymmetric information.

scheme. If a FP contract was initially chosen, then the compensation scheme is a *specific performance compensation scheme* and cannot account for modifications.

3.4.1 Renegotiating Fixed Price Contracts:

If a FP contract is being used, then when the buyer makes a TIOLI offer she chooses an offer w to maximize her expected ex post payoff given by,

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

which yields the FOC 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. Standard assumptions imply that there is a unique solution to (1),[18] 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 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:

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

3.4.2 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 order the contractor to do the change without changing the 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

[18]This is satisfied if $\frac{F(w)}{f(w)}$ is increasing in w, which is the case if m is uniformly distributed (or any log-concave distribution).

all the surplus. When the seller makes the TIOLI offer he can extract the buyer's expected benefit, which is $v - Em$ (where E is the expectations operator). Therefore, when the status quo contract is a C+ contract, we can summarize the expected utility of the buyer and the expected profits of the seller from renegotiation as:

$$\begin{aligned} Eu^{C+}_{RNG} &= \lambda \left(v - \int_0^{v-k} mdF(m) \right) - k \,, \\ E\pi^{C+}_{RNG} &= (1-\lambda) \left(v - \int_0^{v-k} mdF(m) \right) . \end{aligned}$$

4 Fixed Price or Cost Plus?

We can now address our first question: if the buyer was restricted to choose between a FP and a C+ contract, when should each be chosen? As discussed in Section 2.4, the stylized facts imply two phenomena. First, FP contracting is accompanied by a more complete design. Second, if the buyer wishes to engage in a "fast track" project, in which major parts of the design are done in parallel to the construction, C+ contracts are more likely to be chosen. We will demonstrate that our model illustrates simple economic forces that we believe are behind these phenomena. We begin by examining the ex ante expected payoffs under the two extreme contractual arrangements we consider here.

4.1 Ex ante Payoffs: FP

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

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

The seller maximizes (2) above to obtain his optimal effort choice under a fixed price contract, e^{FP}. Notice that the seller bears all the construction costs that are affected by effort, $c(e)$, and the private costs of effort, $g(e)$. Furthermore, these are not affected by the buyer's choice of design, τ, implying that his choice of effort will be optimal.

Turning to the buyer, her 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 as given, and this is equal to e^{FP}. Recall that by assumption the seller earns zero expected profits, which means that we can substitute α from the seller's expected profits (2) above, and after simple algebra we are able to obtain the following representation for the buyer's utility,

$$\begin{aligned} Eu^{FP} &= v - c(e^{FP}) - g(e^{FP}) - d(\tau, T) \\ &\quad -(1-\tau)\lambda(1-F(w^*))v \\ &\quad -(1-\tau)\left[\int_0^{v-k} mdF(m) - \lambda\int_{w^*}^{v-k} mdF(m) + k\right] \end{aligned} \tag{3}$$

Notice that there are three lines that sum up to the buyer's expected utility, each with a simple economic meaning. 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 inefficient, and lose the value v. The third line represents the expected cost of modifications taking into account that when the buyer makes the offer, there is a positive probability that these costs will not be incurred due to renegotiation breakdown.

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.[19] This friction is the loss of gains from renegotiation which is equal to

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

Notice also that w^* is not a function of τ, so this loss can be rewritten as,

$$(1-\tau)\sigma v - \int_{w^*}^{v-k} mdF(m)\,,$$

where $\sigma \equiv \lambda(1-F(w^*))$ is a *friction parameter*, due to inefficient bargaining. We can now rewrite (3), the buyer's ex ante expected utility under FP contracting as,

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

[19] Thus, though it might seem like there is no "hold-up" in our model (in the sense of Grout (1984) or Grossman and Hart (1986) in which ex post bargaining leads to ex ante inefficient investments), the friction due to inefficient renegotiation is a source of hold-up. Furthermore, any division of surplus *ex post* will be undone by competition *ex ante*, since the seller gives up his *ex post* bargaining rents up-front. But giving the buyer some ex post bargaining power is essential to have renegotiation fail.

where $K_1 \equiv \int_0^{v-k} mdF(m) - \lambda \int_{w^*}^{v-k} mdF(m) + k$ from the third line of (3), and it represents the expected costs of modifications in case renegotiation occurs. Thus, (5) represents a reduced form for the derived expected utility of the buyer from a FP contract. This reduced form will be useful for comparing the different contractual arrangements.

