Second Sourcing and the Incentives for R & D Investment

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Second sourcing is a frequently suggested policy in defense procurement, under which the procurer leaves open an option of replacing an initial developer for an alternative supplier in the full-scale production stage. This paper studies the incentives for R&D investment and the welfare performance of second sourcing relative to sole sourcing (under which the procurer commits not to replace the developer). The key feature of the model is that the investment undertaken in the development stage serves to augment the informational superiority of the developer about the production process, and leads to an increase in the information rents accruing to the developer. The resulting tendency for overinvestment, this paper shows, can be correctively discouraged by the use of second sourcing. Also, a comparative static analysis suggests that second sourcing is likely to be valuable when the investment is sufficiently specific and when the procurer can commit to discriminatory competition in the selection of the full-scale producer. (*JEL* Classification: D82, L51)

I. Introduction

When a buyer procures goods from a single supplier over extended periods of time, the supplier can gradually build up monopoly power. This is especially true when the supplier develops specialized technolo-

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gies and/or superior information about the production process, which all contribute to the bargaining leverage of the supplier. To control the supplier monopolization, the buyer may find it in her interest to replace the original supplier for a second source after several rounds of initial transactions. This may allow the buyer to find a more efficient supplier, and, even if this does not happen, the sheer threat of replacement can descipline the incumbent supplier to behave competitively throughout the remaining transaction periods. Indeed, second sourcing is frequently used in many organizational settings characterized by repeated bilateral relationships: e.g., DoD-contractor, regulator-natural monopoly, shareholder-management, etc. Being an area long subject to various cost abuses of contractors, defense procurement has a strong policy interest in second sourcing.

Procurement of major weapons systems typically spans more than a decade with several distinctive stages: initial design, development, initial production and full scale production. Throughout the stages of development and initial production, and original developer collects crucial project-specific technologies and know-hows that enable him to command monopoly rents. The buyer cannot easily dissipate these rents away by competitively selecting a developer, since the extent to which bidders buy in is limited by the size of development contract, which is small relative to the production contracts eventually awarded (Anton and Yao 1987a). Maintaining several suppliers (multiple sourcing) is frequently not a feasible option either, since projects are highly indivisible or subject to some degrees of economies of scale. The only viable option then is to replace the original developer after the initial production stage.[1] Formally we refer to "second sourcing" as a mode where the buyer chooses to leave such an option open. The opposite mode, called "sole sourcing" occurs when the buyer commits not to replace the original developer. The buyer can achieve such commitment by allowing the incumbent supplier to own property rights of critical production assets.

In exploring the crucial trade-offs associated with the two modes, we focus on the investment the developer undertakes in the initial stages. This investment involves a lot of design and technology changes, and

[1]In principle, the competition can occur at any point of the procurement cycle. For practical reasons, however, second sourcing is mostly considered after the initial production is completed. By that time, design stability reaches a certain required level and sizable cost reduction is achieved.

results in sizable cost reduction. Since the investment involves the use of new technologies, however, the amount of the cost reduction is uncertain and ex post unknown to the buyer. The resulting informational asymmetry creates an opportunity for the developer to command some rents; even when the developer has no inherent bargaining leverage, he can understate the actual magnitude of cost reduction and enjoy some resulting slack. As is well-known in optimal regulation literature (for example, Baron and Myerson 1982; Laffont and Tirole 1986), the buyer can limit these information rents, at least to a certain extent, by distorting production assignment downwards (i.e., inducing the developer with small cost reduction to produce less than the first-best level).

In the context of this paper, the potential value of second sourcing stems from its ability to further limit the information rents accruing to the developer. By threatening to replace the developer, the buyer can effectively discourage the developer from understating the ture magnitude of cost reduction. What makes the problem non-trivial, however, is that the investment incentive does not remain intact when second sourcing is adopted. In general, second sourcing discourages the investment: When developer faces a positive probability of being replaced, he will undertake less investment than he would under sole sourcing. In principle, such discouragement effect can be either beneficial or harmful depending on the optimality of the investment level undertaken under sole sourcing. In fact, a largely negative assessment on second sourcing by Riordan and Sappington (1989) is based on their finding that underinvestment occurs under sole sourcing. Based on this, they argue that second sourcing will *aggravate* the underinvestment problem.

This underinvestment result, however, does not accord well with the general observations made by case studies, according to which there appears to be (i) *an excessive number of design changes* (Gansler 1986), (ii) *excessive use of advanced, untested technologies* (Hanrahan 1983), (iii) *gold plating*. These all identify "overinvestment"—rather than "underinvestment"—as a serious problem.

The purpose of this paper is two-fold: First, we would like to theoretically establish the possibility of overinvestment under sole sourcing. Second, as our main proposition, we wish to show that second sourcing can indeed improve the investment incentive by correcting the overinvestment problem. This will allow us to make a more favorable assessment on second sourcing than has been made by the literature.

A key feature of my model which is new relative to the procurement literature is that an R&D investment plays a non-trivial informational role: I assume that the investment makes the project more idiosyncratic and therefore increases informational uncertainty facing the procurer. This assumption is most appropriate in the procurement of many premiere, advanced weapons systems, where higher investment results in a greater use of idiosyncratic, less known technologies, (which are likely to aggravate the informational problem facing the buyer). With the assumption, unless the government somehow controls the investment behavior, the developer would engage in excessive investment that does not take account of the adverse informational effect. The main argument of this paper will be that second sourcing, through its investment dampening effect, can correct the overinvestment.

