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QUALITY VS. QUANTITY IN MILITARY PROCUREMENT: AN ORGANIZATIONAL THEORY OF DECISION BIAS*

by

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Abstract

It is often argued that the same expenditures on military procurement would produce a more effective defense if larger numbers of less sophisticated (and thus cheaper) weapons were purchased. This paper shows that such a result can occur even if the military derives no private consumption value from technically sophisticated weapons. Rather the organization of the decision-making process itself can produce this result. This suggests some possible solutions through organizing decision-making in a different fashion.

1. Introduction

Many institutional analyses of defense procurement raise the issue that the military's choice along the quality-quantity frontier for various weapons systems seems to be biased towards "too high" a level of quality. That is, it is argued that the same expenditures would produce a more effective defense if larger numbers of less elaborate and less technically sophisticated (and therefore cheaper) weapons were purchased. Scherer [1964], for example, documents the military's apparent bias towards quality in a long series of examples.[1] He concludes that the military

> "has generally demanded much more emphasis on technical performance, reliability, and development time than on development cost ... Only infrequently have programs been terminated merely because of development costs much higher than those of competing programs. A much more common cause of termination has been poor technical performance or serious development schedule slippages. In sum, the competitive incentives in weapons acquisition in the 1950's ran strongly in favor of quality maximization and lead time minimization, but almost negligibly in favor of development cost minimization".[2]

Similar points are made by Gansler [1986], Peck and Scherer [1962], Stubbing [1986] and Tobias et. al. [1982].[3]

Critics of the current approach cite the evidence provided in 1978 by a series of mock air battles organized by the Air Force and Navy called ACEVAL/AIMVAL. In these battles, pilots flying the F5E were pitted against pilots flying the F14 and F15. The F5E is a small inexpensive fighter designed primarily for export to other countries. The unit cost is approximately $5 million. The F14 and F15 are the Navy and Air Force's premier fighters. Their unit costs are, respectively, approximately $47 million and $30 million.[4] Thus the premier fighters cost 6 to 9 times as much as the simple fighter. Tobias et. al. [1982] sum the results of the test up as follows.

> "In one-on-one encounters between planes equipped with heat-seeking missiles such as the sidewinder, planes tended to destroy each other (so lethal are these weapons). In two-against-one encounters, no matter how sophisticated the single plane, the two always defeated the one. These results have shaken some of the previously held assumptions about the advantages of very expensive, very sophisticated high-performance aircraft."[5]

The standard explanation for this bias towards quality has been that military decision makers and design engineers derive private "consumption value" from creating and fielding technologically advanced systems.[6] Thus the problem is seen to be that military decision makers reduce military preparedness in order to indulge their own private interests in creating new technological advances. There is undoubtedly some truth to this claim.

The purpose of this paper, however, is to advance a different theory explaining this bias which does not rely on the existence of private "consumption values" of military decision makers. It will be shown that the institutional organization of decision-making may in and of itself result in excessive quality even when the military derives no private value from quality. Thus even agents operating in good faith to maximize military preparedness may choose too high a quality and too low a quantity depending on how the decision-making hierarchy is organized.

The standard theory sees the problem as originating from "bad" agents and suggests few solutions other than attempting to get "better" agents or monitoring the "bad" ones more closely. In contrast, this paper's theory sees the problem as originating from the manner in which decision-making is organized. This suggests that solutions may be obtainable by reorganizing the decision-making process. In particular the theory suggests two types of changes which may help ameliorate the biases generated by the current organization. These are precommitment to fixed budget levels and use of overlapping jurisdictions between military services.

The model can also be interpreted as applying to any organization engaged in a complex production task where design or project selection decisions must be delegated to subordinates. Managers may choose overly-high quality levels for their projects even though they derive no consumption value from quality and are acting in good faith to increase the effectiveness of their programs.

I am not aware of any formal theoretical work which is closely related to this paper. A very interesting paper by Lewis [1986] analyzes the question of optimal organizational design of defense procurement with a formal model. As in this paper, Congress and the military are seen as the two relevant actors to model. (This distinguishes Lewis's [1986] paper and this paper from the bulk of the formal models of procurement which analyze the relationship between the military and its contractors.)[7] However, the model in Lewis'

[1986] paper is quite different from that of this paper and is designed to address different questions.

Section 2 describes the model and key assumptions which generate the results. Section 3 analyzes the model and Sections 4 and 5 explore two possible solutions to the problem. Section 6 argues that the model can be interpreted as applying to any complex organization and Section 7 provides a brief conclusion.

2. The Model

A. The Optimal Program

A weapons program will be assumed to be completely described by two non-negative real numbers, (q,x), where q denotes the quality of the weapon and x denotes the number of units purchased. Let C(q,x) denote the dollar cost of producing a weapons system of quality q in amount x. Let V(q,x) denote the military value of the weapons program (q,x) to Congress, expressed in dollars. The optimal weapons program from Congress's point of view[8] therefore maximizes benefits minus costs. This will also be called the first-best program.