4.2 Ex ante 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:

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

This problem clearly implies that the seller will choose no effort, $e^{C+} = 0$, which is sub optimal since he bears no construction costs and all the private costs of effort. 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. Recall that by assumption the seller earns zero expected profits, which means that we can substitute α from the seller's expected profits (6) above, and after simple algebra we are able to obtain 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, bears all the costs of construction, effort, design, and the expected cost of modifications.

4.3 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 friction, or transactions cost, is endogenous. This plays a key role in the costs and benefits of the two contracting arrangements.[20]

4.3.1 Benchmark: Exogenous Design

Two benchmark cases are described to illustrate the pure economic forces that describe the trade-off 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 3.3, if a FP contract is chosen then the contractor will choose effort e^{FP}, and from (3) above, 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, the following result is obtained:

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

The rather simple proof of Lemma 1 is in Appendix A. 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 there are no unresolved details, then no costly renegotiation occurs. Thus, with complete design a FP contract induces (first best) cost reduction without introducing the transaction cost of *ex post* renegotiations.

---

[20] Another interesting story that can generate selective friction is one of bargaining costs that arise out of the parties' unproductive efforts to increase their share of some fixed surplus (Milgrom and Roberts, 1990a). For example, when bargaining over the surplus, each party can obtain costly legal advice, and in equilibrium both parties may invest in lawyers without changing their relative bargaining power. It is reasonable to assume that different ex ante contracts would be handled differently by a court of law, implying that these unproductive influence activities will have different effects under different ex ante contracts. Such a model, if developed, would be related to the law and economics literature that explores bargaining "in the shadow of the law." (See Cooter, Marks and Mnookin, 1982).

Now, consider the opposite extreme case in which the buyer has a product 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

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

The intuition is again straightforward. If $\tau = 0$ is 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 in the gains have 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 the bare forces that describe the trade-off between fixed price and cost plus contracting. On one hand, fixed price contracts have the benefits of creating cost reducing incentives for the contractor, which benefit the buyer through the ex ante competition between potential contractors. On the other hand, if the design is incomplete, then some surplus will be eroded by the frictions of ex post renegotiation, which is the cost of using a FP contract. The next section completes the analysis by endogenizing the choice of design completeness, and thus completing the comparative analysis between the two contractual arrangements.

4.3.2 Endogenous Design

We now return to having the design τ as an endogenous variable and investigate how this affects the choice of the optimal contract when only FP and C+ contracts are considered. We will, at this stage, employ some standard results from the methods of Monotone Comparative Statics.[21] To proceed, let $x \in \{0, 1\}$ denote the contractual

[21]These methods were developed by Topkis, and introduced into economics by Milgrom and Roberts (1990b) and Milgrom and Shannon (1994). Topkis (1998) provides an elaborate description of these tools. Vives (1999) provides an accessible introduction to the Lattice Theoretic tools employed by these methods, and the direct result that we apply here.

compensation choice of the buyer, where $x = 1$ is the choice of a FP contract, and $x = 0$ is the choice of a C+ contract. The buyer's maximization problem is,

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

Proposition 1: *The buyer's optimal choices $x(T)$ and $\tau(T)$ are monotone non-increasing in T.*

The proof of Proposition 1 is in Appendix A. To put the proposition in words, more complex products have a less complete design and will 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 since 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 then the gains from cost incentives outweigh the losses from inefficient renegotiation. When the design is fairly incomplete, then the losses from inefficient renegotiation outweigh the benefits from cost incentives.[22]

This conclusion is consistent with the stylized facts described in table 2.1 above. Our result explains why more design documentation is linked to the choice of FP contracts, and can shed light on the trade-off 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. Notice that in our model complexity is the important comparative statics parameter. We will exploit this later to explain stylized facts in other industries, and to address the make-or-buy decision.

[22]Notice that assumption A1 (namely that total costs are measurable whereas specific task costs are not) prevents the buyer from writing an initial FP contract, and later requesting changes using a C+ contract. This is important in our specification of ex post bargaining since it is clearly first best optimal to have the change done, and if costs of specific changes are verifiable, then the first best is obtained by this hybrid contract.

4.3.3 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 corollary answers this question:

Corollary 1: *The buyer's optimal choice $x(\sigma)$ is monotone non-increasing in σ, and her optimal choice $\tau(\sigma)$ is non monotonic in σ.*

The proof of Corollary 1 is in Appendix A, and the intuition is again 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 in order 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.