The rest of the paper is organized as follows. The model is described in section II. In section III and IV, optimal contracts under sole sourcing and second sourcing are identified, and the investment incentive created under each mode is examined. Section V compares two sourcing mechanisms. From a simple comparative static analysis, we conclude that second sourcing is likely to be preferred, if the developer's technology is not too easily transferable to the new potential supplier, and when the buyer can commit to a discriminatory break-out rule.

The model is closely related to Riordan and Sappington (1989) and a large part of their framework is utilized. However, there are some important differences: First, in this paper, the informational ramifications of investment activities are explicitly recognized. Second, they assume that developer initially buys in to fully extract future profits, while, in this paper, a complete buy-in is ruled out, to reflect actual practice. Despite these differences, this model can be understood as an extention of their model into a different, but relevent, cost structure. In this sense, the relationship is complementary. In Laffont and Tirole (1987a, b), an optimal break-out rule (which allows for discriminatory competition between the developer and a potential supplier) is analyzed in the model where the buyer has a full commitment power. Our model is distinguished by the lack of the commitment power, which makes the comparison of modes non-trivial in this model. A similar optimal break-out rule is considered in section VI, where the non-commitment assumption is somewhat relaxed. Other related literature includes Anton and Yao (1987b) which focuses on the learning curve and the ratchet effect as a source of the second source benefit without considering the multi-stage effect on investment. Another group of literature

(Farrell and Gallini 1988; Shepard 1987) studies second sourcing as a valuable commitment instrument to a seller who moves first, contrary to this model where the buyer moves first.

II. Model

We develop a stylized two period model of procurement. In the first period, a sole source contractor (developer) develops a design specified by the buyer and undertakes investment. In the second period, either the developer or a second source is selected to perform full scale production. This, along with the level of production, is determined after the buyer receives a cost report from the developer. The objective of the buyer is to maximize the value of procurement net of the cost incurred, subject to the constraint that contractors should sustain no loss ex post.

The sequence of events is more fully described as follows. First, the buyer commits to a type of sourcing (i.e., she decides whether or not to have an option of replacing the developer after initial production). Next, in the development stage, the developer undertakes an investment, I. The purpose of the investment is to lower the expected cost at the full-scale production stage. As a result of investing I, the developer faces a unit cost of production:

$$C(\theta, I) = C - K(\theta ; I),$$

where C denotes the unit cost associated with the use of the conventional technology, and $K(\theta; I)$ denotes the amount of unit-cost reduction. As mentioned in the introduction, the amount of cost reduction is ex ante uncertain (at the time of investment) and ex post privately informed by the developer. The uncertainty is described by a random variable θ, where high θ is interpreted as a favorable technology shock or unexpected innovations related to the new technology. θ follows a distribution $F(\cdot)$ and a positive density $f(\cdot)$ over a positive support $[\underline{\theta}, \bar{\theta}]$ where $0 < \underline{\theta} < \bar{\theta} < \infty$. Throughout, the following regularity condition is assumed.

[A.1] $H \equiv (1-F)/f$ is differentiable and non-increasing; and $\underline{\theta} - H(\underline{\theta}) \geq 0$.[2]

[2]The first condition, which implies that f does not decrease too fast, is satisfied for most of the well-known distributions including the uniform, exponential

A key feature about the investment is that it increases the cost uncertainty. This can be characterized by the complementarity between θ and I: $K_{\theta I} > 0$. According to this condition, a particular realization of the technology shock matters more when a larger investment is undertaken. In what follows, a specific functional form will be assumed for the sake of simplicity. We assume:

[A.2] $K(\theta; I) \equiv \theta g(I)$ where $g' > 0$, $g'' \leq 0$, $\lim_{I \to \infty} g' = 0$,
$\lim_{I \to \infty} g' = \infty$, and $\theta\, g(\infty) < C$.[3]

After the development stage is completed, the buyer awards the full scale production contract. The contract terms depend on the sourcing decision made in the beginning. If the buyer chose sole sourcing, then she offers an exclusive contract to the developer, which specifies quantity to be procured, x and the transfer to the developer, t (possibly as functions of the developer's reports). If the developer accepts the contract, she produces x at the unit cost $C(\theta, I)$. The buyer's benefit is expressed as a function $V(x)$ when x is the amount procured. We assume:

[A.3] $V(\cdot)$ is increasing, concave, and $\lim_{x \to \infty} V' = 0$, $\lim_{x \to 0} V' = \infty$.

If the buyer chose second sourcing in the beginning (i.e., if she did not commit to retain the developer), either the developer or a second source can be selected. If a second source is selected, the buyer offers an analogous contract specifying (y, p) (again as functions of the developer's reports) to the second source. At the same time, the technology developed by the incumbent is transfered to the second source through a short period of so-called "education buy" or "split buy." As a result of the transfer of the technology, the second source faces a unit cost of production:

$$D(\theta, I) = C - s\theta g(I),$$

where $s \in [0, 1]$. Here, s parameterizes the transferability of the developer's newly invested technology. In other words, the higher s is, the more cost reduction benefits a second source receives from the devel-

and the normal distribution. The second condition assures that the investment is valuable even with the most unfavorable technology shock.

[3]This functional form satisfies the complementarity. The second part ensures, among other standard curvature properties an interior solution for any investment decision problems and the positivity of the unit cost.