Definition:

The program (q,x) is optimal or first-best if it satisfies

$$(2.1) \qquad \underset{(\hat{q},\hat{x}) \in R^{+2}}{\text{Maximize}} \quad V(\hat{q},\hat{x}) - C(\hat{q},\hat{x}) \; .$$

It will also be useful to define a second-best program for any given budget level.

Definition:

The program (q,x) is a second-best program given the budget B if it satisfies

$$\text{(2.2)} \qquad \underset{(\hat{q},\hat{x}) \in R^{+2}}{\text{Maximize}} \quad V(\hat{q},\hat{x})$$

$$\text{(2.3)} \qquad \text{subject to} \quad C(\hat{q},\hat{x}) \leq B$$

B. The Equilibrium Program

The decision making process leading up to the adoption of a new weapons program will be viewed as a two-person game between Congress and the military. Two fundamental assumptions about the nature of this game will be made. These will now be described.

The first fundamental assumption concerns the nature of the military's preferences. Let $>_m$ denote the military's preference ordering over weapons programs. It will be assumed that the military's preferences are represented by $V(q,x)$ -- i.e. --

$$\text{(2.4)} \qquad (q,x) >_m (\hat{q},\hat{x}) \iff V(q,x) > V(\hat{q},\hat{x}).$$

Note that there is a sense in which the military is acting as a "good faith" agent for Congress. It cares solely about the military value of programs and it agrees with Congress on the military value of various possible programs. In particular the military derives no private consumption value from quality.

However, the military is not a perfect agent. A perfect agent's preferences would be defined by

$$(2.5) \qquad (q,x) >_m (\hat{q},\hat{x}) \iff V(q,x) - C(q,x) > V(\hat{q},\hat{x}) - C(\hat{q},\hat{x}).$$

Presumably the cost of a program, C(q,x), is fairly easy to objectively measure. If it was equally easy to objectively measure the dollar social value of a program, V(q,x), then Congress could probably induce the military to have preferences given by (2.5). Rewards could be made to vary directly with the size of V-C. However, the dollar social value of a weapons program is clearly not objectively measurable. Given this it may be difficult for Congress to directly induce preferences through incentive contracts which are perfect in the sense of (2.5). Military decision makers' own personal preferences may therefore play a role in shaping the nature of $>_m$.

This paper assumes that the military is as idealistic as one could reasonably expect. The reason for this is that the point of the paper is to show that the inherent structure of the decision-making process will generate a decision-bias in the quality-quantity input mix even when the military is as idealistic as possible.

In what sense are the preferences defined by (2.4) as idealistic as realistically possible? One might reasonably expect even a fairly idealistic agent to derive more satisfaction from increasing the contribution his project makes than from reducing its cost. An idealistic military might therefore be expected to want to maximize military preparedness. In particular, an idealistic military would not purposely reduce military preparedness solely for the sake of pursuing technology or solely for the sake of increasing its budget. However one might presumably expect an idealistic military to be in favor of increasing military preparedness even if on balance the dollar social benefits were less than the dollar social cost. Thus even an idealistic military is likely to weight maximization of V(q,x) more highly than minimization of C(q,x). In order to simplify the exposition, this paper makes the formal assumption that the military places no weight at all on cost-minimization. However it is straightforward to show that the analysis and conclusions of this paper apply to the more general case where the military's utility function is

$$(2.6) \qquad V(q,x) - \lambda C(q,x)$$

where $0 \leq \lambda < 1$.

The second fundamental assumption made by this paper regards the sequential nature of the decision process. It is assumed that the military first chooses the quality of the program. Then Congress chooses the output level, given the pre-determined quality. This assumption reflects two features of the procurement process. The first feature is that the technological characteristics of a weapon are determined in a development phase which precedes the production phase. The second feature is that only the military has the expertise to fully evaluate, choose and determine the technological characteristics of the weapon. Thus Congress must delegate this decision to the military. In the stylized model of this paper, "quality" is the variable describing the technological characteristics of the system. Thus the development phase consists of the military choosing a quality. In the production phase Congress is faced with the weapon system as designed by the military. By choosing a funding level for production, Congress determines how many units will be produced.

Another way to describe the second fundamental assumption of this paper is that Congress is incapable of evaluating how V - C would vary for different values of q. Congress can only evaluate how V - C varies as x varies for the value of q described to it by the military. Since Congress cannot independently conceive of weapons systems of varying designs it must simply rely on the military to present a design and then decide how many to purchase.

Note that in reality Congress probably has some influence on the design choice as well as the output choice since information on design choice is not totally in the hands of the military. This paper makes the extreme assumption that the military has total control over the quality choice in order to most clearly illustrate the effects of this asymmetry of information and expertise.

