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ABSTRACT

We develop a procurement model where given sensible rules regarding contractor selection cost overruns are expected to occur. In this model, altough the sponsor has access to unbiased ex ante estimates of project costs, the selection mechanism induces an ex post downward bias as to project costs. We further investigate the relationship between signal's accuracy and the expected magnitude of the bias.

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1. INTRODUCTION.

This paper is concerned with providing a positive explanation for the phenomenon commonly known as cost overruns. Two of the more prominent examples where cost overruns appear common are the procurement of new weaponry and the development of new nuclear power plants. The existence of cost overruns in large scale, government sponsored procurement has always been a concern to economists and politicians. Peck and Scherer (1962) estimated that for U.S. defense programs development costs exceeded original predictions by 220 percent on average, and in some cases by as much as 14 times. More recent estimates in different countries as well as recent political debate in the United States about the development of new weapons systems also indicate that procurement costs are a very serious problem.

Though there has been considerable recent work on government procurement, e.g. Riordan (1986) and Tirole (1986), there has been very little written regarding the occurrence of cost overruns in government sponsored procurement.

The two papers that we are aware of which are explicitly devoted to formally analyzing cost overruns are Lewis (1986) and Arvan and Leite (1989). Lewis considers the Bayes equilibrium of a repeated contract game where the sponsor learns over time about the contractor's private information and the sponsor may cancel the project at any time if the sponsor's beliefs about this private information are sufficiently pessimistic. This setup is complicated by assuming that when the cost distribution is unfavorable the contractor can exert cost reducing effort, unobserved by the sponsor, to improve the cost distribution. Lewis' model does predict cost overruns as equilibrium outcomes but he takes the sharing rule by which the contractor is compensated to be parametric. Since the incentive for the contractor to exert cost reducing effort is provided by expected future rents, one may wonder why these rents are present and whether Lewis' results would be sustained if the compensation were determined endogenously.

Arvan and Leite develop a model where the compensation scheme is determined endogenously. They consider a dynamic contract game between a sponsor and a contractor concerning a project which requires a finite number of tasks to be completed before the benefit from the project can be realized. In every period there are expected future rents to be earned by the contractor which, at the start of each task observes some private information, relevant in determining cost. When the task is completed the sponsor observes a noisy signal of the contractor's cost. Focusing on the case where the sponsor cannot precommit to compensation per task and where the contractor is not bound to complete the project, the authors demonstrate that in equilibrium both the distribution of cost per task, given that the task is completed, and the compensation scheme rise as the project nears completion, giving the appearance of cost overruns towards the tail end of the project.

However, this twofold effect of unfavorable shifts in the cost distribution and tilting in the compensation scheme, which Arvan and Leite interpreted as cost overruns, can be anticipated ex ante, given the structure of the model, meaning that, in fact,there are no cost overruns in a statistical sense. This problem motivated our paper.

We develop a positive model where given sensible procurement rules regarding project selection cost overruns are expected to occur. The sponsor receives a noisy though unbiased estimate of project costs from a prespecified number of potencial contractors[1]. She then selects the contractor which signals the least ex ante expected cost. Although the estimates constitute ex ante unbiased estimators of the true project costs, the selection mechanism induces an ex post bias. Specifically, when the sponsor uses the initial estimates to predict the costs of completing the project she will on average underestimate them. The intuition behind this result is that the chance of a given contractor being selected is an increasing function of how much the original signal underestimates the true cost. In fact, given the selection mechanism, the sponsor will choose the signal which underestimates the true cost the most, in an expected value sense.

This is very similar to the winner's curse phenomenon in the auctions literature, e.g., Capen, Clapp and Campbell (1971), Milgrom (1981), Milgrom and Weber (1982), et. al.. The basic idea in these papers, is that the bidders that have the highest chance of winning a given object in a public auction are those which have overestimated the value of the object. Consequently, the bidders which made nonbiased estimations of the value of the objects will ex post realize that they have, on average, overestimated that value for the objects which they have won. In the problem that we analyze, we do not havecompetition among bidders, but we do have situations where sensible selection rules on the part of the sponsor, which ex ante does not have biased estimates regarding project costs, lead to ex post biased estimates, i.e., there are cost overruns in a statistical sense. In both the winners' curse and the cost overruns problems the ex post bias is induced by the selection mechanism.

