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TURBULENCE, COST ESCALATION, AND CAPITAL INTENSITY BIAS IN DEFENSE CONTRACTING

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The recent growth of defense expenditures has once more raised public concern about cost overruns on defense contracts. Economists have pointed out that cost overruns are not necessarily bad *per se*; instead, attention should be directed to the question as to whether the procurement policies of the Department of Defense (DoD) satisfy the criterion of economic efficiency (see Peck and Scherer (1962)). In connection with this, applications of the principal-agent model to defense contracting show that not only do cost plus fixed fee (CPFF) contracts create moral hazard problems, but that in fact so long as contractors are risk averse and perfect monitoring of their activities is not possible, inefficiencies will arise whatever the form of the contract employed in DoD procurement (see Ross (1973), Harris and Raviv (1979), and Weitzman (1980)). It has been suggested that improvements in efficiency might be achieved if contracts more closely resembling Arrow-Debreu contingent claims were employed (see Cummins (1977)), but this raises problems of manipulation of the probabilities of occurrence of the relevant states of the world. Looking at the problem of cost escalation from a completely different point of view, biases might be introduced into cost comparisons and into decision making with respect to risky projects simply because of the methodology employed by cost estimators (see Quirk and Terasawa (1983)).

In this paper, we examine one further source of cost escalation and inefficiency in defense contracting namely, "turbulence." By turbulence is meant fluctuations over time in product specifications, in delivery schedules, in order quantities, and in other aspects of procurement. In the present paper, we restrict our attention to turbulence with respect to order quantities, but the approach we use can be extended to other forms of turbulence as well. Turbulence in order quantities is introduced into defense contracting because most DoD contracts (the so called "annual" contracts) provide only for tentative time paths of purchases by DoD, time paths that can be changed unilateraly by DoD. Turbulence in order quantities occurs as a result of the Congressional budgeting process, DoD decision making, the cost history of a weapon system, and a myriad of other factors, both random and nonrandom. A portion at least of the turbulence that is observed represents simply a rational response on the part of DoD to new information as it becomes available--a change in the nature of external threats as perceived by DoD, or developments or lack of developments in competing and complementary weapon systems, for example. Uncertainties introduced into the procurement process by the availability of new information

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may be an inherent part of the acquisition process. If so, this kind of uncertainty is the price for flexibility and there is no ground for arguing that it should be removed from the procurement process by means of guarantees or legislative action. On the other hand, if the turbulence observed in order quantities is due to poor planning or the lack of coordination between DoD and the contractor, reduction of such uncertainties would be a desirable endeavor in a move toward an efficient allocation of resources.

In any case, it is generally believed in DoD that turbulence is a major source of cost escalation in weapon systems, and that reforms in the budgeting process that would permit long term commitments by DoD to definite time paths of procurement levels, could substantially decrease the cost of defense procurement. One way in which reducing turbulence might produce savings is through the adoption of more capital intensive production processes by defense contractors, who are known to be characterized by low capital intensity coefficients, presumably in part because of the uncertainty as to the time path of orders under defense contracts.

Documentation as to the effect of turbulence on procurement costs is difficult to obtain, because the accounting system used by DoD to identify the causes of cost growth in a weapon system provides little in the way of useful information on this score. In the next section, we illustrate the kinds of changes that occur in DoD procurement schedules by looking at the case of one recently developed weapon system. In addition, we summarize some empirical evidence for

the low capital/output ratios of defense contractors.

We then examine the effect of turbulence on the behavior of defense contractors in the setting of a simplified two period model. If a contractor is risk neutral, then under any of the usual DoD contracting approaches except CPFF, an increase in turbulence results in an increase in expected cost of production for the contractor, assuming a convex cost function. Increases in turbulence have a less predictable effect on the amount of capital used in production. In the case of a CES production function, less capital is employed if capital and labor are close substitutes for one another, under constant or increasing returns to scale. But this conclusion is reversed when capital and labor are poor substitutes for one another, under constant or decreasing returns.

The appropriate measure of "cost" in the risk averse case is the lump sum payment required by the contractor to restore him to the level of expected utility enjoyed before turbulence was increased. This sum is always positive for risk neutral or risk averse contractors, given a convex cost function, under any of the usual DoD contracting arrangements other than CPFF. Moreover, considering the terms arrived at in the contract to be the result of a bargaining game between DoD and the contractor, DoD will share some of the increased costs due to turbulence except in the case where all the gains from trade are captured by the contractor. While a high degree of substitutability between capital and labor provides an explanation for a capital intensity bias in the risk neutral case, more complicated conditions would be required to extend this result in the risk averse case. Consequently an alternative explanation is explored. What is argued here is that the renegotiation process employed by DoD might offer an explanation for a capital intensity bias. If it is assumed that contracts get renegotiated when the contractor would suffer out of pocket losses (revenue does not cover variable costs), then this form of renegotiation induces a capital intensity bias--defense contractors use less capital than they would under the same circumstances (but without renegotiation) in nondefense work. Renegotiation might also result in a preference by contractors for more rather than less turbulence, depending upon whether they are over or under compensated for turbulence through renegotiation.