The two fundamental assumptions described above result in the following structure to the game between Congress and the military. As usual, it is most convenient to think about this sort of game by beginning at the end and working backwards. At stage 2 Congress chooses an output to maximize V(q,x) - C(q,x) taking the military's choice of q as given. Then at stage 1 the military chooses q to maximize V(q,x), realizing how the choice of q will affect Congress's choice of x.

Formally, then, an equilibrium outcome is defined as follows.

<u>Definition</u>:

An equilibrium program satisfies the following:

$$\text{(2.7)} \qquad \underset{(q,x) \in R^{+2}}{\text{Maximize}} \quad V(q,x)$$

$$\text{(2.8)} \qquad \text{subject to} \quad x \in \underset{\hat{x} \geq 0}{\text{argmax}} \quad V(q,\hat{x}) - C(q,\hat{x})$$

C. Technical Assumptions

The various optimization problems described above will be assumed to be "well-behaved." Specifically, the following four assumptions will be made. They will be discussed after their formal statement.

Assumption 1

V and C are twice continuously differentiable over $(0,\infty)^2$. All first derivatives are non-negative. The iso-utility curves for V are strictly decreasing and strictly convex. The iso-cost curves for C are strictly decreasing and strictly concave. Finally, the function V-C is strictly concave over $(0,\infty)^2$.

Assumption 2:

A unique optimal program exists. Let (q^*, x^*) denote this program.

Assumption 3:

For every $q \geq 0$ there is a unique solution to (2.8). Let $\phi(q)$ denote the solution to (2.8) given q. Assume that $\phi(q)$ is continuously differentiable.

Assumption 4:

A unique equilibrium program exists. Let (q^e, x^e) denote this program.

Assumptions 1 and 2 are straightforward. An immediate consequence of Assumption 1 is that unique second-best programs exist for every budget level. Let $(q^s(B), x^s(B))$ denote the unique second-best program given budget B.

Assumption 3 requires that Congress always has a unique optimal output choice for any quality level chosen by the military. Assumption 4 is straightforward.

One other piece of notation will be useful. Let E(q) denote the amount of money Congress will spend on the weapons program if the military chooses quality q. This is defined by

$$(2.9) \qquad E(q) = C(q,\phi(q)).$$

3. Analysis

The purpose of this section is to investigate whether the equilibrium quality level is too large or too small. There are two possible quality levels to compare q^e with. The most obvious is the optimal quality, q^*. The second possible comparison point is the quality level of the second-best program given the equilibrium budget level. Formally, this comparison point is defined by

$$(3.1) \qquad q^s(C(q^e,x^e)).$$

Under the second comparison, the equilibrium quality is too large (too small) if a greater level of military preparedness could be achieved with the same budget by choosing less (more) quality and more (less) output.

Clearly both comparisons are interesting. Fortunately there is no need to conduct two separate analyses. This paper's problem is well-behaved enough that both comparisons yield the same answer -- i.e. -- the equilibrium quality is too large (too small) relative to the first-best quality if and only if it is too large (too small) relative to the second-best quality. This is proven in Proposition 1.

<u>Proposition 1</u>:

$$q^e \gtreqless q^* \iff q^e \gtreqless q^s \quad (C(q^e, x^e))$$

proof:

See Appendix.

QED

Because of Proposition 1 the following analysis will restrict itself to comparing equilibrium quality with the first-best quality. By Proposition 1 the results also apply to the second-best comparison.

It is clear from the structure of the military's optimization problem that the equilibrium quality will not generally be first-best. The military's objective function is

$$(3.3) \qquad M(q) = V(q, \ \phi(q)) \ .$$

Thus the equilibrium quality satisfies

$$(3.4) \qquad M'(q^e) = 0.$$

The optimal quality maximizes the following objective function.

$$(3.5) \qquad M(q) - E(q)$$

Thus the optimal quality satisfies

(3.6) $$M'(q^*) - E'(q^*) = 0 .$$

Therefore the optimal quality, q^*, will be an equilibrium only if $E'(q^*) = 0$ which would occur only by coincidence. If $E'(q^*)$ is positive, then M is locally increasing in quality and the military will locally desire to increase quality above the first best. If $E'(q^*)$ is negative, then M is locally decreasing in quality and the military will locally desire to decrease quality below the first best. If M is single-peaked the local results are of course global. This will be stated as Proposition 2 below.

<u>Proposition 2</u>:

Suppose M is single-peaked. (i.e. -- M is strictly increasing (decreasing) for $q < (>) q^e$.) Then

(3.7) $$q^e \gtreqless q^* \iff E'(q^*) \gtreqless 0 .$$

<u>proof</u>

As above.