Note that this explanation for cost overruns should be seen as a complement to Arvan and Leite's, not as a substitute, since it uses a static framework to analyze this phenomenon.

As we have previously mentioned, cost overruns seem to be particularly pervasive in long term projects. Besides their sequential structure these projects are also caracterized by typically involving less reliable cost estimates than projects in ordinary business. This aspect can be captured in our static framework, in which we show the positive relationship between greater uncertainty and larger expected cost overruns, i.e., there are, on average, larger cost overruns in long term projects because they have associated a greater degree of uncertainty. The remainder of the paper is organized as follows. In the next section we present the basic structure and the main results of the model. Section 3 is devoted to the analysis of the relationship between riskiness and the extent of cost overruns. Section 4 offers an application to insurance problems using a different selection mechanism. This suggests that what causes the pediciton bias is

2. THE BASIC MODEL AND MAIN RESULTS.

We consider the relationship between a sponsor and a contractor regarding the construction of a project. Initially the sponsor receives n unbiased signals, s_i, $i=1,2,\ldots,n$ concerning the cost of the project from n different potencial contractors. The signals may be provided to the sponsor by an independent expert whose only task is to evaluate potencial contractors' costs. These signals result from the sum of an idiosyncratic cost component, c_i, unobserved by the sponsor, and a measurement error, ε_i, $i=1,2,\ldots,n$. c_i is assumed to be normally distributed with mean μ and variance σ_c^2, i.e., $c_i \sim N(\mu,\sigma_c^2)$. The measurement error is also a normally distributed random variable with zero mean and variance σ_ε^2, $\varepsilon_i \sim N(0,\sigma_\varepsilon^2)$. c_i and ε_i are assumed to be independent random variables.

Let f denote the signal's probability density function and F the corresponding distribution function. Since $s_i=c_i+\varepsilon_i$, f is a normal density function with mean μ and variance $\sigma_c^2+\sigma_\varepsilon^2$.

In order to maximize the expected value of her net benefits the sponsor selects the contractor whose costs are evaluated by the expert as being the lowest.

Let $s^*=\min(s_1,s_2,\ldots,s_n)$ where $(s_1,s_2,\ldots,s_n)$ is an n dimensional sample drawn from f. Define $\Psi(s^*)$ as the probability density function of s^*. $\Psi(s^*)$ is given by:

$$\Psi(s^*)=\mathrm{pdf}(\min(s_1,s_2,\ldots,s_n))=nf(s^*)(1-F(s^*))^{n-1} \tag{1}$$

We can now state our first lemma:

LEMMA 1:

$\Psi(\mu-k)>\Psi(\mu+k)$, for $k>0$.

Proof:

Since f(.) is symmetric we have that:

$f(\mu-k)=f(\mu+k)$. We also have that:

$F(\mu-k)<F(\mu+k)$, because $k>0$. Hence,

$nf(\mu-k)(1-F(\mu-k))^{n-1}>nf(\mu+k)(1-F(\mu+k))^{n-1}$

or

$\Psi(\mu-k)>\Psi(\mu+k)$ ■

We can now use this result to prove the following lemma:

LEMMA 2:

$\int_{\Omega} E(\varepsilon|s^*)\Psi(s^*)ds^*<0$, with $\Omega=]-\infty,+\infty[$.

Proof:

$E(\varepsilon|s^*) = (s^*-\mu)\dfrac{\sigma_\varepsilon^2}{\sigma_c^2+\sigma_\varepsilon^2}$ is a well known result in the context of the signal extraction problem (see, for example, Sargent (1979))[2]. Therefore we may write:

$$\int_{\Omega} E(\varepsilon|s^*)\Psi(s^*)ds^* = \int_{\Omega}(s^*-\mu)\frac{\sigma_\varepsilon^2}{\sigma_c^2+\sigma_\varepsilon^2}\Psi(s^*)ds^*.$$

This expression is strictly negative given the symmetry of

$$(s^*-\mu)\ \frac{\sigma_\varepsilon}{\sigma_c^2+\sigma_\varepsilon^2}$$

and lemma 1. ■

It happens that despite the ex ante unbiasedness of signals, the sponsor, on average, underestimates the true cost of the selected project by using the expert estimate for the selected contractor. This result constitutes our first theorem.