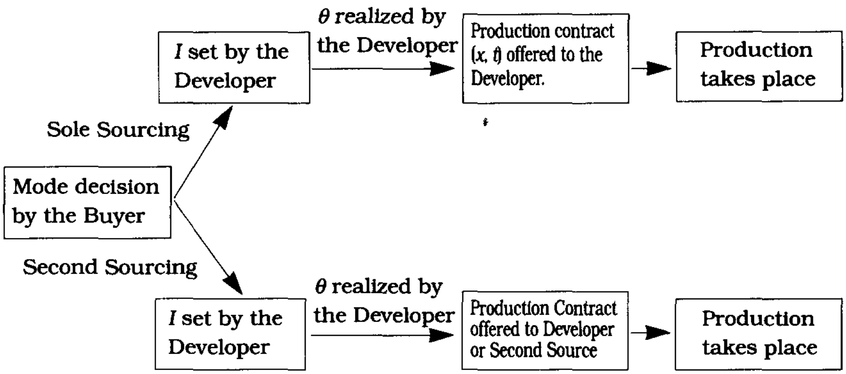

FIGURE 1

oper's investment. Alternatively, $1 - s$ measures "switching cost" or "specificity" of the developer's investment: a fraction of the cost reduction benefit, $(1 - s)\theta g(I)$, is lost when the incumbent is replaced.[4] The time line is summarized by Figure 1.

Serveral remarks are in order. First, we assume limited liability on the part of the developer. Namely, the developer cannot sustain any loss ex post. This implies that even though the developer is initially chosen through a competitive process, his future rents cannot be dissipated away because of his limited ability to bear loss. Although this assumption may appear somewhat restrictive, it is a reasonable institutional constraint: the Department of Defense (DoD) has been always concerned with maintaining a broad industrial base in military supply and tries to avoid the bankruptcy of the contractors. In some incidences, it was actively engaged in bailing out the financially ailing contractors.[5]

[4]The parameter s depends not only on the technological requirement of given project but also on such institutional factor as DoD's policy on the ownership of technologies (or data). For example, if the policy allows the developer to own most of the technology she develops, then s will be very low; and vice versa. In this sense, s is potentialy under the control of the buyer (DoD). However, we will treat s as a given parameter for analytical tractability.

[5]There are other reasons that explain why the buy-in is limited. First, the the process of selecting the developer is not, in general, very competitive. For example, only 8 percent of the total contracts are based on fully advertised price competition (Gansler 1986). Second, even though the initial bidding foreces some degree of buy-in, it is likely to take the form of wasteful influence activities (Milgrom 1988) or design competition (Che 1992).

Second, the buyer has a limited commitment power; i.e., she is unable to offer a production contract before θ is realized (and thus before the investment is undertaken). In major defense contracting, the DoD's commitment power is significantly limited by lengthy contracting period, unforeseen program revisions and the intervention from a third party like Congress. If the buyer had a full commitment power, the problem would be trivial. Even with the limited liability imposed here, second sourcing will be always better since the buyer can always commit to a certain *discriminatory* break-out rule and do as well as and possibly better than under sole sourcing.[6] Thus, the limited commitment feature in this model makes the comparison of second and sole sourcing meaningful.

Third, information asymmetry exists in this model. It is assumed that, while the developer attains perfect information about the investment I and the technology shock, θ, (after it is realized) the buyer and any potential second source learn only imperfect information about them. Frequently, unexpected innovations occur through critical learning (that is gained from a new technology), and are not easily monitored by outside auditors. In this model, we assume that, when θ is realized, it is only known to the developer, while the buyer (and the second source) observes only its distribution, F. The resulting adverse selection (hidden information) will play a major role in our analysis, as it creates information rents for the developer. As for the investment, it is hard for the buyer to verify thousands of technical changes and figure out the monetary investment needed for them. Therefore, it is impossible for the buyer to control the level of investment through any contracting arrangement. This creates moral hazard for the developer; i.e., his choice of the investment level would differ from the one desired by the buyer. Also, the asymmetric information on the investment affects the way the investment is reimbursed. In particular, with the strong limited liability assumed in this model, the investment undertaken by the developer must be reimbursed on a cost-plus basis. Note, however, that in this model this does not create infinite investment. The buyer in this model reimbureses a conjectured amount of investment and not the actual investment. Therefore, as it will turn out, any particular choice of reimbursement method does not affect the developer's investment decision. In fact, this kind of cost-plus reimbursement

[6] If, in addition, the developer's liability is unlimited, the buyer could achieve the first best outcome by selling the whole process to the developer at an approriate franchise fee.

is consistent with the standard practice of DoD contracting, which, after a brief period of incentive contracting, almost always reverts to a cost-plus contracting to reimburse the design modifications. (See Osband 1989)

Finally, complememtarity of the cost function in [A.3] is crucial in linking the first period moral hazard to the second period adverse selection problem. This feature formalizes the notion that, in advanced weapons development, investment tends to create the "social cost" of aggravating informational uncertainty. This feature of the cost function yields the main results of the paper that were overlooked by the existing literature.

III. Investment under Sole Sourcing

Although our ultimate interest lies in the case where both θ and I are unobservable to the buyer, we first solve the benchmark problem where I can be controlled by the buyer. This will show the efficient level of investment under the given informational condition (where, of course, θ is still unobservable). Using this as a benchmark, we can measure the bias that would result if I could not be controlled by the buyer.