QED

There is a very natural intuition for this result. Differentiate M(q) to yield

$$(3.8) \qquad M'(q) = V_q(q,\phi(q)) + V_x(q,\phi(q))\phi'(q).$$

The effect on M of an increase in q can be broken into two parts. The first part is the direct effect -- i.e. -- an increase in q directly increases V because V_q is positive. This is the first term in (3.8). The second effect is the indirect effect. An increase in q causes Congress to change its choice of x which in turn affects V. This is the second term of (3.8). The indirect effect may be positive or negative depending upon whether an increase in q induces an increase or decrease in x.

Suppose the military has provisionally chosen q^* and is evaluating whether to increase q slightly. The direct effect of an increase in q is always positive. If increasing q would induce Congress to increase x then the indirect effect is also positive and the military will want to increase q. If an increase in q causes only a very small drop in Congress' choice of x the indirect effect will be negative but very small and the net effect of increasing q will still be positive. However, if an increase in q causes a very large drop in x, the indirect effect will be negative and large and could overwhelm the positive direct effect. In this case the military would want to reduce quality below q^* in order to induce a more-than-compensating increase in x.

Thus the military will want to increase q above q^* if x will not drop "too much" in response. Proposition 2 shows that the correct measure of "too much" is whether expenditures fall when quality increases. When quality is increased, expenditures will also increase if output stays constant or increases. Even if output drops a small amount in response to a quality increase, expenditures will still increase. However if output drops enough in response to a quality increase then expenditures will in fact decrease.

The conclusion of Proposition 2 is therefore that the military will increase quality above the first-best level if by doing so it can induce Congress to increase its expenditures on the weapons program. Thus the military will increase quality if Congress will increase output in response or if the induced drop in output is small enough so that expenditures will still increase. However if the induced drop in output would be large enough to decrease expenditures the military will choose to reduce quality below the first best.

Proposition 2 is very useful for providing an intuition explaining why the equilibrium and optimum will in general diverge. However the proposition is not cast in terms of easily observed variables since we are presumably observing equilibrium quality choices and not optimal quality choices in existing programs. Thus if we were to guess at the sign of $E'(q)$ by looking at existing programs we would be guessing the sign of $E'(q^e)$ and not $E'(q^*)$. Proposition 3 shows that information on $E'(q^e)$ can also be used to infer whether the quality choice is too large or not. In particular, Proposition 2 remains true if q^e is substituted for q^*.

<u>Proposition 3</u>:

$$(3.9) \qquad q^e \gtreqless q^* \Leftrightarrow E'(q^e) \gtreqless 0$$

proof:

Because V(q,x) - C(q,x) is globally concave in q and x, it is straightforward to show that M(q) - E(q) is also globally concave in q. Therefore it is sufficient to prove that

$$(3.10) \qquad M'(q^e) - E'(q^e) \lesseqgtr 0 \iff E'(q^e) \gtreqless 0 .$$

This is true because $M'(q^e) = 0$.

QED

Thus if we could estimate or guess the sign of E'(q) for current programs, we could use this information to infer whether quality was too high or too low.

One factor affecting the sign of E'(q) will be the substitutability of quality for quantity. If they are very good substitutes Congress will respond to an increase in quality by a large decrease in quantity (since the increased quality is a good substitute for quantity). However if they are very poor substitutes then an increase in quality will not induce a large decrease in quantity. Therefore equilibrium quality will tend to be too large when quality and quantity are poor substitutes. In this case the military can raise quality without fearing a large drop in Congress' choice of quantity.

Thus if it is true that quality and quantity are poor enough substitutes in most weapons programs so that increases in quality do not generate large decreases in quantity, then this paper provides a theory explaining why quality is chosen to be too high even when the military derives no private consumption value from quality.

4. Fixed Budget Levels

Suppose Congress could precommit to a fixed budget level of B for a program prior to the point in time when the military chooses quality. That is, regardless of the quality chosen by the military, Congress commits to spend B dollars on the program. In this case the military would choose q and x to solve the following problem[9]

$$(4.1) \qquad \max_{q,x} \; V(q,x)$$

$$(4.2) \qquad \text{s.t.} \;\; C(q,x) \le B$$

The solution is of course the second-best program given the budget B. Therefore, in particular, if Congress chose a budget level equal to the cost of the first-best program, the military would choose the first-best program. Let B^* denote the first-best budget level. It is defined by

$$(4.3) \qquad B^* = C(q^*,x^*).$$

The results of the above paragraph are summarized in Proposition 4.

Proposition 4:

(1) If Congress precommits to a budget B, the military will choose the second best program given B.

(2) Therefore if Congress precommits to B^*, the military will choose the first-best program.

<u>proof</u>:

As above.