5 Optimality of Extreme Contracts

In this section we address our second question: Why are most observed contracts either FP or C+? We introduce two arguments that make the procurement problem "non convex" due to discontinuities at the extreme choices of FP, $\beta = 0$, and C+, $\beta = 1$. This section will refrain from formally modifying the previous analytical setup. The arguments, however, are rather straightforward and the formal modifications needed are simple and will be clearly laid out.[23] For this section we consider the more general problem in which all linear contracts for which $\beta \in [0, 1]$ are considered. Under reasonable continuity conditions that we have basically assumed, the objective function over the domain $\beta \in (0, 1)$ is continuous in β. Thus, if we confine β to be in the open range $(0, 1)$, we can find functional forms and parameter values to support any $\beta \in (0, 1)$ as a solution.

First, we argue that there is a fundamental difference between a FP contract with $\beta = 0$, and any other cost sharing contract with $\beta \in (0, 1]$. The difference lies in the fact that for a FP contract no measurement of costs by the buyer is necessary, whereas any cost sharing contract requires such measurement. This obvious fact, which is documented in the engineering management literature, leads to a clear non-convexity in the cost of measuring and monitoring product costs. This is easily incorporated into the model using the following assumption:

Assumption A2: If $\beta > 0$ then the buyer incurs a fixed monitoring cost $M > 0$.

The implication of this assumption on the optimal contract is straightforward: ignoring monitoring costs, there exists solutions β close to 0 (close to FP) that are no longer optimal once monitoring costs are introduced, in which case a FP contract dominates them. To see this, assume that with no costs of monitoring some $\beta^* > 0$ close to FP is optimal. If, however, monitoring costs are introduced, then by moving towards $\beta = 0$, the buyer (continuously) loses expected utility, and when $\beta = 0$ then the monitoring costs are eliminated. Thus, for any monitoring costs M, there exists $\beta(M) > 0$ such that all $\beta \in (0, \beta(M))$ will be dominated by a FP contract. This argument implies that FP contracts are optimal for a generic set of parameter values, and we should not observe contracts that are "close" to FP, which is indeed the case.

Second, we argue that there is a fundamental difference between a C+ contract with $\beta = 1$, and any other incentive contract with $\beta \in [0, 1)$.[24] We propose to consider a richer model in which the seller has to engage in more than one task, as analyzed in the seminal multi-tasking paper by Holmstrom and Milgrom (1991). For example, assume that the seller can engage in two activities: effort in cost reduction, e_c, and effort in quality enhancement, e_q. Assume, as in Holmstrom and Milgrom (1991), that:

---

[23]Note, however, that performing the actual formal analysis requires additional notation and would add several pages of formalities that are predictable, thus adding unnecessary volume to rather simple and appealing arguments.

[24]We use the term "incentive contract" to distinguish a C+ contract where the seller has *no incentives* to reduce costs, versus any other contract that provides some incentives to reduce costs.

1. the tasks are substitutes in the seller's private cost function, $g(e_c + e_q)$,

2. costs are verifiable but quality is not.

Using such a setup, it is quite straightforward to generate a result similar to Proposition 1 in Holmstrom and Milgrom (1991). In particular, giving the seller incentives to reduce cost, without the ability to write contracts that provide quality incentives, will encourage the seller to ignore quality considerations completely, and engage only in cost reductions.[25] Thus, in our simple model that ignores quality considerations, there exists solutions β close to 1 (close to C+) that are no longer optimal once quality concerns are introduced as demonstrated above, and a C+ contract will dominate these solutions. This argument implies that C+ contracts are optimal for a generic set of parameter values in a richer model, and we should not observe contracts that are "close" to FP, which is indeed the case.[26]

It is hard to assess the magnitude of these non convexities, though there existence is clear from the stylized facts. Thus, we conclude that FP and C+ contracts are more "robust" in the sense that they optimally solve the procurement problem for a wide range of parameter values. The arguments suggest that we should not observe contracts that are close to either FP or C+. This is a testable implication that seems to fit a rather casual observation of procurement contracts. However, more elaborate contract data needs to be gathered to carefully test this prediction.

McAfee and McMillan (1986) analyze a model in which agents (contractors) bid for a product, and the buyer is faced both with adverse selection (contractor's private cost information) and moral hazard (cost savings effort) where the contractor's are assumed to be risk averse. In their model the trade off between risk sharing, incentives, and information revelation cause incentive contracts that like 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 (i.e., reveal their type). McAfee and McMillan acknowledge that most government contracts are FP, and some are C+, and use their results to encourage more use of incentives contracts. Our analysis shifts the focus of attention and justifies the use of these extreme contracts.