THEOREM 1:

On average the use of the above mentioned selection mechanism leads to an underestimation of project costs, i.e.:

$$\int_\Omega E(c|s^*)\Psi(s^*)ds^* > \int_\Omega s^*.\Psi(s^*)ds^*.$$

Proof:

We have that:

$$\int_\Omega E(c|s^*)\Psi(s^*)ds^* = \int_\Omega s^*\Psi(s^*)ds^* - \int_\Omega E(\varepsilon|s^*)\Psi(s^*)ds^*$$

Since

$$\int_\Omega E(\varepsilon|s^*)\Psi(s^*)ds^* < 0$$

from lemma 2, we can therefore write:

$$\int_{\Theta} E(\theta|s^{*}) f(s^{*}) ds^{*} > \int_{S} s^{*} \cdot q(s^{*}) ds^{*}.$$

3. SIGNAL ACCURACY AND COST OVERRUNS.

Let us now consider the relation between signal accuracy and the magnitude of cost overruns. In order to do that suppose that we had two n-dimensional samples of cost signals drawn from two normal distributions f^1 and f^2 with the same mean, μ, and variances $\sigma_1^2=\sigma_c^2+\sigma_{\varepsilon_1}^2$ and $\sigma_2^2=\sigma_c^2+\sigma_{\varepsilon_2}^2$ with $\sigma_{\varepsilon_1}^2<\sigma_{\varepsilon_2}^2$.

We may now state the following result regarding the expected value of the minimal signal drawn from the sample.

LEMMA 3:

$E(s_1^*)>E(s_2^*)$ with $s_i^*=\min(s_1^i,s_2^i,\ldots,s_n^i)$, $i=1,2$.

Proof[9]:

$$E(s_i^*)=\int_\Omega s^*.\Psi^i(s^*)ds^*=\int_\Omega s^* nf^i(s^*)(1-F^i(s^*))^{n-1}ds^*.$$

Now, let $y=F(s^*)$. Then:

$$E(s_i^*)=\int_0^1 nF^{i^{-1}}(y)(1-y)^{n-1}dy.$$

Now, let $z=1-y$. Hence, we have:

$$E(s_1^*) - E(s_2^*) = \int_0^1 n\left[F^{1^{-1}}(1-z) - F^{2^{-1}}(1-z)\right] z^{n-1} dz.$$

Given the shape of $F^{i^{-1}}(1-z)$, $i=1,2$, which is illustrated in Fig.1, and the fact that $F^{1^{-1}}(1-z)-F^{2^{-1}}(1-z)<0$ for $z<1/2$ and $F^{1^{-1}}(1-z)-F^{2^{-1}}(1-z)>0$ for $z>1/2$, we have that $E(s_1^*)-E(s_2^*)>0$. ∎

Given lemma 3 we have that:

$$\mu-\int_\Omega s^* n f^1(s^*)(1-F^1(s^*))^{n-1} ds^* -$$

$$-\left\{\mu-\int_\Omega s^* n f^2(s^*)(1-F^2(s^*))^{n-1} ds^*\right\}<0.$$

Since:

$$\mu-\int_\Omega s^* n f^i(s^*)(1-F^i(s^*))^{n-1} ds^* =$$

$$=\int_\Omega (\mu-s^*)\Psi^i(s^*) ds^*,$$

we have:

$$\int_\Omega (\mu-s^*)\Psi^1(s^*) ds^* - \int_\Omega (\mu-s^*)\Psi^2(s^*) ds^* < 0$$

$$\Delta_i=\int_\Omega E(c|s^*)\Psi^i(s^*)ds^*-\int_\Omega s^*.\Psi^i(s^*)ds^*=$$

$$=\int_\Omega\left[(s^*-\mu)\ \frac{\sigma_c^2}{\sigma_c^2+\sigma_{\varepsilon_i}^2}+\mu-\ s^*\right]\Psi^i(s^*)ds^*=$$

$$=\int_\Omega\left[(\mu-s^*)\ \frac{\sigma_{\varepsilon_i}^2}{\sigma_c^2+\sigma_{\varepsilon_i}^2}\ \right]\Psi^i(s^*)ds^*.$$

This result allows us to state Theorem 2, indicating that, on average, a less accurate signal leads to larger cost overruns.