QED

It is tempting to view Proposition 4 as providing a complete solution to the problem analyzed in the preceding sections. This, however, is not the case. In order to calculate B^*, Congress must in general know both V and C and calculate q^* and x^*. In this case Congress would not need to delegate decision-making authority to the military. It could simply instruct the military to choose q^*. That is, the rationale for having Congress delegate the quality choice to the military was the military's greater expertise in evaluating the potential costs and benefits of various design choices. However the use of fixed budget levels provides a first-best outcome only when Congress is fully expert itself. Thus precommitment to fixed budget levels is not likely to be a good solution when Congress is very poorly informed about possible design choices.

Proposition 4 does suggest, however, a more limited sense in which delegated design choice with fixed budget levels may be useful. Suppose that Congress is relatively well informed about possible design choices for some project and thus can directly calculate q^*, x^*, and B^*. The following two strategies for Congress yield identical outcomes. First, Congress could delegate no decision-making authority and simply order the military to produce the quality q^*. In the procurement phase Congress would then purchase x^* units. The second possible strategy for Congress would be to tell the military that the project budget will be B^* and to delegate the choice of q and x.

Even though both strategies yield identical outcomes it may be that the second strategy of using delegation together with a fixed budget would be preferable from a transactions-cost point of view. Telling the military that its budget is B^* is a very simple, objectively verifiable instruction. However, directly ordering the military to choose the quality q^* may involve a very complex set of instructions. This is because no simple objectively verifiable scalar measure of quality is likely to exist. To provide an objectively verifiable description of the design choice yielding q^* could be quite complex and difficult. Recall that the military will in general prefer to choose some other quality level than q^*, so any design description which leaves leeway in the military's choice is likely to be purposefully misinterpreted.

There is also a second major problem with the fixed budget approach suggested by Proposition 4. For a major new program the design decision may be made five years or more before procurement begins and procurement may continue over a ten or twenty year period. It is hard to believe that Congress would have the ability to precommit ten years in advance to anything. More importantly, however, many factors in the environment will change between the time the design is chosen and the time that procurement decisions are made. A first-best program should involve changing the amount procured in response to these changes in the environment. Thus, in a more realistic model, the first-best solution does not involve fixing a budget level at the time of the design choice. This issue will now be explored in a simple formal model.

Let $\theta \in \Theta$ represent environmental factors which are unknown at the time of the design decision. Assume θ is distributed according to the density

$f(\theta)$. Both the military value and cost of a new system could potentially depend on θ. Thus these are now written, respectively, as $V(q,x,\theta)$ and $C(q,x,\theta)$.

The sequence of decisions is now as follows. At the time of the design decision θ is unknown. After the design decision is made θ becomes known and then the output decision is made. Therefore a program is now an ordered pair $(q,\psi(\theta))$ where q denotes the quality choice and $\psi(\theta)$ denotes the output decision given over θ.

A first-best program is defined as follows. Let $E\left\{ \quad \right\}$ denote the expectation operator over θ.

Definition:

The program $(q^*,\psi^*(\theta))$ is first-best optimal if it satisfies

$$(4.4) \qquad \psi^*(\theta) \in \underset{x \geq 0}{\text{argmax}}\ V(q^*,x,\theta) - C(q^*,x,\theta)$$

for every $\theta \in \Theta$ and

$$(4.5) \qquad q^* \in \text{argmax}\ E\left\{V(q,\psi^*(\theta),\theta) - C(q,\psi^*(\theta),\theta)\right\} .$$

Under the first-best solution, the budget level depends on the realization of θ. Let $B^*(\theta)$ denote the first-best budget rule for the optimal program $(q^*,\psi^*(\theta))$. It is defined by

(4.6) $B^*(\theta) = C(q^*, \psi^*(\theta), \theta)$.

Using the same reasoning is in the proof of Proposition 4, it is clear that Congress could induce the military to choose q^* by precommitting to the fixed budget rule defined by (4.6). That is Congress should commit to spending $B^*(\theta)$ dollars if θ occurs independent of the quality level chosen by the military. This will induce the military to choose q^* and then $\psi^*(\theta)$ units will be procured.

Thus in theory there still exists a method for Congress to induce the optimal quality decision. It simply commits to a fixed budget rule instead of a fixed budget level. However, Congress is much less likely to be able to precommit to such a rule for two related reasons. First, the space of possible environmental factors which might affect the social cost or benefit of a new weapons program five or ten years in the future is almost limitless in size. Thus describing the set of all major conceivable contingencies and the budget level for each one would in general be an impossible task. A second related problem is that many of the contingencies described by θ may be observable only to Congress or at least are difficult to describe in an objectively verifiable way. Thus it may be difficult for Congress to describe the rule it will follow in such a way that whether or not it follows the rule will be objectively verifiable and non-controversial.

The conclusion of this section is therefore that the organizational device of precommitting to fixed budgets will be of limited usefulness for major new weapons systems where design choices involve new technologies and there are long time lags between the design decision and actual production.

Fixed budgets may play a more useful limited role in shorter-run projects involving better understood technological choices.