Turbulence: An Example

Turbulence in the time path of order quantities is present in most defense contracting. Here we present data on a major weapon system, the UH-60A (Black Hawk) helicopter, based on an excellent recent study by Gates [1983]. The UH-60A is the first new helicopter to be developed by the Army since the 1960s. Its operational mission is that of expanding on the role of the UH-1 Huey helicopter, with added lifting capacity, speed, maneuverability and range.

The Black Hawk is currently in production and has been a technical success, meeting or exceeding all of the operational requirements set forth in the initial performance specifications. Moreover, development of the Black Hawk came within four months of meeting schedule deadlines set six and one half years earlier. The

original schedule provided for initial operational capability to occur in July, 1977. (Initial operational capability was defined as one company equipped with 15 Black Hawk helicopters, complete with training and all support equipment on line). Actual initial operational capability was achieved in November, 1977.

However, the procurement schedule for the Blackhawk has been revised several times over the course of its development history. The total number of units to be produced has remained constant in all of these revisions, but the schedule has been stretched out and the time path of order quantities varied. Table 1 provides a summary of these changes.

TABLE 1

BLACK HAWK PROCUREMENT SCHEDULE

Fiscal Year	Initial Schedule	Fiscal Year 1976	Fiscal Year 1980	Fiscal Year 1981	Sept. 1981	Oct. 1982
1977	15	15	15	15	15	15
1978	24	56	56	56	56	56
1979	46	129	129	92	92	92
1980	121	168	145	94	94	94
1981	168	168	145	80	80	80
1982	168	168	145	96	96	96
1983	168	180	145	75	96	96
1984	180	180	145	29	84	84
1985	180	43	145	31	63	78
1986	37		37	65	54	78
1987				96	70	78
1988				96	54	85
1989				96	96	96
1990				96	96	79
1991				90	61	
Totals	1,107	1,107	1,107	1,107	1,107	1,107

(The original (1971) procurement schedule provided for a delivery of 276 aircraft over the initial three year period. This was revised down to 85 before the October 1976 Baseline Cost Estimate was prepared).

Source: Gates [1983].

During the course of development of the Black Hawk, cost estimates have been prepared on a more or less regular basis, reflecting both supply side factors such as delays, inflation and the like, and the effect of turbulence and other demand side factors. The cost history of the Black Hawk has shown a pronounced escalation over time. Table 2 summarizes cost estimates for the projected 1,107 helicopters over the period 1971-1982.

TABLE 2

BLACK HAWK COST ESTIMATES, CURRENT DOLLARS, 1971-1982

Date	Cost Estimate (millions of $)
December 31, 1971	$1,897.4
December 31, 1973	2,249.6
June 30, 1974	2,955.8
September 30, 1974	3,520.2
March 31, 1975	3,157.5
June 30, 1975	2,864.0
December 31, 1979	5,242.7
December 31, 1980	6,099.6
March 31, 1981	6,812.6
September 30, 1981	7,262.7
September 30, 1982	7,230.8

Source: Gates [1983].

Gates' study does not attempt to estimate the quantitative impact of turbulence on cost or cost estimates. In fact, the information system used by DoD in identifying sources of cost growth (primarily the Selected Acquisition Report (SAR)) is not structured so as to provide data to answer such questions. The Gates study simply identifies turbulence as one of several factors contributing to cost growth for the Black Hawk, while recognizing the "chicken and egg" nature of the links between turbulence and costs. Thus an increase in cost can lead to a stretch out of orders (turbulence) because of budgetary constraints on DoD, just as a change in order quantities can induce growth in cost due to the need to cancel or accelerate input orders, revise delivery dates for components, provide for overtime or for layoffs, and the like.

Capital Intensity Bias in Defense Contracting

The empirical evidence for a capital intensity bias in defense contracting comes from several studies, beginning with one by Weidenbaum (1967). Weidenbaum selected a small sample of firms engaged in defense contracting, and compared data on these firms with data from a small sample of non-defense firms, using the periods 1952-55 and 1962-65. The defense firms showed a lower profit margin on sales (roughly 2.8% vs. 4.5% for the non-defense firms), and a higher rate of return on net worth (18% vs. 12% for the non-defense firms). The reason for this discrepancy between return on sales and return on net worth is that the "capital turnover" ratio of defense firms was significantly higher than that for non-defense firms (6.5 vs. 2.6). Capital turnover is the ratio of sales to net worth. Weidenbaum argues that the higher capital turnover ratio of defense firms reflects the large amounts of government supplied capital that defense firms use, this capital not being accounted for in net worth. Weidenbaum does not explain why it is that defense firms rely on government supplied capital rather than investing in capital on their own.

