Is there a bias toward excessive quality in defense procurement?

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Abstract

Anecdotal evidence suggests that defense procurement processes lead to the purchase of weapons of apparently excessive quality. In this paper, we present a model that suggests that this could be the result of the timing and informational structure of procurement decisions. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Most observers of military procurement decisions have argued that there is a tendency for militaries to purchase an insufficient number of excessively ‘high quality’ weapons. Among the papers that provide anecdotal evidence of this are Gansler (1980) and Stubbing (1986), while a theoretical justification for this tendency is provided in Rogerson (1990).

In this paper, we present a simple model that suggests that there may be no actual bias towards excessive weapon quality. Rather, this perceived bias is the result of evaluating procurement decisions without reference to their time frame and informational structure.

The model’s central feature is that decisions regarding weapon quality must be made prior to any decision regarding quantity. During weapon development, there is uncertainty regarding the future evolution of security threats. As a result, the optimal choice of weapon quality is likely to be higher than the average level that would be chosen if full information was attainable. This explains the
anecdotal evidence cited so frequently by observers. Ex-post, average weapon quality appears too high.

This paper has five sections. In Section 2, we present and solve a model of the defense procurement decision-making process under conditions of full information. In Section 3, we introduce uncertainty regarding the future evolution of security threats, and we identify the optimal choice of weapon quality under uncertainty. In Section 4, we demonstrate that the optimal level of quality chosen under uncertainty is likely to be higher than the average quality level chosen under conditions of certainty. In Section 5, we conclude the paper.

2. The model with perfect foresight

In this model, the government must procure a new weapon system. First, the government must choose the level of weapon quality. When the government chooses weapon quality, it does not know what the national security situation will be like when the weapon is ready for production, but has certain beliefs regarding the evolution of security threats. During the protracted period required to develop the new weapon, the government observes the actual development of the external security threat. Following this observation, the government chooses the quantity of weapons to be purchased.

Let the function $V$ represent the level of national security. $V$ is a multiplicative function of $q$ (the quality of weapons), $n$ (the quantity of weapons), and $\theta$ (external security conditions). Formally:

$$V(q, n, \theta) = f(n)h(q)g(\theta)$$

(1)

We assume that the functions $f$, $g$, and $h$ are continuous twice differentiable monotone increasing and strictly concave functions.

Security conditions are assumed to have only two possible values — $\theta^p$ or $\theta^w$ — with positive probability. $\theta^p$ is greater than $\theta^w$, and implies that the country is in a state of peace. A realization of $\theta^w$ implies that the country is at war. We further assume that the prior distribution of $\theta$ is known and in the public domain.

The function $C$ represents the cost of purchasing weapons. We assume that quality (quantity) is measured by the funds devoted to research and development (production). Hence:

$$C(q, n) = q + n$$

(2)

We assume that the objective function of policy-makers is to minimize the cost of defense, subject to the constraint that national security must not be allowed to fall below a threshold level called $V^*$. Formally:

$$\min_{q, n} C(q, n) \quad \text{s.t.} \quad V(q, n, \hat{\theta}) \geq V^*$$

(3)

The optimization problem is ‘safety first.’ Nations must always assure that they are adequately defended. We believe that this is a reasonable characterization of how national security decisions are made. Consider the primacy of ‘worst case scenarios’ in national security planning. Security decisions made on the basis of providing adequate defensive capability in the event of worst case scenarios would seem to be a definitive example of safety first thinking.
All decision-makers — be they politicians, bureaucrats, or officers — share the objective described by (3). Hence, we can ignore the role of institutional arrangements in the procurement process. All decision-makers, regardless of institutional identity, make identical decisions.

We now identify the values of $q$ and $n$, $q^*$ and $n^*$, that minimizes the objective in (3), assuming that policy-makers have perfect foresight regarding the future evolution of security threats. Let $q^{p*}$ and $n^{p*}$ ($q^{w*}$ and $n^{w*}$) be the optimal choices for $q$ and $n$ in the event of peace (war).

We will solve for $q^*$ and $n^*$ in a two-stage process. The first step is to identify $n^*$ as a function of $q$ and $u$. For notational convenience, we will ignore the indices $w$ and $p$ for a while. Since $q$ and $u$ are known when $n$ is chosen, $n^*$ is simply the value of $n$ that assures that $V$ equals $V^*$. Formally:

$$V^* = f(n) h(q) g(\theta)$$  \hspace{1cm} (4a)

which implies:

$$n^*(q,\theta,V^*) = f^{-1}[(1/h(q))(V^*/g(\theta))] = F[(1/h(q))(V^*/g(\theta))]$$  \hspace{1cm} (4b)

The first and second order derivatives of the inverse function $F$, $F'$ and $F''$, are both positive.

Note that

$$n_q^* = (F')[-(h_q V^*)/h g] < 0$$  \hspace{1cm} (5a)

and

$$n_{qq}^* = V^*/gh^4[F'' h_q^2(V^*/g) + F' h(2 h_q^2 - hh_q)] > 0$$  \hspace{1cm} (5b)

where $n_q^*$ and $h_q$ are first derivatives and $n_{qq}^*$ and $h_{qq}$ are second derivatives with respect to $q$. It can also be easily verified that the partial derivative of $n_q^*$ with respect to $\theta$ is positive:

$$n_{q\theta} > 0$$  \hspace{1cm} (5c)

Expression (5c) implies that for any given level of $q$ (say $q$):

$$n_q^*(q,V^*,\theta^p) > n_q^*(q,V^*,\theta^w)$$  \hspace{1cm} (5c')