5. Overlapping Service Jurisdictions

Overlapping service jurisdictions are said to occur when two or more of the three military services (the Army, Navy and Air Force) share and compete for responsibility for the same military function or mission. Such overlaps are widespread. For example, all three services originally developed separate strategic nuclear missile programs. Eventually the Army's program was discontinued and currently the Air Force and Navy both develop and produce missiles to carry nuclear warheads. The Navy and Air Force both operate fighter jets, bombers, and cruise missiles. Finally, the Army and Air Force both perform the mission of supplying close-air-support to ground troops, the Army with helicopters and the Air Force with fixed-wing aircraft.[10]

Traditional military analysts have noted these overlaps and cited them as examples of inefficient organization within the military. For example, Stubbing [1986] concludes that

> "The potential for unnecessary duplication is clearly high when two services share in any given mission. Each is likely to determine its own 'requirement' without considering the forces available from a sister service, and each will likely seek a capability to perform the mission independently. One possible solution to this dilemma involves a realignment of service roles and missions to give full responsibility to a single service."[11]

There is undoubtedly some truth to this point of view. Having two services each perform overlapping portions of the same mission and compete for the right to perform new related functions may well produce outcomes that seem inefficient relative to the full-information first-best standard. Thus in a world with no asymmetric information or incentive issues complicating the problem of organizational design, there may be little role for overlapping service jurisdictions.

The general purpose of this section is to argue that overlapping jurisdictions may play a very useful role in a world where the military services do not necessarily have identical preferences as Congress and where Congress is not as fully informed as the military. Congress (or the DoD) can use rivalry between competing services to improve the performance of each service. Specifically, it will now be shown that in this paper's model, the first-best program can be achieved by having two services compete for the right to operate a given program.

Consider the same model as described in Section 2 only now assume that there are two military services which could manage the program. Call them service 1 and 2. Assume that each service has absolutely identical capabilities. That is each service can choose any $q \geq 0$ to yield a program with military benefits of $V(q,x)$ and costs of $C(q,x)$. Finally, assume that each service only derives satisfaction from a program if it is selected to run the program.

Suppose that Congress now runs the competition as follows. Each service announces a quality of design. Let q_i denote service i's announcement. Then Congress selects the service to run the program whose proposed quality level will yield the highest net benefits to Congress. Recall that $\phi(q)$ is the optimal output choice given quality q. Let S(q) denote the social value of a project of quality q.

$$S(q) = V(q,\phi(q)) - C(q,\phi(q)) \tag{5.1}$$

Then Congress selects service 1 if

$$S(q_1) > S(q_2) \ . \tag{5.2}$$

It selects service 2 if the inequality is reversed. Finally it selects either service with a 50% probability if (5.2) holds with equality.

The two services are thus in a game where the strategy for each service is a quality announcement, q_i. Let $R_i(q_1,q_2)$ denote the return to service i given the announcements q_1 and q_2. These are defined by

$$R_1(q_1,q_2) = \begin{cases} V(0,0) \quad , & S(q_1) < S(q_2) \\ \dfrac{V(q_1,\phi(q_1))}{2}, & S(q_1) = S(q_2) \\ V(q_1,\phi(q_1)), & S(q_1) > S(q_2) \end{cases} \tag{5.3}$$

and

$$R_2(q_1,q_2) = \begin{cases} V(0,0) \quad , & S(q_2) < S(q_1) \\ \dfrac{V(q_2,\phi(q_2))}{2}, & S(q_2) = S(q_1) \\ V(q_2,\phi(q_2)), & S(q_2) > S(q_1) \ . \end{cases} \tag{5.4}$$

So long as $V(q^*,\phi(q^*)) > V(0,0)$, it is clear that the unique Nash equilibrium to this game has each service announce q^*. The reason for this is clear. If one service announces a $q \neq q^*$, then the other service can always announce q^* and take the entire program. This result is stated as Proposition 5.

Proposition 5:

Suppose that $V(q^*,\phi(q^*)) > V(0,0)$. Then the unique Nash-equilibrium to the quality announcement game between the two services is for both services to announce q^*.

proof:

As above

QED.

Therefore, overlapping service jurisdictions may well provide a benefit of reducing quality bias in program design choices. These benefits of course must be weighed against the costs in order to make an overall evaluation of whether overlapping jurisdictions are useful. There are probably two major costs. First, two separate development efforts to develop design proposals must be paid for. This paper's model does not explicitly consider development cost. Second, there may well be a number of inefficiencies induced by having two separate services operate related and similar missions of the sort described by Stubbings [1986] as quoted above. The major point of this section is that overlapping service jurisdictions should not necessarily be viewed simply as an unfortunate inefficiency. Given the information and incentive problems inherent in the procurement process, they may be a useful method for organizing decision-making.