Belden (1969) divided the Fortune 500 into three groups, based on the fraction of total sales represented by DoD and NASA sales for each firm over the period 1957-1967. Belden finds that the average capital turnover ratios for firms with zero or low DoD and NASA sales ratio was low (around 2.75) as compared to the capital turnover ratios for firms for which DoD and NASA sales represent more than 50% of

total sales (average capital turnover ratio of 5.80).

A GAO [1969] study involved a survey of 74 large defense contractors to determine financial data broken down by type of business. The GAO study found that the average capital turnover ratio on DoD business was 4.9 as compared to a turnover ratio of 2.3 on commercial business.

Pegram [1983] looks instead at the value of property, plant and equipment (PP&E) per employee. Using a sample of four large defense contractors and a sample of 6 non-defense firms, data ver the 1977-1982 period show that PP&E per employee for the defense contractors is $11,716 while the figure for non-defense contractors is $16,157. Thus all of these studies show a capital intensity bias for defense contractors as compared to non-defense firms.

The Theory--The Risk Neutral Case

Turning next to the theory, consider the following simplified model. A defense contractor is engaged in the production of a weapon system, under a DoD contract. This is a two-period model. At time 1, the quantity ordered for the first period, q_1, is known with certainty, but q_2, the second period order quantity, is a random variable with probability density function $f(q_2)$. The production function for the contractor is time independent, being given by

$$q_t = g(K,L_t) \quad t = 1,2 \qquad (1)$$

Capital K is a fixed input; K is chosen at time 1 and is fixed thereafter. Labor L_t is a variable input. In particular, L_2 is chosen only after the order quantity q_2 is known. Production must meet order quantities.

We are interested in determining the effects of turbulence on cost and on the capital intensity of the production process chosen by the contractor. In this section we examine the case of a risk neutral contractor; in the succeeding sections we look at the case of a risk averse contractor.

Let $C(q_1,q_2,K)$ denote the discounted cost of production to the contractor for order quantities q_1,q_2, and a choice of capital K. Then $C(\cdot)$ is given by

$$C(q_1,q_2,K) = PK + wL_1(q_1,K) + \delta wL_2(q_2,K) \tag{2}$$

where P is the price per unit of capital, w is the wage rate, δ is a discount factor, and L_1,L_2 satisfy

$$g(L_1(q_1,K),\ K) = q_1;\quad g(L_2(q_2,K),\ K) = q_2 \tag{3}$$

We assume that $g_L > 0$, $g_K > 0$, $g_{LL} < 0$, $g_{LK} > 0$. Under these assumptions, it follows that C is monotone increasing and strictly convex in q_2 for any given K, since $C_{q_2} = \delta w/g_L > 0$, $C_{q_2q_2} = (-\delta wg_{LL})/g_L^3 > 0$.

Consider next the expected value of cost under the pdf f, E_fC:

$$E_fC = PK + wL_1(q_1,K) + \delta w \int_0^\infty L_2(q_2,K)f(q_2)dq_2 \tag{4}$$

Suppose that f is replaced by the pdf $h(q_2)$ where h represents a mean preserving increase in the spread of f. We will interpret the change from f to h to be an increase in "turbulence." Then Proposition 1 follows:

<u>Proposition 1</u> An increase in turbulence results in an increase in $\min_K EC$; that is, if h is a mean preserving increase in the spread of f, then $\min_K E_hC > \min_K E_fC$.

<u>Proof</u>: Following Rothschild and Stiglitz (1970), if h is a mean preserving increase in the spread of f, then f stochastically dominates h in the sense of second degree stochastic dominance (see Hadar and Russell (1968)). That is

$$\int_0^{q_2} F(t)\,dt \leq \int_0^{q_2} H(t)\,dt$$

for all $q_2 \geq 0$, with strict inequality for some q_2. When f stochastically dominates h in the sense of second degree stochastic dominance, then $E_f\phi(q_2) < E_h\phi(q_2)$ for all strictly convex functions $\phi(q_2)$.

Since $C(\cdot)$ is strictly convex in q_2 for any given K, it follows that $\min_K E_fC < \min_K E_hC$.*

Proposition 1 asserts that if K is chosen to minimize expected cost, then an increase in turbulence increases expected cost. Does an increase in turbulence also have a predictable effect on the capital intensity of production, under a cost minimizing strategy? Proposition 2 indicates that this depends on the third derivative of the

*See the appendix for an alternative proof of this proposition.

production function:

<u>Proposition 2</u> If K is chosen to minimize expected cost, then an increase in turbulence results in a decrease (increase) in K if C_K is strictly convex (strictly concave) in q_2, for every K.