A. Benchmark Solution

When I is observed and chosen, the revelation principle ensures that the buyer faces the following problem:

$$\max_{I,x(),t()} E_\theta \{V(x(\theta)) - t(\theta)\} - I$$

subject to (IR) $U(\theta;\theta) \equiv t(\theta) - \{C - \theta g(I)\}x(\theta) \geq 0 \quad \forall\, \theta$

(IC) $U(\theta;\theta) \geq U(\theta;\hat{\theta}) \equiv t(\hat{\theta}) - \{C - \theta g(I)\}x(\hat{\theta}) \quad \forall\, \theta, \hat{\theta}$

The buyer chooses $\{I, x(\cdot), t(\cdot)\}$ such that its objective function is maximized while the developer is induced to tell the truth (IC) and guaranteed a minimum participation payoff (IR). The solution to this second best problem is obtained by using the standard argument due to Baron and Myerson (1982) (or Guesnerie and Laffont 1984).

Lemma 1

Under the second best setting where θ is unobeservable but I can be controlled by the buyer, the optimal solution $\{x_1^*(\cdot), I_1^*, t_1^*(\cdot)\}$ satisfies:

$$x_1^*(\theta) = x(\theta, I_1^*) \quad \forall\, \theta,$$

where $x(\theta, I)$ satisfies $V'(x) = C - (\theta - H(\theta))g(I) \quad \forall\, I;$ (1)

I_1^* satisfies $g'(I)E\{(\theta - H(\theta))x(\theta, I)\} = 1;$ (2)

$$t_1^*(\theta) = g(I_1^*) \int_{\underline{\theta}}^{\theta} x_1^*(a)da + (C - \theta g(I_1^*))x(\theta). \tag{3}$$

Proof: Omitted.

Existence of the solution is easy to establish: $x(\theta, I)$ is finite by [A.3]. This together with [A.2] implies that there exists some I that satisfies (2). We assume that the solution is unique.

In the optimal contract, the buyer chooses quantity by equating the marginal benefit to the full marginal cost which consists of the physical marginal cost, $C - \theta g(I)$, and the information cost, $H(\theta)g(I)$. As usual, the distortion by the additional term reflects the cost of revealing the developer's private information. Rather unusual here is that the information cost term interferes with the optimal investment decision, distorting its level downward from what otherwise would be an optimal level. This is because of the complementarity between θ and i that is assumed in this model. Since an increase in investment, by increasing the impact of the given change in θ, strengthens the informational advantage of the developer in a way that increases the information rents accruing to the developer in the second period, the buyer, if she can, would want to discourage the investment level away from a first-best level.

Finally, note that the second-best investment level, I_1^*, is the best (value maximizing) level under the given information environment. In other words, if we describe the value function[7] at any given I by

$$\Gamma_1(I) \equiv \max_{x()} E_\theta[V(x(\theta)) - \{C - (\theta - H(\theta))g(I)\}x(\theta)] - I,$$

then $I_1^* = \text{argmax}_I\, \Gamma_1(I)$.

B. Unobservable Investment

When the buyer does not observe the developer's investment level, she cannot write a second period contract (x, t), conditional on the actual level of investment. Instead, she must offer the contract based on her belief about the investment, $\hat{I}$. Except for these, the second peri-

[7]This value function is obtained as a result of substituting the constraints (IR) and (IC) into the objective function and reswitching the double integrals (Baron and Myerson 1982).

od problem that the buyer faces is essentially the same as one under the observable investment case.

Given that the second period problem is solved in a similar way as before, let us focus on how the developer chooses the investment level in the first period. Let $\hat{\theta}$ denote the report by the developer when the true state is θ. Also, I denotes the actual investment while $\hat{I}$ is the belief held by the buyer. Then, the second period pay-off for the developer can be described as:

$$U(\theta, \hat{\theta}; I, \hat{I}) = t(\hat{\theta}, \hat{I}) - \{C - \theta g(I)\}x(\hat{\theta}, \hat{I}).$$

The following lemma is useful.

***Lemma* 2**

If $r(\theta, I, \hat{I})$ denotes an optimal report $\hat{\theta}$ given θ, I and $\hat{I}$, then $r(\cdot, \cdot, \cdot)$ is differentiable with respect to I and $(\partial U / \partial \hat{\theta})_{\hat{I}=I} = 0$, almost everywhere.

Proof: See the appendix.

Lemma 2 allows us to use the envelope theorem when evaluating the first order condition for the investment decision. In the first period, the developer solves the problem:

$$\max_{I} \quad E\{U(\theta, r(\theta, I, \hat{I}), I, \hat{I})\} - I.$$

In equilibrium, the belief has to be correct. Thus, $\hat{I} = I$. Then, by using Lemma 2 the necessary condition for the optimal investment in equilibrium is simply described by

$$E\left(\frac{\partial U}{\partial I}\right)_{\hat{I}=I} = 1.$$

The equilibrium solution under unobservable investment is characterized in Lemma 3.

***Lemma* 3**

When the investment is chosen by the developer and unobservable to the buyer, the equilibrium contract $\{x_1(\cdot), t_1(\cdot)\}$ and investment I_1 satisfy:

$$x_1(\theta) = x(\theta, I_1) \quad \forall \theta,$$

$$\text{where } x(\theta, I) \text{ satisfies } V'(x) = C - (\theta - H(\theta))g(I) \quad \forall I; \tag{4}$$

$$I_1 \text{ satisfies } g'(I)E\{\theta x(\theta, I)\} = 1; \tag{5}$$

$$t_1(\theta) = g(I_1) \int_{\underline{\theta}}^{\theta} x_1(a)da + (C - \theta g(I_1))x(\theta). \tag{6}$$

Here, again we assume the uniqueness of the solution. (Existence of the solution is straightforward to establish by using the same argument as before.) Note that the quantity decision rule is exactly the same under the observable investment case given the same investment (compare (1) and (4)). However, in the investment decision, the information cost $g'(I)E\{x(\theta, I)H(\theta)\}$ of equation (2) does not appear in (5). This is because when the investment is unobservable the developer cannot be induced to reflect the buyer's informational costs in his investment decision. Failure to recognize the informational costs leads to overinvestment.