6. Application to the Theory of Organization of the Firm

The model of this paper can also be interpreted as applying to the relationship between the central management of a firm and the manager of a particular project or division within the firm. Central management delegates selection of many aspects of the operation of a project or a division to the manager directly in charge of it because it does not have the time or expertise to make all of these decisions itself. However it retains final budgetary authority for the project or division.

In terms of the notation of the model, q is the design parameter for the project which central management delegates to the project manager. The project manager reports his decision of q to central management and then central management decides the "level" to operate the project at, denoted by x. The revenues to the company from the project are given by V(q,x) and the costs of the project are given by C(q,x). The parameter q can still be interpreted as a quality choice since higher values of q raise both revenues and costs. The parameter x does not necessarily have a simple physical interpretation such as "units purchased." In terms of realistically interpreting the model it might be better to suppress the variable x and think of central management as simply choosing a budget level given the project manager's design announcement of q. When the project manager announces a quality level $\hat{q}$ for the project he can be viewed as informing management that any revenue-cost pair from the set

(6.1) $\{(V(\hat{q},x),\ C(\hat{q},x)): x \geq 0\}$

is possible. Central management then chooses a budget level for the project and a corresponding revenue. Higher values of x correspond to the choice of a higher budget and a higher revenue stream. Thus x can be thought of as a choice of what "level" to run the project at. In some cases x may be units purchased. For example the project could be an advertising campaign and x could be minutes of air-time purchased. In other cases x may be some aspect of quality which central management reserves to decide for itself. However in general central management should be thought of as making a budget choice when confronted with the set (6.1). The variable x may not have a specific real interpretation but is simply a technical convenience for describing central management's choice of a budget.

The remaining question to investigate is the nature of the project manager's preferences. As with the Congress-military interpretation, the key factor determining this is whether V and C can be easily measured in an objectively verifiable way. If they are objectively measurable, central management should be able to use incentive contracts to directly induce project management preferences defined by (2.5). However when they are not objectively measurable, the project manager's personal preferences are likely to play a role in determining his actions. As argued in Section 2, preferences defined by (2.4) are then as idealistic as could be realistically hoped for. In the Congress-military interpretation, V was clearly not objectively measurable. In the interpretation of this section, V and C may or may not be objectively measurable. The conclusions of this paper apply to cases where they are not measurable.

The key factor determining whether V and C can be easily measured is how separable the project is from the rest of the firm's operations. Suppose for example that the project is for the firm to enter a new market and to build a totally separate organization to market and produce it. Then the project's revenues and costs will accrue separately from those of the rest of the firm and are thus easy to objectively measure. However, now suppose that the output of the project will simply be an input for the production process of the entire firm. For example, the project might be an advertising campaign or creation of a new computing system. No objectively verifiable measure of the marginal contribution of the project to the firm's revenues is likely to exist. There may also be problems with objectively measuring C(q,x) if the project is purchasing some of its inputs from other divisions of the firm.

7. Conclusion

This paper can be viewed as making a general point about organizational design. When the divisions of an organization are not totally separate entities but rather contribute inputs to a complex joint productive effort, central management cannot really expect its subordinates to attempt to perform the calculation of how funds should be allocated across the divisions. This is the job of central management. Rather the best that central management can realistically hope for is that its subordinates in good faith attempt to produce the most effective program they can. If the central management could calculate the first best allocation of budget levels across its subordinate divisions this would yield the first-best outcome. However, the limited calculation ability of the central authority means that the central authority may have to delegate design decisions to its subordinates and choose budget levels given the design decisions. This results in non-optimal outcomes. In particular, if a division can increase its budget by suggesting a higher quality, then quality will be too high. This occurs even though subordinates derive no consumption value from quality and are in one sense acting in good faith to benefit the central authority.

Appendix -- Proof of Proposition 1

The proof will be broken into two steps.

Step 1:

It will be shown that

$$\frac{d}{dq}\left[V_q(q,\phi(q)) - C_q(q,\phi(q))\right] < 0 . \tag{A.1}$$

proof:

For the purposes of this proof assume that V and C and their derivatives are evaluated at $(q,\phi(q))$ unless otherwise stated. Differentiate $V_q - C_q$ with respect to q to yield

$$V_{qq} - C_{qq} + \phi'(q)[V_{qx} - C_{qx}] . \tag{A.2}$$

The function $\phi'(q)$ is defined by

$$\phi'(q) = \frac{-[V_{qx} - C_{qx}]}{V_{xx} - C_{xx}} . \tag{A.3}$$

Substitute (A.3) into (A.2) to yield

$$V_{qq} - C_{qq} + \frac{-[V_{qx} - C_{qx}]^2}{V_{xx} - C_{xx}} . \tag{A.4}$$

Since $V_{xx} - C_{xx}$ is negative, (A.4) is negative if and only if

(A.5) $[V_{qq} - C_{qq}][V_{xx} - C_{xx}] - [V_{qx} - C_{qx}]^2 > 0$.