<u>Proof</u>: This is another application of Rothschild and Stiglitz' result. If f stochastically dominates h in the sense of second degree stochastic dominance, then

$$E_f(C_K(q_2,K)) < E_h(C_K(q_2,K))$$

if C_K is strictly convex in q_2 for any K. Let K_f be the cost minimizing choice of K under f, and let K_h be the cost minimizing choice of K under h, so that $E_f(C_K(q_2,K_f)) = E_h(C_K(q_2,K_h)) = 0$. It follows that $E_h(C_K(q_2,K_f)) > 0$, so that $K_h < K_f$. If C_K is strictly concave in q_2 for any given K, then $K_h > K_f$.

The condition that C_K be convex in q_2 is clearly highly restrictive. For example, if the production function g is of the CES variety, then C_K is convex in q_2 if the elasticity of substitution coefficient is greater than 2, and if there are constant or increasing returns to scale. If the elasticity of substitution coefficient is less than 1, then under constant or decreasing returns to scale, C_K is concave. (See the appendix for details).

In the case of the CES function, an increase in turbulence leads to less capital being used when capital and labor are relatively good substitutes for one another (and the scale parameter is sufficiently large), and to more capital being used when the inputs

are poor substitutes (and the scale parameter is sufficiently small). Just what the interpretation is in the general case is somewhat problematical.

Thus far, we have looked at the way in which expected cost and capital intensity respond to turbulence under an expected cost minimizing strategy. Consider next the choices of defense contractors acting to maximize expected profits. Contractors are employed by DoD under one of four kinds of contracts: fixed price (FP), cost plus a fixed fee (CPFF), cost plus incentive fee (CPIF), or a modified fixed price contract. (MFP). We examine the effects of turbulence on expected cost and capital intensity treating the contractual arrangement as given. Later we look at the role of contract renegotiation in the decision making of contractors.

Let $R(q_1,q_2,K)$ denote the discounted revenue function for the contractor. Then $R(\cdot)$ varies by contract type as follows:

<u>Fixed Price contract</u>:

$R(\cdot) = pq_1 + \delta pq_2$, for some constant p;*

<u>Cost Plus Fixed Fee contract</u>:

$R(\cdot) = C(q_1,q_2,K) + A$, for some constant A;

<u>Cost Plus Incentive Fee contract</u>:

$R(\cdot) = aC(q_1,q_2,K) + p'q_1 + \delta p'q_2$, for some constants p', a, $0 < a < 1$;

<u>Modified Fixed Price contract</u>:

*Strictly speaking, fixed price contracts can be divided into fixed price with redetermination (of the price) at some future date, and firm fixed price contracts. See Morse (1962).

$R(\cdot) = p''q_1 + \delta p''q_2 + bPK$ for some constants p'', b, $0 < b < 1$.

Given a risk neutral contractor, and given one of the above types of contracts, the contractor chooses K to maximize expected profits $E\pi$, where

$$\pi = R(q_1, q_2, K) - C(q_1, q_2, K) \quad (5)$$

Then the following proposition holds:

Proposition 3 Given a risk neutral contractor, the effects of an increase in turbulence are the following:

(1) Fixed Price: expected cost increases, capital intensity decreases (increases) if C_K is convex (concave) in q_2;
(2) Cost Plus a Fixed Fee: effects on EC and K are indeterminate;
(3) Cost Plus Incentive Fee: effects are as with fixed price;
(4) Modified Fixed Price: effects are as with fixed price.

Proof:

(1) Under a fixed price contract, K is chosen to maximize $E\pi = ER - EC$. Since $ER = pq_1 + pq_2$ is independent of K, this means K is chosen to minimize EC. Hence the conclusions of Propositions 1 and 2 apply.

(2) Under a CPFF contract, $E\pi = A$, where A is a constant independent of K. Thus the choice of K and the resulting EC are indeterminate for any pdf.

(3) Under a CPIF contract, $E\pi = p'q_1 + \delta p'Eq_2 - (1 - a)EC$, $0 < a < 1$. Clearly the argument of (1) applies.

(4) Under an MFP contract, $E\pi = p''q_1 + \delta p''Eq_2 - EC + bPK$, where $-EC + bPK = -(1 - b)PK - wL_1 - \delta wEL_2$. Because $(1 - b)P$ is the implicit price of K, EC is not minimized. However, changes in EC and in K because of turbulence are those predicted in Propositions 1 and 2, since the EC − bPK function is an EC function with $(1 - b)P$ the price of capital.