***Proposition* 1**
Sole sourcing creates overinvestment.

Proof: See the appendix.

IV. Investment under Second Sourcing

We use a symmetric methodology to examine the investment problem under second sourcing: The benchmark solution under the artificial regime where I can be chosen in the best interest of the buyer, is first solved. Then, we consider a more realistic case where the developer privately chooses the level of investment.

A. Benchmark Solution

When the investment is observable, the buyer can specify a contract for the developer $\{I, x, t\}$ and for the second source $\{y, p\}$ to maximize its own objective function. The revelation principle ensures that the problem of the buyer can be described as follows:

$$\max_{I, x(\,), t(\,), y(\,), p(\,)} E_\theta\{V(x(\theta)+y(\theta))-t(\theta)-p(\theta)\}-I$$

subject to

$$\text{(IR1)}\ U(\theta;\theta) \equiv t(\theta) - \{C - \theta g(I)\}x(\theta) \geq 0 \quad \forall\theta$$

$$\text{(IR2)}\ U_2(\theta;\theta) \equiv p(\theta) - \{C - s\theta g(I)\}y(\theta) \geq 0 \quad \forall\theta$$

$$\text{(IC)}\ U(\theta;\theta) \geq U(\theta;\hat{\theta}) \equiv t(\hat{\theta}) - \{C - \theta g(I)\}x(\hat{\theta}) \quad \forall\theta, \forall\hat{\theta}.$$

This is the second sourcing version of the second best program solved in section III with the additional individual rationality constraint for the second source. Note that there is no incentive compatibility constraint for the second source, since the second source does not have any informational advantage over the buyer.

Substitution of the constraints through the enveloper theorem and the reswitching of the integrals yields the following value function for any given investment level I.

$$\Gamma_2(I) \equiv \max_{x(),y()} E_\theta[V(x(\theta)+y(\theta))-\{C-(\theta-H(\theta))g(I)\}x(\theta)-\{C-s\theta g(I)\}y(\theta)]-I.$$

Differentiaing the objective function with respect to x and y yields the following first-order conditions:

$$V' = C-(\theta-H(\theta))g(I) \text{ for } x \tag{7}$$

$$V' = C-s\theta g(I) \text{ for } y. \tag{8}$$

From this, we can easily see that the developer wins the competition if and only if $\theta - H(\theta) \geq s\theta$. Since from the regularity condition $H = (1-F)/f$ is decreasing and $H(\overline{\theta}) = 0$, for any $s \in [0, 1]$ there exists a cut-off point θ_c in $[\underline{\theta}, \overline{\theta}]$ such that the developer is retained if and only if the technology shock is more favorable than the threshold level; i.e., $\theta \geq \theta_c$. Note that the cut-off point is non-decreasing in s. That is, the more specific (i.e., less transferable) the developer's technology is, the more likely the developer wins the competition. When the buyer picks the investment level, she will set it to maximize $\Gamma_2(I)$.

Let us summarize the solution.

Lemma 4

When the buyer controls the investment, the optimal contracts under second sourcing will be $\{x_2^*(\cdot), I_2^*, t_2^*(\cdot)\}$ for the developer and $\{y_2^*(\cdot), p_2^*(\cdot)\}$ for the second source, where

$$x_2^*(\theta)=\begin{cases} x(\theta,I_2^*) & \text{if } \theta\geq\theta_c; \\ 0 & \text{elsewhere}\end{cases} \tag{9}$$

$$y_2^*(\theta)=\begin{cases} y(\theta,I_2^*) & \text{if } \theta<\theta_c; \\ 0 & \text{elsewhere}\end{cases} \tag{10}$$

where $x(\theta, I)$ and $y(\theta, I)$ satisfy (7) and (8)
and $\theta_c = \max\{0, \min\{\theta', 1\}\}$
where θ' solves $\theta - H(\theta) = s\theta$.

$$I_2^* \text{ solves } g'(I)[\int_{\underline{\theta}}^{\theta_c} s\theta y(\theta,I)f(\theta)d\theta+\int_{\theta_c}^{\overline{\theta}}(\theta-H(\theta))x(\theta,I)f(\theta)d\theta]=1; \tag{11}$$

$$t_2^*(\theta) = g(I_2^*)\int_{\theta_c}^{\theta} x_2^*(a)da + (C - \theta g(I_2^*))x(\theta); \tag{12}$$

$$p_2^*(\theta) = \{C - s\theta g(I_2^*)\}y_2^*(\theta). \tag{13}$$

Proof: Omitted.

Again, the existence of the optimal contract is easily established, and its uniqueness is assumed. As before, in determining quantity, the buyer weighs the marginal benefit of production against the effective unit cost. Besides the physical cost, now the effective unit cost includes two additional terms: (1) the informational cost, $H(\theta)g(I)$, that arises when the developer is selected and (2) the cost associated with the loss in technology transfer, $(1 - s)g(I)$, when the second source takes over. When the former is bigger, as is likely for unfavorable shocks (i.e., low θ), it is less costly for the second source to produce; so, the second source should win; and vice versa.