Expression (A.5) is true because V-C is concave.

QED

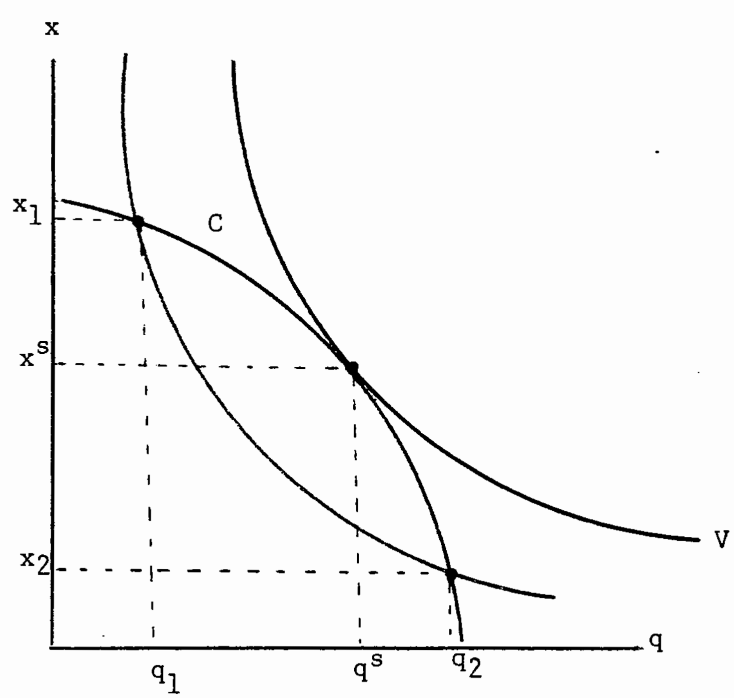
Step 2:

Consider any program (q,x). Let B denote the cost of (q,x) -- i.e. --

(A.6) $B = C(q,x)$

Let (q^s,x^s) be the second-best program given the budget B. This is illustrated in Figure (A.1).

Figure A.1



The line C is the iso-cost line of all programs costing B dollars. The line V is the highest iso-utility curve which can be attained on C. Their tangency determines the second-best program.

There are three possible cases to consider. First, if $q < q^s$, it is clear that the indifference curve through (q, x) is steeper than C. This is illustrated by point (q_1,x_1) in the figure. Second, if $q > q^s$, it is clear that the indifference curve through (q,x) is flatter than C. This is illustrated by point (q_2,x_2) in the figure. Finally, if $q = q^s$, then the indifference curve and C are tangent. These observations can be formally summarized by the following result.

$$\text{(A.7)} \qquad q \gtreqless q^s(C(q,x) \Longleftrightarrow \frac{C_q(q,x)}{C_x(q,x)} \gtreqless \frac{V_q(q,x)}{V_x(q,x)} .$$

Now consider the program $(q,\phi(q))$. By construction

$$\text{(A.8)} \qquad C_x(q,\phi(q)) = V_x(q,\phi(q)) .$$

Substitution of (A.8) into (A.7) yields

$$\text{(A.9)} \qquad q \gtreqless q^s(C(q,\phi(q)) \Longleftrightarrow C_q(q,\phi(q)) \gtreqless V_q(q,\phi(q)) .$$

The first-best program satisfies

$$\text{(A.10)} \qquad V_q(q^*,\phi(q^*)) - C_q(q^*,\phi(q^*)) = 0 .$$

Combining (A.1) and (A.10) therefore yields

(A.11) $$V_q\,(q,\phi(q)) - C_q(q,\phi(q) \gtreqless 0 \iff q \lesseqgtr q^*\ .$$

The result now follows from (A.11) and (A.9).

QED

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Footnotes

1. Scherer [1964], pages 29-38.

2. Scherer [1964], page 36.

3. Gansler [1986] pages 15-21, Peck and Scherer [1962], chapter 13, Stubbing [1986], chapter 8, and Tobias et. al. [1982], pages 366-378.

4. These figures are from Tobias _et_. _al_. [1982], pages 211, 213, and 217.

5. Tobias et. al. [1982], page 216.

6. See, for example, Gansler [1986], pages 101 and 103.

7. See Baron and Besanko [1987], McAfee and McMillan [1986], Riordan and Sappington [1986], and Tirole [1986], for example.

8. Congress's preferences will be interpreted as society's preferences. Therefore the optimal program from Congress' point of view will be spoken of simply as the optimal program.

9. The military actually only chooses q. Then Congress chooses x so that the program costs B dollars. Formally, however, this is equivalent to having the military choose q and x subject to the constraint that the program cost at most B dollars. Thus the military will be viewed as choosing q and x.

10. See Stubbing [1986], chapter 7 for a more complete description of these and other overlaps.

11. Stubbing [1986], p. 143.