Thus, except for the CPFF case, an increase in turbulence produces an increase in expected cost given risk neutral contractors, while the effect on capital intensity is more speculative, depending on relatively obscure aspects of the production function.

The Theory--The Risk Averse Case

Consider next the case of a risk averse contractor. Let $U(\pi)$ denote the monotone increasing strictly concave utility function for the contractor. Given a revenue function $R(\cdot)$ associated with one of the four contract types above, the contractor chooses K to maximize expected utility:

$$\max_K V = U(\pi_1) + \delta EU(\pi_2) \quad (6)$$

$$\text{where } \pi_1 = R(q_1) - PK - wL_1$$

$$\pi_2 = R(q_2) - wL_2.$$

The effect of turbulence on capital intensity bias is ambiguous in the risk averse case. By the arguments given earlier, K decreases (increases) as turbulence increases, if U_K is a convex (concave) function of q_2. But $U_{Kq_2q_2}$ is given by

$$U_{Kq_2q_2} = U'\pi_{Kq_2q_2} + U''[2\pi_{q_2}\ \pi_{Kq_2} + \pi_K\ \pi_{q_2q_2}] + U'''\ \pi_K\ \pi_{q_2}^2 \quad (6)$$

When $\pi_{Kq_2q_2}$ is positive, then an increase in turbulence decreases the capital intensity of production in the risk neutral case, under FP, CPIF, or MFP contracting. When there is risk aversion, then even assuming constant or decreasing absolute risk aversion (which implies $U''' > 0$) together with $\pi_{Kq_2q_2}$ positive does not remove the indeterminacy since π_{q_2} is of unknown sign. It is clear that conditions guaranteeing convexity or concavity of U_K will be obscure in terms of economic content.

Thus we have the following.

Proposition 4

Given a risk averse contractor, an increase in turbulence has indeterminate effects on the choice of K, for all DoD contract types. The direction of change in this variable, as well as the quantitative magnitude of the change, will depend in general on the functional forms of the utility and production functions, as well as on the pdf.

Consider next the effect of turbulence on cost. In a world of risk neutral contractors, the cost of turbulence to the contractor is reflected in the EC measure, since it is only expected profits that are of concern to contractors. In a world of risk averse contractors, the appropriate notion of the cost of turbulence to the contractor is the lump sum payment that would be required to restore the contractor's expected utility level to that he achieved before turbulence was introduced into the picture. Is such a lump sum

payment always positive? The answer again follows from the Rothschild and Stiglitz result.

Proposition 5 An increase in turbulence increases cost to the contractor, in the sense that there is a decrease in the expected utility of any contractor experiencing turbulence. This holds under risk neutrality or risk aversion, given FP, CPIF, or MFP contracts.

Proof: Given a monotone increasing concave utility function $U(\pi)$ and given that π_2 is a strictly concave function of q_2, these conditions holding for all K, then for h a mean preserving increase in the spread of f we have

$$\max_K V_h = U(\pi_1) + \delta E_h U(\pi_2) < \max_K V_f = U(\pi_1) + \delta E_f U(\pi_2)$$

from second degree stochastic dominance. Thus the cost to the contractor increases with turbulence given risk averse or risk neutral contractors. In the risk neutral case, the cost to the contractor reduces to EC.

The fact that cost to the contractor increases with an increase in turbulence is not simply an abstract theoretical notion from the point of view of DoD. The contract terms arrived at in negotiations between DoD and a given contractor represent the solution to a bargaining game between a monopsonist and (often) a monopolistic contractor. Just how the gains from trade will be shared between these two parties depends on threat points and like notions of bargaining strength. Given a solution to such a bargaining game, then when turbulence is introduced into the picture, the contractor suffers a loss as indicated in Proposition 5. Turbulence reduces the desirability of DoD contracts to contractors, which should have the effect of shifting bargaining strength away from DoD and to contractors. In the extreme case where DoD has all the bargaining power and contractors are indifferent between undertaking a contract or leaving the defense industry, the introduction of turbulence imposes all of its costs on DoD. In the other extreme case, where DoD is indifferent between signing a contract or going without the item, the costs of turbulence will be borne by the contractor. In the intermediate cases, both DoD and contractors presumably share the costs of turbulence, either under current contracts or under contracts to be negotiated in the future. Since turbulence is costly for contractors under all DoD contracts (except possibly CPFF), the following corollary to Proposition 5 is immediate.

<u>Corollary</u> Turbulence increases DoD costs under FP, CPIF, or MFP contracts, unless DoD is on the margin of indifference between executing or not executing a contract.