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

[26] The study of Ashley and Workman (1986) demonstrates that providing cost incentives in a contract is more likely to lead to disagreements and spoiled relationships. Thus, we can argue that if *any* cost incentives are provided, then there will be friction at the renegotiation stage, which may be due to disagreements over quality, or over other issues for which incentive contracts provide grounds for adversarial relationships.

6 The Make-or-Buy Decision

The framework developed so far may help shed some light on a fundamental question in the literature on the theory of the firm: which activities should be performed inside the firm, and which should be procured across the market? This question is also known as the "make-or-buy" decision, and lies at the heart of what determines a firm's boundaries. 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 Holmstrom and Roberts (1998) for an excellent summary.)

To apply our model to this question, we first adopt the following interpretation. A buyer (firm) that produces some good is facing the decision of whether an input component will be produced inside the firm (make) or whether to purchase the component across the market (buy). We interpret the *make* decision as one in which the buyer bears all the costs of producing the component, and in which the relationship between the buyer and the "unit" that produces the good is very much in the spirit of a C+ contract. Similarly, we interpret the *buy* decision as one in which the seller (a different firm) bears all the cost of producing the component. Furthermore, the impression one gets from reading the vast literature on the make-or-buy decision is that the *buy* option is governed primarily by FP contracts.[27]

Once our framework is adopted in this way, the comparative statics of our model suggest that the *complexity of the component* should determine whether the buyer should make it or buy it. Namely, if the component is easy to define, and changes are not expected to be important, then market transactions would dominate internal production. If, however, the component is complex, changes are anticipated to be an important part of the relationship, and the relationship is likely to last over a longer period of time, then internal production would be optimal.[28]

This theme is hardly new, and can be traced back to Williamson (1975, 1985) who addresses the trade-off between incentives and governance costs to determine the choice of vertical integration. Williamson addresses several considerations that

[27]Clearly, a firm can buy components using C+ contracts. In this section we do not distinguish between a C+ contract across firms or a decision to vertically integrate. The question of why weak incentives are used inside a firm and string incentives across forms is left for future research.

[28]Wernerfelt (1997) develops a game-form model which integrates bargaining costs and communication costs with the need for ex post adaptation. Hierarchies are associated with fixed costs whereas price systems have adaptation costs that increase with the number of adaptations. This is in spirit close to the issues we raise here, but the modelling approach is very different since incentives are not considered in Wernerfelt's model.

influence the make or buy decision. Much in the spirit of our analysis, Williamson 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). However, Williamson has not pointed to *why* it is that ex post adaptation is easier in the firm compared to the market. Indeed, the main emphasis of Williamson's work is asset specificity and relationship specificity.[29] Specificity, together with the inability to write comprehensive contracts lead to the celebrated "hold-up" problem. More precisely, when asset specificity increases, the governance costs of internal organization (or, vertical integration) drop, and when asset specificity is large enough then internal organization is favored "...because 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." (Williamson, 1985, p. 91).

Riordan and Williamson (1985) extend Williamson's arguments to include neoclassical choices such as scope and scale. Our analysis in section 4 is related to their analysis in that it studies binary institutional choice, and it has a very similar reduced form structure. However, Williamson and Riordan "...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 foundation, it is difficult to adopt 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 trade-offs between incentive provision and renegotiation costs, both of which touch on core issues of bilateral transaction relationships. This allows us not only to address the question of contractual form, but also offers insights into the make-or-buy decision.

Klein, Crawford and Alchian (1978) describe the hold-up problem by laying out the effects of relationship specificity on the ex ante investments that parties need to engage in, thus focusing on the ex ante inefficiencies that are caused by hold-up. These themes of specificity and hold-up are the centerpiece of what is now known as Transaction Cost Economics (TCE). Grossman and Hart (1986) and Hart and Moore (1990) develop the hold-up problem further and provide a clear and precise

[29]In a more recent paper, Williamson (1991) suggests that a major difference between market transactions and vertical integration is that renegotiation in the former relies on contract law while the latter uses fit authority which has adaptive advantages. This explanation would be compromised if courts viewed interfirm and intrafirm disputes alike, which may or may not be the case.

definition of a firm: the set of non-human capital assets that are owned by the same entity. Their theory – currently known as the "property rights theory of the firm" – gives clear predictions of ownership based on how important it is to provide ex ante incentives to the different parties of the transaction. Again, hold-up (due to incomplete contracts) is the driving force, and ex ante incentive provisions is the problem that firms face. In this line of investigation, there is no discussion of the different transaction costs that arise from internal production and those that arise from market procurement.