The second step is to identify $q^*$. Since decision-makers enjoy perfect foresight, they know with certainty what $\theta$ will be realized. Hence, the optimal values of $q$ are given by:

$$q^{p*} = \text{argmin} C[q, n^{p*}(q,V^*,\theta^p)]$$  \hspace{1cm} (6a)

and

$$q^{w*} = \text{argmin} C[q, n^{w*}(q,V^*,\theta^w)]$$  \hspace{1cm} (6b)

The first order conditions required to satisfy (6a) and (6b) assure that:

$$1 + (n_q^{p*}) = 0$$  \hspace{1cm} (7a)

and

$$1 + (n_q^{w*}) = 0$$  \hspace{1cm} (7b)
Since $n_{q*}^* > 0$, the second order conditions for minimization are satisfied. The assumptions we have made regarding the nature of $V$ assure that $q$ and $n$ are normal factors of security production. Hence $q^{**} > q^p*$ and $n^{**} > n^p*$.

3. The model with imperfect foresight

We will now identify the optimal levels of $q$ and $n$ when decision-makers must choose $q$ prior to observing the realization of $\theta$. As with perfect foresight, $\theta$ and $q$ are known prior to the choice of $n$. Hence, $n^*$ is simply the value of $n$ that assures, given $\theta$ and $q$, that $V$ equals $V^*$. These values are given by (4b).

The decision-maker must choose, prior to observation of $\theta$, a single value for $q$ that will minimize the expected value of $C$. Let that value of $q$ be known as $q^{**}$. Then:

$$q^{**} = \arg\min E[C(n^*(\theta, q, V^*), q)]$$

where $E$ is the expectations operator. The first order condition required to satisfy (8) is:

$$E(1 + n_{q}^*) = 0$$

Let $\alpha (1 - \alpha)$ be the probability that $\theta$ equals $\theta_w$ ($\theta_p$). Then:

$$E[C(n^*(\theta, q, V^*), q)] = \alpha[q + n_{q}^*(q, \theta_w, V^*)] + (1 - \alpha)[q + n_{q}^*(q, \theta_p, V^*)]$$

and (9) can be rewritten as:

$$\alpha[1 + n_{q}^*(q^{**}, \theta_w)] + (1 - \alpha)[1 + n_{q}^*(q^{**}, \theta_p)] = 0$$

To satisfy (9a), the two bracketed expressions must have opposite signs. Recalling (5c') and remembering that $n_{q}^*$ is negative, it can easily be verified that:

$$[1 + n_{q}^*(q^{**}, \theta_w)] < 0$$

while

$$[1 + n_{q}^*(q^{**}, \theta_p)] > 0$$

Complete differentiation of (9a) with respect to $\alpha$ and $q$ implies that:

$$\text{sign}[dq^{**}/d\alpha] = \text{sign}[n_{q}^*(q^{**}, \theta_p) - n_{q}^*(q^{**}, \theta_w)]$$

By (5c'), this is larger than zero.

Utilizing (5b), (7a), (7b), (10a), and (10b), it can easily be verified that:

$$q^{**} \geq q^{**} \geq q^p*$$

The result identified in (12) is consistent with the author’s experience. During peacetime, observers complain that weapon quality is too high. Following wars, however, military officers typically
complain that weapon quality was too low. Both observations may be correct ex-post, but neither observation demonstrates that, ex-ante, anything is amiss in the weapon procurement process.

4. Is quality ‘too high’ under imperfect foresight

By definition, $q^{**}$ is the optimal ex-ante setting for weapon quality. Nevertheless, $q^{**}$ may appear too high if observers evaluate procurement decisions without reference to their timing and informational structure. If governments had perfect information, the optimization process would result in an average weapon quality equal to $E(q^*)$, the expected value of $q^*$. Observers unappreciative of the government’s actual informational constraints will mistakenly identify a bias towards excessive quality if $q^{**} > E(q^*)$.

The expected value of $q^*$ is given by:

$$E(q^*) = \alpha q^{**} + (1 - \alpha)q^p$$

When $\alpha = 0$, the expression simplifies to:

$$dq^{**}/d\alpha = \{n_q(q^{**}, \theta_p) - n_q(q^{**}, \theta_w)\}/\{\alpha n_{qq}(q^{**}, \theta_w) + (1 - \alpha) n_{qq}(q^{**}, \theta_p)\}$$

When $\alpha = 1$, the expression simplifies to:

$$dq^{**}/d\alpha = \{n_q(q^{**}, \theta_p) - n_q(q^{**}, \theta_w)\}/n_{qq}(q^{**}, \theta_w)$$

Since the numerators in (15a) and (15b) are identical, it is a sufficient but not necessary condition for $dq^{**}/d\alpha$ to be monotonically decreasing that $n_{qq}(q^{**}, \theta_w) > n_{qq}(q^{**}, \theta_p)$. For many reasonable functional forms, including the Cobb–Douglas, $n_{qq}(q^{**}, \theta_w) > n_{qq}(q^{**}, \theta_p)$. Hence, it is quite likely that $q^{**}$ is greater than $E(q^*)$ for $\alpha \in (0,1)$.

5. Conclusion

In this paper, we presented a simple model of defense procurement decision-making. The model suggests that the optimal level of weapon quality under ‘real world’ conditions of uncertainty is likely to be greater than it would be under conditions of perfect foresight. We believe that this result can, at least partially, explain the empirical evidence presented in studies such as Gansler (1980) and Stubbing (1986). Such studies, due to their focus on case studies and the obvious limitations imposed
by national security considerations, cannot fully evaluate the role of timing and uncertainty in the defense procurement process. Hence, they are likely to mistakenly conclude that weapon quality is too high.

References