Calculation of the lump sum payment representing the cost to the contractor of an increase in turbulence can be made as follows. Let α denote a parameter that shifts the pdf f in such a way as to produce a mean preserving increase in spread. As above, let

$$V = U(\pi_1) + \delta EU(\pi_2).$$

Then we have

$$dV = \{\frac{\partial V}{\partial K}\frac{\partial K}{\partial \alpha} + \frac{\partial V}{\partial \alpha}\}d\alpha + U'(\pi_1)dR_1,$$

where $R_1 = pq_1$. By the first order condition, $\frac{\partial V}{\partial K} = 0$. dR_1 is the lump sum payment required to offset the change $d\alpha$, hence $dV = 0$ in solving for dR_1 to obtain

$$dR_1 = -\{\frac{1}{U'(\pi_1)}\}\frac{\partial V}{\partial \alpha} = -\{\frac{\delta}{U'(\pi_1)}\int_0^\infty U(\pi_2)\frac{df}{d\alpha}dq_2\}d\alpha$$

Integrating by parts twice we have

$$dR_1 = -\frac{\delta}{U'(\pi_1)}(\int_0^\infty \{[U''(\pi_2)\pi_{q_2q_2} + U'(\pi_2)(\pi_{q_2})^2] \int_0^{q_2}(\frac{dF(t,\alpha)}{d\alpha})dt\}dq_2)d\alpha$$

from which it follows that $dR_1 > 0$, given that the change in α induces a change in f that satisfies second degree stochastic dominance.

Given a change from, say, α_0 to α_1, the payment ΔR_1 required to restore the level of expected utility is given by

$$\Delta R_1 = \int_{\alpha_0}^{\alpha_1}\{-\frac{\delta}{U'(\pi_1)}\}(\int_0^\infty\{[U''(\pi_2)\pi_{q_2q_2} + U'(\pi_2)\pi_{q_2}^2]\int_0^{q_2}\frac{dF(t,\alpha)dt}{d\alpha}\}dq_2)d\alpha \qquad (7)$$

<u>Renegotiation of DoD Contracts</u>

One common method of compensating contractors for the loss in expected utility they suffer due to turbulence is through renegotiation of an existing contract, as in annual contracting. In the case of fixed price contracts this can come about through a redetermination of the price to be paid, after order quantities are determined. There are legal precedents indicating that when turbulence is DoD induced, DoD might be held responsible for any resulting losses, under CPFF as well as other contracting arrangements.

The most comprehensive study of contracting arrangements of DoD relevant to the renegotiation issue is the RAND study by Morse (1962). Turbulence was a major factor in renegotiations in the post World War II period. One classic case that went through the renegotiation process involved Boeing Aircraft, accused of earning excess profits by the Renegotiation Board in 1952 in connection with its development of the B-47. The case was finally settled in 1962, in a decision in which turbulence played a critical role. At one point the court said the following:

"Throughout its existence, petitioner has never experienced normal business as that term is generally understood.... In fact, whether petitioner was working to capacity or completely idle has been almost entirely governed by the exigencies of international politics and the safety or danger to the United States engendered thereby. Its business has always been characterized by peaks and valleys and abnormality rather than normalcy." (Morse, p. 131).

Morse's interpretation of the court's decision in favor of the company was this: "In the court's view the company is the victim of rapid shifts in demand and should not be blamed for inefficiencies in the use of plant or equipment that arise on that score. No distinction is drawn between the variability in demand that is common to most commerce and that which is peculiar to the weapons industry.

The implication is that the government must be held almost wholly responsible for such variability." (Morse, p. 132).

In his study of the use of fixed price contracts, Morse found that in 1960, 31% of the fixed price contracts were firm (no later price renegotiation) while only 6% were redeterminable (price subject to later change). However, in dollar terms, redeterminable fixed price contracts were only about 10% smaller in total than firm fixed price contracts. Thus renegotiable fixed price contracts (in dollar terms) were roughly as common as firm fixed price contracts, as of 1960. They far exceeded firm fixed price contracts earlier in the post World War II period. It also is of interest that in a study of actual profit rates under incentive type contracts (including firm fixed price and redeterminable fixed price contracts), of 100 contracts, only two actually showed a loss, both being relatively small contracts, with 98 contracts showing a profit, most at a rate higher than the negotiated rate of profit then being paid on CPFF contracts. Thus Morse's study offers some empirical evidence for the importance of renegotiation, even when the contract is of the fixed price variety.

What we will argue is that to the extent that renegotiation is intended to offset potential out of pocket losses due to turbulence, this induces a factor hiring bias that might well be a prime reason for the observed low capital intensity bias of contractors.