Now, consider the investment decision. From equation (11) it is easily noticed that the first term of the left hand side describes an external benefit from the investment. Since the investment is chosen by the buyer, this kind of spill-over effect is reflected in the investment decision. This will be no longer the case when the investment is left to the developer as a hidden action.

B. Unobservable Investment

We now consider a case where both θ and I are unobservable. The argument here is symmetric to the unobservable investment case in sole sourcing. As far as the second period is concerned, the buyer faces essentially the same problem as the second best program just considered. The only difference is that the buyer has to base his contract offer (to the developer and the second source) on her belief on the investment rather than the actual investment.

The value function $\Gamma_2(I)$ is still a relevant measure of welfare under given investment I. What distinguishes this regime most is the fact that here the investment is not necessarily set to maximize the value function. Instead, the developer picks an investment level that maximizes his own payoff described by

$$E\{t(\hat{\theta};\hat{I})\} - \int_{\theta_c}^{\bar{\theta}} (C - \theta_g(I))x(\hat{\theta};\hat{I})f(\theta)d\theta - I,$$

where $\hat{I}$ denotes the buyer's belief of I, and $\hat{\theta}$ denotes the developer's report of θ. Optimal contracts are derived as before.

Again the equilibrium solution is reported without proof.

Lemma 5

When the investment is privately chosen by the developer and unobservable to the buyer, the equilibrium contracts under second sourcing are $\{x_2(\cdot), I_2, t_2(\cdot)\}$ for the developer and $\{y_2(\cdot), p_2(\cdot)\}$ for the second source, where

$$x_2(\theta)=\begin{cases} x(\theta,I_2) & \text{if } \theta \geq \theta_c; \\ 0 & \text{elsewhere} \end{cases} \tag{14}$$

$$y_2(\theta)=\begin{cases} y(\theta,I_2) & \text{if } \theta < \theta_c; \\ 0 & \text{elsewhere} \end{cases} \tag{15}$$

where $x(\theta, I)$ and $y(\theta, I)$ satisfy (7) and (8)
and $\theta_c = \max\{0, \min\{\theta', 1\}\}$
where θ' solves $\theta - H(\theta) = s\theta$.

$$I_2 \text{ solves } g'(I)[\int_{\theta_c}^{\bar{\theta}} \theta x(\theta,I) f(\theta)d\theta = 1; \tag{16}$$

$$t_2(\theta) = g(I_2)\int_{\theta_c}^{\theta} x_2(a)da + (C - \theta g(I_2))x(\theta); \tag{17}$$

$$p_2(\theta) = \{C - s\theta g(I_2)\}y_2(\theta). \tag{18}$$

Again the existence and the uniqueness of the equilibrium contracts are established (or assumed) as before. Since the second period solutions ((14), (15), (17) and (18)) are the same as the ones under observable investment, let us focus on the equilibrium investment decision. Equation (16) describes the developer's optimal balancing between the marginal benefits and costs of investment. Comparing with the efficient investment decision in (11), two terms are absent in equation (16): First, the spill-over effect $g'(I) \int_{\underline{\theta}}^{\theta_c} \theta y(\theta, I)f(\theta)d\theta$ is absent because, when the second source takes over the operation, the developer does not recover the returns to his investment. This effect obviously discourages the investment. Secondly, the information cost term, $\int_{\theta_c}^{\bar{\theta}} H(\theta)x(\theta, I)f(\theta)d\theta$, is not internalized to the developer because, even though the investment aggravates the information problem, the cost is not borne by the developer. This effect tends to encourage the investment relative to the efficient level. In sum, we have two competing effects: the social benefit that is not internalized as a private benefit (spill-over effect) and the social cost that is not internalized as private cost (information cost). Therefore, we have no clear-cut characterization as to whether "underinvestment" or "overinvestment" would result under second sourcing. However, it is safe to say that, under second sourcing, the magnitude of overinvestment, if there is any, would not be as big as that under sole sourcing.

Proposition 2

$I_2 \leq I_1$ and $I_2^* \geq I_1^*$. That is, the developer would invest less under second sourcing than under sole sourcing; while the opposite is true for the desired level of investment. Strict inequality holds for both, when $s \in (s(\underline{\theta}), 1)$ so that $\theta_c \in (\underline{\theta}, \bar{\theta})$.

Proof: See the appendix.

The intuition behind Proposition 2 is as follows: Given that the investment is fixed, second sourcing brings about two benefits. First, since the second source earns zero profit while the developer earns information rents, the buyer can save some rents when the second source takes over. Second, that the buyer does not pay any rents to the second source implies that the quantity distortion is diminished ($\theta(1 - s) < H(\theta)$) under second sourcing. This enhances the efficiency of quantity decision. These two effects increase the desired level of investment under second sourcing relative to sole sourcing. On the other hand, the opposite is true for the actual investment. Under second sourcing, the developer has fewer incentives for investment because of the possibility that he may be replaced and cannot reap the benefits of his investment when the second source takes over.

Proposition 2 implies that $I_2 - I_2^* \leq (<)\ I_1 - I_1^*$ (resp. when $s \in (s(\underline{\theta}), 1)$). Therefore, the magnitude of overinvestment decreases under second sourcing.

V. Comparing Modes

In this section, we study the desirability of second sourcing under different values of s (the specificity of technology). In comparing the modes, we focus on the value difference, $\Gamma_2(I_2) - \Gamma_1(I_1)$ as the relative welfare superiority of the second sourcing over the sole sourcing. A key element of the exercise will be to examine the differing investment incentives under two modes.