THEOREM 2:

$\Delta_2-\Delta_1>0$.

Proof:

$$\Delta_2-\Delta_1\ =\ \int_\Omega\left[(\mu-s^*)\ \frac{\sigma_{\varepsilon_2}^2}{\sigma_c^2+\sigma_{\varepsilon_2}^2}\ \right]\Psi^2(s^*)ds^*\ -$$

$$-\ \int_\Omega\left[(\mu-s^*)\ \frac{\sigma_{\varepsilon_1}^2}{\sigma_c^2+\sigma_{\varepsilon_1}^2}\ \right]\Psi^1(s^*)ds^*.$$

Given that $\frac{\sigma_{\varepsilon_2}^2}{\sigma_c^2+\sigma_{\varepsilon_2}^2}>\frac{\sigma_{\varepsilon_1}^2}{\sigma_c^2+\sigma_{\varepsilon_1}^2}$ and that:

$$\int_\Omega(\mu-s^*)\Psi^1(s^*)ds^*-\int_\Omega(\mu-s^*)\Psi^2(s^*)ds^*<0\ ,$$

we have that $\Delta_2 - \Delta_1 > 0$. ∎

This result implies that the extent of cost overruns is a negative function of the accuracy of the cost signal. Therefore cost overruns are more likely to occur in large scale, long term projects where costs are less accuratly predictable.

4. AN APPLICATION TO INSURANCE.

Let c_i, $i=1,2,\ldots,n$ be the cost, for the insurance company, of insuring individual i. s_i, $i=1,2,\ldots,n$ represents a signalthat the company receives from its experts as to the cost of insuring individual i. Let ε_i, $i=1,2,\ldots,n$ denote the measurement error.

c_i is normally distributed with mean μ and variance σ_c^2. The measurement error is also normally distributed with zero mean and variance σ_ε^2.

The insurance company chooses a selection mechanism for picking its potencial insurees that can be described as follows: it will insure any individual whose signalled cost does not exceed a prespecified maximum, $\bar{s}$, i.e., it will insure any individual i such that $s_i = c_i+\varepsilon_i \leq \bar{s}$.

It turns out that, by adopting this selection mechanism, the insurance company will insure individuals whose actual cost will be, on average, higher than their signalled cost. This result constitutes Theorem 3.

THEOREM 3:

For any $s_i\leq\bar{s}$ we have $E(c_i|s_i) > s_i$.

Proof:

$$E(c_i|s_i) = E(s_i|s_i) - E(\varepsilon_i|s_i) =$$
$$= s_i - E(\varepsilon_i|\varepsilon_i\leq\bar{s}-c_i).$$

Since $E(\varepsilon_i|\varepsilon_i\leq\bar{s}-c_i) < 0$, then: $E(c_i|s_i)>s_i$. ■

5. CONCLUSION.

In both Lewis (1986) and Arvan and Leite (1989) the notion of cost overruns appears to be identified with the occurence of unfavorable shifts in the distribution of realized costs as project nears completion. Neither paper provides a comparison between benchmark cost expectations and realized costs. We think that such a comparison constitutes a more natural framework for analyzing cost overruns.

In this paper we were able to show that the mere existence of a selection mechanism is enough to explain the ex post bias of an ex ante unbiased cost prediction. This is the phenomenon we identify with cost overruns.

Both Lewis (1986) and Arvan and Leite (1989) analyze cost overruns in the context of long term relationships between a sponsor and a contractor. We do not focus on the sequential structure of long term projects. We are nevertheless able to explain why cost overruns are so pervasive in long term projects, the reason being simply that the cost estimates for such projects are less reliable than those in ordinary business.

NOTES:

1. The unbiasedness assumption is made to abstract from, namely, incentive problems associated with signal's transmission. We then focus on the effects of the selection mechanism on the statistical properties of the signal as a predictor of true cost.