The argument is this. Suppose that because of turbulence, the contractor finds that he cannot even cover his variable costs on the order quantity announced by DoD. In such a situation, the contractor has a positive incentive to renege on his contract, unless nonperformance penalties exceed his contemplated out of pocket losses. Presumably this is precisely the time when the contractor is most apt to obtain the most favorable terms in contract renegotiation. We next explore the implications of a model in which the contractor has assurance that in the case of prospective out of pocket losses, DoD will provide compensation sufficient so that the contractor's out of pocket costs are covered. The results we obtain generalize in an obvious way to the case where there is a subjective pdf over the fraction of his losses that will be absorbed by DoD. We consider the case of a FP contract, but clearly the analysis can be extended to cover the case of CPIF or MFP contracts. Given our assumptions, the profit function under renegotiation becomes the following:

$$\pi(q_1,q_2,K) = \begin{cases} pq_1 - PK - wL_1 + \delta(pq_2 - wL_2) & \text{for } q_2 \leq \bar{q} \\ pq_1 - PK - wL_1 & \text{for } q_2 \geq \bar{q} \end{cases} \qquad (8)$$

where $\bar{q}$ satisfies $p_2\bar{q} - wL_2(\bar{q},K) = 0$.

(Because g is strictly concave in L, it is only on sufficiently large orders that out of pocket losses can occur due to rising marginal production costs; with a more general production function, renegotiation could take place either at sufficiently low or at sufficiently high order quantities.)

In considering renegotiation as an alternative to turbulence in explaining low capital intensities of defense contractors, the

appropriate question to ask is "how does the capital choice of a firm operating in nondefense contracting (with renegotiation not available) compare with the choice of the same firm, under the same turbulence conditions, in defense contracting?" Proposition 6 provides the intuitively appealing answer.

Proposition 6 Under renegotiation, the level of capital is less than that which would be chosen by the same contractor under the same conditions without renegotiation. This holds for risk averse or risk neutral contractors, and it holds under FP, CPIF, or MFP contracting.

Proof: Let $U(\pi_t)$ be the monotone concave utility function of the contractor for t = 1,2, normalized so that U(0) = 0, and let f be the pdf. Let K^* denote the level of capital chosen under renegotiation and let K^{**} denote the level of capital chosen when renegotiation is not available. Then we have

$$V_K(K^*) = U_K(\pi_1(K^*)) + \delta \int_0^{\bar{q}} U_K(\pi_2(K^*))f(q_2)dq_2 = 0, \text{ and}$$

$$\tilde{V}_K(K^{**}) = U_K(\pi_2(K^{**})) + \delta \int_0^{\infty} U_K(\pi_2(K^{**}))f(q_2)dq_2 = 0$$

Suppose $K^* = K^{**}$. Then we would have

$$V_K(K^{**}) = (-)\ \delta \int_{\bar{q}}^{\infty} U_K(\pi_2(K^{**}))f(q_2)dq_2 \leq 0,$$

since $U_K(\pi_2) = U'\frac{d\pi_2}{dK} = U'(-\frac{wdL_2}{dK}) = \frac{U'wg_K}{g_L} > 0.$

Since $V_{KK} < 0$, it follows that $K^* \leq K^{**}$ with strict inequality when $F(\bar{q}) < 1$.

The use of renegotiation as a device to compensate for turbulence induces a capital intensity bias into input hiring because DoD in effect offers a kind of insurance against out of pocket losses, an insurance that produces a moral hazard response of underinvestment in capital on the part of the defense contractor.

Renegotiation does more than this, however. Whether renegotiation is of the crude type indicated in expression (8) or of a more sophisticated type involving partial coverage of out of pocket losses on a probabilistic basis, in any case renegotiation introduces a nonconvexity into the profit function. In turn this means that Proposition 5 no longer necessarily holds. If the compensation paid by renegotiation to the contractor exceeds the costs of turbulence as given in (7), then the contractor would have a preference for more turbulence rather than less, and vice versa. To the extent that contractors can influence the level of turbulence by their own actions, this introduces a new source of inefficiency into the procurement process. In any case, of course, DoD costs still rise with an increase in turbulence; with a renegotiation scheme that overcompensates the contractor, DoD bears more than 100% of the costs of turbulence.

Conclusion

This study of the effect of turbulence on cost and a capital intensity bias on the part of defense contractors verifies that turbulence is a source of cost increases for DoD on all contracts other than CPFF, where the results are indeterminate. Turbulence might also be a factor helping to account for the low capital/output

ratios of defense contractors, but this can be guaranteed only under conditions that are difficult to interpret economically.

An alternative suggestion is that the possibility of renegotiating defense contracts when out of pocket losses could occur offers an explanation for capital intensity bias. It also can result in a situation in which positive incentives are created for contractors to increase turbulence.