Recall from Proposition 2 that second sourcing mitigates overinvestment that arises in sole sourcing. Lemma 6 shows how the investment incentives change as s vary.

Lemma 6
$dI_2^*/ds \geq 0$ and $dI_2/ds \leq 0$. Strict inequality holds when $\theta_c > \underline{\theta}$.

Proof: See the appendix.

Lemma 6 demonstrates some intuitive results: When the technology is less specific (i.e. more transferable), the external benefit from the investment will be greater, thus increasing the desired level of investment. On the other hand, the actual investment will fall, because the expected return from the investment will go down as the cut-off point for the incumbent goes up. The main proposition of this paper is now presented. Let $I_2(s)$, $I_2^*(s)$ and $\Gamma_2(I(s); s)$ denote I_2, I_2^* and $\Gamma_2(I)$ under the parameter value s.

Proposition 3
(1) There exists $s^* \in (0, 1)$ such that, for $s < s^*$, $I_2 > I_2^*$ (i.e. overinvestment occurs) and for $s > s^*$, $I_2 < I_2^*$ (i.e. underinvestment occurs).
(2) There exists $s_c \in (s^*, 1)$ such that $s \leq s_c$ implies $\Gamma_2(I_2(s); s) \geq \Gamma_1(I_1)$ (strict inequality holds for $s \in (s(\underline{\theta}), s_c)$).
(3) For s sufficiently close to 1, $\Gamma_2(I_2(s); s) < \Gamma_1(I_1)$.

Proof: See the appendix.

Several remarks can be made. First, both underinvestment and overinvestment can occur with second sourcing. When the technology is specific enough ($s < s^*$), overinvestment still prevails. However, the magnitude of overinvestment is reduced relative to sole sourcing. This reinforces other benefits of second sourcing (rent saving and producion efficiency increase). Second, when the technology is sufficiently specific ($s \leq s_c$), second sourcing outperforms sole sourcing. This is because, when s is sufficiently small, invesment discouragement effect of second sourcing is beneficial since it reduces overinvestment. However, as technology becomes more transferable ($s > s^*$), the investment discouragement effect begins to harm, rather than correct, the investment incentive. When the technology is close to fully transferable, this harmful effect of underinvestment can dominate other beneficial effects so that second sourcing is no longer valuable. To see this more clearly, let us decompose the relative value of second sourcing: When $s < s^*$,

$$\Gamma_2(I_2(s);s)-\Gamma_1(I_1)=\int_0^s\left[\frac{\partial\Gamma_2}{\partial I}\frac{dI_2}{ds}\right](\tilde{s})d\tilde{s}+\int_0^s\left[\frac{\partial\Gamma_2}{\partial s}\right](\tilde{s})d\tilde{s}.$$

Two sources of benefits from second sourcing are identified: The first term measures the benefit associated with the improved investment. This term is non-negative since $\partial\Gamma_2/\partial I_2$ is non-positive when $s < s^*$. The second term measures the benefit from rent saving and the reduced distortion in production. On the other hand, when $s > s^*$,

$$\Gamma_2(I_2(s);s)-\Gamma_1(I_1)=\int_0^{s^*}\left[\frac{\partial\Gamma_2}{\partial I}\frac{dI_2}{ds}\right](\tilde{s})d\tilde{s}+\int_{s^*}^s\left[\frac{\partial\Gamma_2}{\partial I}\frac{dI_2}{ds}\right](\tilde{s})d\tilde{s}+\int_0^s\left[\frac{\partial\Gamma_2}{\partial s}\right](\tilde{s})d\tilde{s}.$$

Now the first and the third terms are the same as before, exhibiting benefits from second sourcing. Observe the second term is negative due to the underinvestment effect ($\partial\Gamma_2/\partial I_2 > 0$). When s is close to 1, this term overwhelms the other terms, favoring sole sourcing.

VI. Discirminatory Competition and Second Sourcing

It is generally known that when the bidders have known difference in characteristics, discriminating bidders can lead to a better outcome for the buyer (Laffont and Tirole 1987a). In the context of our framework, the incumbent and the second source are "discriminatorily competed" if the buyer can commit to a cut-off point which differs from the ex post optimal level, θ_c (defined in Lemma 4 and 5). For example, letting $\hat{\theta}$ denote a new cut-off type, if $\hat{\theta} > \theta_c(I)$, the second source is favored over the incumbent and vice versa. The optimal discrimination rule is characterized as follows.

Proposition 4

An ex ante optimal cut-off, $\hat{\theta}^*$ satisfies the following: $\hat{\theta}^* > \theta_c$, if $s(\underline{\theta}) < s < s^*$; $\hat{\theta}^* < \theta_c$, if $s > s^*$, (i.e., the developer is discriminatorily favored over the second source if and only if $s > s^*$).

Proof: Suppose $s > s^*$, then for $\hat{\theta} \geq \theta_c$, $\partial\Gamma_2/\partial I_2 < 0$ by Proposition 3. Thus, for $\theta \geq \theta_c$,

$$\left(\frac{d\Gamma_2}{d\theta_c}\right)_{\theta_c=\theta}=\left[\frac{dI}{d\theta_c}\frac{\partial\Gamma_2}{\partial I}+\frac{\partial\Gamma_2}{\partial\theta_c}\right]_{\theta_c=\theta}$$
$$=(-)(+)+(-)<0.$$

This proves that $\hat{\theta}^* < \theta_c$. Suppose on the other hand, $s(\underline{\theta}) < s < s^*$. Then, for $\hat{\theta} < \theta_c$,

$$\left(\frac{d\Gamma_2}{d\theta_c}\right)_{\theta_c=\theta} = \left[\frac{dI}{d\theta_c}\frac{\partial\Gamma_2}{\partial I} + \frac{\partial\Gamma_2}{\partial\theta_c}\right]_{\theta_c=\theta}$$
$$= (-)(-) + (+) > 0.$$

This proves that $\hat{\theta}^* > \theta_c$, if $s(\underline{\theta}) < s < s^*$.