2. Note that this formula simply indicates that the greater the relative variance of the error, the greater the proportion of the deviation of the signal relative to the mean that should be attributed to the error term.

3. We gratefully acknowledge Gabriel Talmain forproviding us with this proof.

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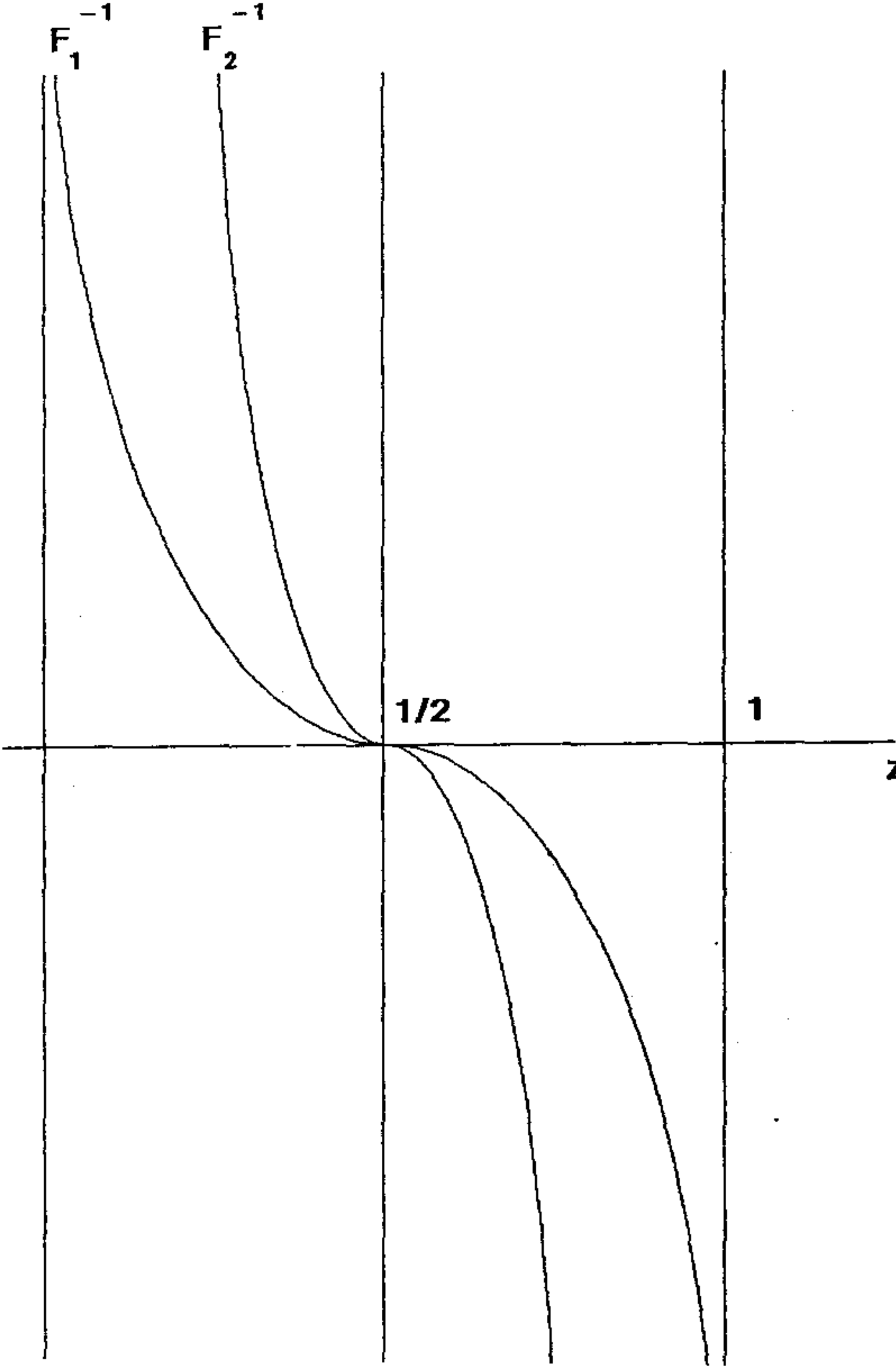

F_1^{-1}
F_2^{-1}
1/2
1
z