Holmstrom and Roberts criticize this narrow focus and say that "ownership patterns are not determined solely by the need to provide investment incentives..." (1998, p.75). Our approach, it seems, would contribute to the existing literature on the make-or-buy decision in two ways. First, we provide a clear formalization of how the product's complexity (namely, the cost of ex ante specification) will affect the make-or-buy decision. This precisely identifies the endogenous transaction costs that arise from ex post bargaining, and together with our agency approach to incentives, erects a comprehensive bridge between the informal TCE literature, and the more formal modern agency models. Second, by focusing on product complexity as the determinant of the make-or-buy decision, our model has clear empirical predictions.

Indeed, several empirical papers provide evidence that supports our findings. Masten (1984) studies procurement practices in the aerospace industry and shows that both a higher degree of specialization (specificity), and a higher level of complexity, will increase the probability that an item is procured internally. Monteverde and Teece (1982) study procurement in the automobile industry and similarly show that more complexity, identified by more engineering investment, will increase the likelihood that a component is produced internally. A recent study of the automobile industry by Novak and Eppinger (1999) shows that increasing complexity in product architecture drives vertical integration.

A closely related question to that of make-or-buy is whether a job should be performed by an "in-house" employee, or by an outside contractor (see, e.g., Simon, 1951). Again, one can view the employment relationship as cost-plus in which the employer bears all the costs, whereas the arms-length relationship bears more resemblance to fixed-price. Using the logic described above, if the task is easy to define, and changes or interventions are not expected to be important, then market transactions would dominate the employment relationship. If, however, the task is complex, continuous changes and guidance are anticipated, and the relationship is likely to last over a long period of time, then employment would be the optimal arrangement. Anderson (1985) studied the choice of hiring salespeople in the electronics components industry, and finds that product specificity is positively correlated with the choice of direct employment (in contrast to an outside "sales rep"). Anderson describes an increase in product specificity as "...the more that products are technical, have high engineering content, change fast, and are sophisticated, customized, unique and complex." This corresponds nicely to our notion of complexity, and is consistent with the prediction of our theory.

7 Discussion

7.1 Relation to the Literature

Our model departs 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 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 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. As for its positive implications, the mechanism design methodology predicts that,

1. there is no reason that most contracts should be FP or C+, in fact we should mostly see some intermediate strength of incentives;
2. screening of sellers should occur via menus of contracts;
3. project complexity and design are ignored and thus cannot be directly related to the choice of incentives;
4. the distribution of "types" should affect incentives, rents, and compensation;
5. the likelihood of renegotiation is not related to types of contract.[30]

As we describe in section 2, the facts do not seem to support predictions 1, 2 and 5, and the mechanism design approach cannot account for the strong empirical

[30] 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.

regularities that 3 and 4 ignore.[31] 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.[32] At one extreme, the complete contracts (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. Furthermore, they are related in a systematic way: Fixed price contracts feature high levels of design, high cost reducing incentives, and possibly large amounts of frictions when changes are required. Cost plus contracts feature low levels of design, fast tracking, low cost incentives, and small amounts of friction.[33] Another contrast to the incomplete contracts literature is that we do 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.[34]

Finally, and in a similar vein, we depart from the hold-up approach of procurement (Tirole, 1986) by assuming that there are no ex-ante relationship specific investments. Our modelling approach rather focuses on the problem of ex post renegotiation under different regimes, and the relationship between design and cost incentives. Note,

---

[31]The comparative statics on the distributions of types is quite useless since it is possible to rationalize any choice of contracts with the right asymmetry of information.

[32]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. In both these papers explaining endogenously incomplete contacts is the central issue, while in our model the incompleteness is a vehicle to cause ex post renegotiation, which is tied to the incentives of the ex ante contract.

[33]Two papers in the economics literature are similar in flavor to ours. Using both supermodularity and non convexities, Milgrom and Roberts (1990) present a model of an optimizing firm that reflect many of the observed trends in manufacturing. Taylor and Wiggins (1997) also exploit supermodularity to explain the coexistence of two separate systems of incentives and trade relationships, namely the "American" and "Japanese" systems used by automobile manufacturers.