APPENDIX

An alternative approach to the issue of the effect of turbulence on expected cost (Proposition 1 of the paper) is this:

Let $g(L_2,K)$ be a real valued function with continuous second partial derivatives that is monotone increasing and concave in L_2. Assume the existence of a cost minimizing choice of capital under certainty and under uncertainty for any pdf over q_2. To simplify notation, let $x = q_2$ and $Y = a(x - \mu) + \mu$ where $\mu = E(x)$ and $0 \leq a \leq 1$. Then have $E(Y) = \mu$ and $V(Y) = a^2\alpha^2$ where $\alpha^2 = V(X)$. Then

$$\min_K \{W_1 f(q_1,K) + P_k K + \delta W_2 E_Y[f(Y,K)]\} \leq$$

$$\min_K \{W_1 f(q_1,K) + P_k K + \delta W_2 E_x[f(x,K)]\}$$

<u>Proof</u>:

It suffices to show $E_Y[f(Y,K)] \leq E_x[f(x,K)]$, or $\int f[a(x - \mu) + \mu,K]h(x)dx \leq \int f(x,K)h(x)dx$ for every K. Since $Y = a(x - \mu) + \mu = ax + (1 - a)\mu$, then $f(Y,K) \leq af(x,K) + (1 - a)f(\mu,K)$ by convexity of f in q_2. Therefore $\int f(Y,K)h(x)dx \leq a \int f(x,K)h(x)dx + (1 - a)f(\mu,K)$

Let $Z = \int f(x,K)h(x)dx - \{a \int f(x,K)h(x)dx + (1 - a)f(\mu,k)\}$.

Then $Z = (1 - a)\{E_x f(x,K) - f(\mu,k)\} \geq 0$ by Jensen's Inequality. Hence we have established the proposition,

$E_y[f(Y,K)] \leq aE_x[f(x,K)] + (1 - a)f(\mu,K) \leq E_x f(x,K)$.

In the case of the CES function, the effect of turbulence on

the amount of capital hired is the following:

(i) If the production function is CES production function and if the return to scale parameter $\gamma \geq 1$ and the parameter for elasticity of substitution $\alpha \geq 2$, then an increased uncertainty in production requirement will force the firm to invest less in capital.

(ii) If the production function is CES and if the return to scale parameter $\gamma \leq 1$ and the parameter for elasticity of substitution $\gamma \leq 1$, then an increased uncertainty will lead to increase in capital investment.

<u>Proof</u>:

(1) Note that CEC production function is given by:

$$q_2 = [\delta L_2^{-\rho} + (1 - \delta)K^{-\rho}]^{-\gamma/\rho}$$

where δ is a distribution parameter, $0 < \delta < 1$

γ is a return scale parameter, $\gamma > 0$

ρ is a substitution parameter and is given by

$\rho = \frac{1 - \alpha}{\alpha}$ with α the elasticity of substitution, $\alpha \geq 0$.

(2) Then $L_2 = f(q_2,K) = \delta^{1/\rho} q_2 - A^{-1/\rho}$

where $A = 1 - (1 - \delta)K^{-\rho} q_2{}^{\rho/\gamma}$, $0 < A < 1$

$f_{211} = B(1 + 2\rho - (\rho + \gamma)A)$

where $B = \delta^{1/\rho}\delta^{-2} q_2^{(\frac{1+\rho-2\gamma}{\delta})} A^{-(\frac{1+3\rho}{\rho})} K^{-(1+\rho)}(\delta - 1) < 0$

(3) For (i) it suffices to show $f_{211} > 0$. In particular, we want to show $1 + 2\rho - (\rho + \gamma)A \leq 0$, or $\frac{2}{\alpha} - 1 -(\frac{1}{\alpha} - 1 + \gamma)A \leq 0$. Since

$\alpha \geq 2$ we have $\frac{2}{\alpha} - 1 - (\frac{1}{\alpha} - 1 + \gamma)A \leq -(\frac{1}{\alpha} - 1 + \gamma)A(1 - \gamma)A$.

Since $\gamma \geq 1$ and $A > 0$, we have $(1 - \gamma)A \leq 0$, thus $f_{211} > 0$.

(4) For (ii) it suffices to show $f_{211} < 0$. In particular we want to show $\frac{2}{\alpha} - 1 - \frac{1}{\alpha} - 1 + \gamma)A > 0$. Since $\alpha \leq 1$ we have $\frac{2}{\alpha} - 1 - (\frac{1}{\alpha} - 1 + \gamma)A > \frac{1}{\alpha} - 1 + (1 - \gamma)A \geq (1 - \gamma)A$. Since $\gamma \leq 1$ and $A > 0$, we have $(1 - \gamma)A \geq 0$, thus $f_{211} > 0$.

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