[34]It is worth noting that the property rights approach is concerned about the effect of ownership and control on incentives, and does not address the issue of cost-based incentives. Thus, applying that methodology to procurement does not seems like an approach that would address many of the stylized facts we uncovered.

however, that a form of hold-up is present in our model: ex post there is friction in renegotiation, which means that the buyer cannot costlessly replace the contractor and have outsiders compete to continue the product. This is in essence a manifestation of Williamson's (1985) "fundamental transformation."

7.2 Evidence from Other Industries

Although our focus was motivated by the building construction industry, it is evident that ex post adaptation is an important consideration 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." We believe that similar forces of incentives and friction are likely to play a role in defence procurement as well.

More specifically, our model suggests that if the likelihood of changes to a design is large, then the buyer should choose a C+ contract, whereas a FP contract 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 (following 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 data set of 236 contracts, which are either fixed-price or cost-plus (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 may affect his contract. Banerjee and Duflo also show that older firms, and firms that are ISO-certified, do on average larger and more complex products than younger or non ISO-certifies firms.

The results of Banerjee and Duflo are not inconsistent with our model. If a buyer wishes to procure software that is simple, or small, then we would expect the design to be easy. This would lead to a fairly complete set of instructions, and a fixed-price contract. It is reasonable to argue that in the software industry young, small firms will generally bid lower and more aggressively than established large firms.[35] If, however,

[35]This would be either to establish themselves as capable, or because larger more established firms

the product is complex, or large, then design is more costly, resulting in less complete design and a cost-plus contract. In the latter case, since competitive bidding is not an option, then the buyer needs to select a firm using some 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 by Banerjee and Duflo would be interpreted by a different causality: the type of product determines the contract, and the latter determines the type of firm that is selected.

7.3 Concluding Remarks

Our goal was to illustrate a model that illustrates what we believe to be a fundamental problem of procurement contracting. We argue that an important aspect of contractual arrangements is their ability to accommodate adaptation, thus creating a trade-off 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 reduction incentives disappear, but the process of adaptation is far smoother since the reimbursement process is simple, well defined, and leaves little room for haggling. Evidence from procurement contracts in private construction, defence 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. However, for complex systems, in particularly 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[36] Mr. Liam P. Sarsfield, a Senior Policy Analyst with the Science and Technology Policy Institute at Rand, expressed concerns regarding "how can NASA 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

have higher overhead and greater profit margins.

[36]The Newshour with Jim Lehrer, 12/7/1999. Transcript available at http://www.pbs.org/newshour/bb/science/july-dec99/mars_12-7.html

spacecrafts 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, Ms. 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 resonates with the theme of out paper, and we believe our analysis provides some guidance as to when relaxing stringent fixed price rules is warranted.

Finally, applying our model to the make-or-buy decision sheds light on the Transaction Cost Economics literature and its attempts to explain the organization of production. We exactly model the ways in which ex ante incentives affect ex post bargaining and provide testable predictions that are supported by several empirical studies. The main contribution of our analysis to this literature is identifying a clear and precise difference between the transaction costs that arise inside the firm, and those that are generated by market procurement. Namely, the benefit of market procurement is providing incentives, while the costs are associated with inefficient ex post bargaining under asymmetric information. Internal procurement, however, eliminates these ex post efficiencies due to low incentives, but these low incentives have unwanted cost ramifications. Clearly, the modeling approach we propose just provides a first step in clarifying some aspects of the organization of production.

Appendix A: Proofs

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 returns, 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', $S \geqslant S'$, such that

$$\sum_{t=1}^{S-1} \pi_t < \tau \leqslant \sum_{t=1}^{S} \pi_t \text{ and } \sum_{t=1}^{S'-1} \pi'_t < \tau \leqslant \sum_{t=1}^{S'} \pi'_t \,,$$

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

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

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

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

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 $Eu^{FP} \geqslant Eu^{C+}$, which reduces to,

$$c(0) \geqslant c(e^{FP}) + g(e^{FP}) \,. \tag{10}$$

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

$$\begin{aligned} \max_{e} \; E\pi^{FP} &= \alpha - c(e^{FP}) - g(e^{FP}) \\ &\geqslant \alpha - c(0) \,, \end{aligned}$$

which is equivalent to (10) above. *Q.E.D.*

Proof of Proposition 1: From well known results in monotone comparative statics (see Vives (1999), Theorem 2.3(ii)) 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 non-negative. We first compute two of the partial derivatives:

$$\frac{\partial f}{\partial \tau} = x(\sigma v + K_1 - K_2) - \frac{\partial d(\tau, T)}{\partial \tau} \tag{11}$$

$$\frac{\partial f}{\partial (-T)} = \frac{\partial d(\tau, T)}{\partial T} \tag{12}$$

Differentiating (12) with respect to x and τ respectively gives,

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

where the inequality follows from the supermodularity of the derived function $d(\tau, T)$. Differentiating (11) with respect to x gives,

$$\frac{\partial^2 f}{\partial x \partial \tau} = \sigma v + K_1 - K_2$$

$$= \lambda(1 - F(w^*))v + \int_0^{v-k} mdF(m) - \lambda \int_{w^*}^{v-k} mdF(m) + k - \int_0^{v-k} mdF(m) - k$$

$$= \lambda \left[(1 - F(w^*))v - \int_{w^*}^{v-k} mdF(m) \right] > 0$$

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 4.1 above. This concludes that $f(\cdot,\cdot,\cdot,\cdot)$ has increasing differences in $(x, \tau, -T)$, completing our proof. *Q.E.D.*

Proof of Corollary 1: From (11) we obtain $\frac{\partial^2 f}{\partial x \partial(-\sigma)} = (1 - \tau)v > 0$, while $\frac{\partial^2 f}{\partial \tau \partial(-\sigma)} = -xv \leqslant 0$. *Q.E.D.*

Appendix B: Optimality of Linear Contracts

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 of ε. 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^*. However, 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 FOC is,

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

Now let

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

It is easy to see that (α^*, β^*) implement effort level e^* and given the seller zero expected profits by construction. This exercise works because the seller and buyer are assumed to be risk neutral, and thus linearity is not without loss of generality.

References

Anderson, Erin (1985), "The Salesperson as Outside Agent or Employee: A Transaction–Cost Analysis," Marketing Science, 4 (Summer), 234–254.

Ashley, David and Workman (1986) "Incentives in Construction Contracts," The Construction Industry Institute, Austin, Texas.

Banerjee, Abhijit and Esther Duflo (2000) "Reputation Effects and the Limits of Contracting: A Study of the Indian Software Industry," forthcoming, *Quarterly Journal of Economics.*

Bartholomew, Stuart H. (1998) *Construction Contracting: Business and Legal Principles,* Prentice-Hall, Inc.Procurement and Renegotiation,"

Battigalli, Pierpaolo and Giovani Maggi (2000) "Imperfect Contracting," mimeo, Princeton University.

Business Roundtable (1987) *Contractual Arrangements*, CICE product A-7.

Clough, Richard and Glenn Sears (1994) *Construction Contracting,* Wiley, NY.

Coase, Ronald. (1937). "The Nature of the Firm," *Economica*, **4**:386-405.

Cooter, Robert, S. Marks and Robert Mnookin (1982). "Bargaining in the Shadow of the Law: A Testable Model of Strategic Behavior," *Journal of Legal Studies,* **24**: 225-51.

Crocker, Keith J. and Reynolds, Kenneth J. (1993) "The Efficiency of Incomplete Contracts: An Empirical Analysis of Air Force Engine Procurement," *Rand Journal of Economics,* **24(**1):126-46.

Dye, Ronald, A. (1985) "Costly Contract Contingencies," *International Economic Review,* **26(**1):233-50.

Engineering News-Record. 12/12/94. Getting to the Top: Getty Center builders say elevating art in L.A. is no small task.

Engineering News-Record. 10/15/97. Getty Center Wraps Up Work Eight Years and $1Billion Later.

Engineering News-Record, 11/30/98 "The World is a 3.2 Trillion Construction Market", pp 35-68.

Finkel, Gerald. (1997) *The Economics of the Construction Industry.* M.E. Sharpe.

Grout, Paul (1984) "Investment and Wages in the Absence of Binding Contracts: A Nash Bargaining Approach," *Econometrica* **52(2)**: 449-60.

Grossman, Sanford and Oliver Hart (1986). "The Costs and Benefits of ownership:A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, **94**:691-719.

Hart, Oliver and John Moore (1990). "Property Rights and the Nature of the Firms," *Journal of Political Economy*, **98**:1119-1158.

Hester, Weston T., John A. Kuprenas, and T.C. Chang, (1991) "Construction Changes and Change Ordes: Their Magnitude and Impact," The Construction Industry Institute, Austin, Texas.

Hinze, Jim. (1993) *Construction Contracts*, McGraw-Hill Series in Construction Engineering and product Management. Irwin/McGraw-Hill.

Holmstrom, Bengt and Paul Milgrom (1991) "Multitask Principal-Agent Analyses: incentive Contracts, Asset Ownership, and Job Design," *Journal of Law, Economics and Organization*, **7(1)**:24-51.

Holmstrom, Bengt and John Roberts (1998) "The Boundaries of the Firm Revisited," *Journal of Economic Perspectives*, **12(4)**:73-94.

C. William Ibbs et al., (1986) "Determining The Impact of Various Construction Contract Types And Clauses On product Performance: Volumes I and II." The Construction Industry Institute, Austin, Texas.

Klein, Benjamin, Robert G. Crawford, and Armen A. Alchian (1978) "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, **21(2)**:297-326.

Laffont, Jean-Jacques and Jean Tirole (1993) *A Theory of Incentives in Procurement and Regulation*. MIT Press.

Manelli, Alejandro M. and Daniel R. Vincent (1995) "Optimal Procurement Mechanisms," *Econometrica* **63(3)**: 591-620.

Masten, Scott E. (1984) "The Organization of Production: Evidence from the Aerospace Industry," *Journal of Law and Economics*, **27**(3):403-17.

McAfee R. Preston and John McMillan (1986) "Bidding for Contracts: A Principal Agent Analysis" *Rand Journal of Economics*, **17**(3):326-38.

Milgrom Paul and John Roberts (1990b) "The Economics of modern Manufacturing: Technology, Strategy, and Organization," *American Economic Review*, **80(3)**:511-28.

Milgrom Paul and Christine Shannon (1994) "Monotone Comparative Statics," *Econometrica*, 62(1):157-180

Monteverde, Kirk, and David J. Teece (1982) Supplier Switching Costs and Vertical Integration," *Bell Journal of Economics,* **13**:206-13.

Novak, Sharon and Steven D. Eppinger (1999) "Sourcing by Design: Product Architecture and the Supply Chain," mimeo, Northwestern University and MIT.

Riordan, Michael and Oliver Williamson (1985) "Asset Specificity and Economic Organization," *International Journal of Industrial Organization*, **3**: 365-78.

Rogerson, William (1994) "Economic Incentives and the Defense Procurement Process," *Journal of Economic Perspectives*, **8(4)**: 65-90.

Simon, H. (1951) "A Formal Theory of the Employment Relationship," *Econometrica*, **19**:293-305

Sweet, Justin (1994) *Legal Aspects of Architecture, Engineering and the Construction Process,* West Publishing Company, MN.

Taylor Curtis and Steven Wiggins (1997) "Competition or Compensation: Supplier Incentives Under the American and Japanese Subcontracting Systems," *American Economic Review*, **87(4)**:598-618.

Tirole, Jean (1986) "Procurement and Renegotiation," *Journal of Political Economy*, **94(2)**: 235-259

Topkis, Donald (1998) *Supermodularity and Complementarity,* Princeton, Princeton Univ Press

U.S. Department of Commerce. Bureau of the Census. 1992a. Census of Construction Industries. United States Summary. Establishments With and Without Payroll. Washington DC: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. 1992b. Census of Construction Industries. General Contractors-Residential Buildings, Other Than Single-Family Homes. Washington DC: Government Printing Office.

U.S. Department of Commerce. Bureau of the Census. 1992c. Census of Construction Industries. General Contractor-Nonresidential Buildings, Other Than Industrial Buildings and Warehouses. Washington DC: Government Printing Office.

Vives, Xavier (1999) *Oligopoly Pricing: Old Ideas and New Tools*, Cambridge, MIT Press

Wernerfelt, Birger (1997) "On the Nature and Scope of the Firm: An Adjustment-Cost Theory," *Journal of Business*, **70(4)**: 489-514.

Williamson, Oliver E. (1975) *Markets and Hierarchies,* New York: Free Press

Williamson, Oliver E. (1985) *The Economic Institutions of Capitalism,* New York: Free Press

Williamson, Oliver E. (1991) "Comparative Economic Organization: The Analysis of Discrete Structural Alternatives," *Administrative Science Quarterly,* **36**:269-296