Q.E.D.

This shows that when there is overinvestment, discrimination in favor of the second source will be beneficial since it mitigates overinvestment. On the other hand, if underinvestment is a problem (when s is close to 1), favoring the incumbent will be needed to encourage the investment. Committing to a discriminatory competition rule of this kind, if feasible, is beneficial since it provides the buyer with an extra instrument to influence the investment activity. In fact, it is straightforward to see that, with such a commitment available, second sourcing always dominates sole sourcing; for second sourcing can always mimic the performance of sole sourcing ($\hat{\theta} = \underline{\theta}$ would be equivalent to sole sourcing) and possibly do better. More non-trivial question is whether such a commitment power would be available to the buyer before the developer undertakes investment. Choosing a cut-off level different from θ_c is not ex post optimal and may be subject to renegation after the investment is undertaken. Therefore, the optimal break-out rule may not be credible in the first place. Nevertheless, one may view various forms of entry and exit barriers that exist in the defense industry as serving as handicapping devices characterized in Proposition 4. Although these forms of institutional variables are not easily fine-tunable, they may increase the value of second sourcing.

VII. Concluding Remarks

One of the policy concerns in defense procurement is to control the excessive investment by the developer in advanced and untested technologies, which have been the source of frequent cost overruns, higher cost of procurement and added uncertainty. The major finding of this paper is that second sourcing can serve to this end by properly disciplining the developer's investment activities. This finding is most relevant in the procurement of premier, high-tech weapons systems, because of their emphasis on the use of advanced and untested technologies. Since the informational difficulties arising from such technologies are ignored by the developer, a sole source developer tends to overinvest. According to this paper, second sourcing is likely to be helpful in mitigating the excessive investment incentives.

Several extensions of the model are possible. First, it may be useful to endogenize the specificity of technology. In this model, s is treated as a given datum known from the beginning. In reality, however, s is likely to be negatively correlated with the amount of invetment. Second, multiple sourcing in the development stage may be a useful institutional arrangement to consider. Employing multiple developers may help correct the overinvestment problem to a certain extent, even though the cost associated with duplicating development efforts may not be negligible.

Appendix

***Proof of Lemma* 2:** From the incentive compatibility condition of the second period problem, $r(\theta, \hat{I}, \hat{I}) = \theta\ \forall \hat{I}$ and that $r(\theta, I, \hat{I})g(\hat{I}) = \theta g(I)$, implying that r is differentiable and increasing in I. Also, the incentive compatibility implies that x and t are non-decreasing in $\hat{\theta}$, implying that U is almost always differentiable with respect to $\hat{\theta}$. Therefore, first order condition for the interior solution holds for a.a. θ. That is, at $\hat{\theta} = r(\theta, I, \hat{I})$, $(\partial U / \partial\hat{\theta})_{\hat{I}=I} = 0$ a.a.

Q.E.D.

***Proof of Proposition* 1:** We want to show $I_1 > I_1^*$. We first show that $I_1 \neq I_1^*$. From (1) and (4), $x_1^* = x(\theta, I_1^*)$. Now, evaluate dU/dI at second best level, $I = I_1^*$.

$$E\left[\frac{dU}{dI}\right]_{I=I_1^*} = [g'(I)E\{\theta x(\theta,I)\}-1]_{I=I_1^*}$$

$$= g'(I_1^*)E\{H(\theta)x(\theta,I_1^*)\}+g'(I_1^*)\}+g'(I_1^*)E\{(\theta-H(\theta))x(\theta,I_1^*)\}-1>0.$$

Therefore, $I_1 \neq I_1^*$. To show that $I_1 > I_1^*$, let $z = E\{(\theta - H(\theta))x(\theta, I)\}$ and $Z = E\{\theta x(\theta, I)\}$. I_1 (respectively, I_1^*) can be viewed as a solution to $\max_I g(I)z - I$ and $z = E\{(\theta - H(\theta))x(\theta, I)\}$ (respectively, $\max_I g(I)Z - I$ and $Z = E\{\theta x(\theta, I)\}$). New observe that $g(I)z - I$ is supermodular in I and z and that z is increasing in I from equation (1) (which comes from the supermodularity of the buyer's objective function in x and I). Since $Z > z$, and the equilibrium solution is assumed to be unique for each problem, by the monotone comparative static theorems from Milgrom and Shannon (1991), $I_1 > I_1^*$.

***Proof of Proposition* 2:**

(1) $I_2^* \geq I_1^*$:

Here, we also use the monotone comparative static results from Milgrom and Shannon (1991). By the uniqueness of equilibrium solutions and the supermodular structure, it suffies to show that for any I and I',

$$g'(I)[\int_{\underline{\theta}}^{\theta_c} \theta y(\theta,I')f(\theta)d\theta + \int_{\theta_c}^{\bar{\theta}} (\theta - H(\theta))x(\theta,I')f(\theta)d\theta]$$
$$\geq g'(I)E\{(\theta - H(\theta))x(\theta,I')\}.$$

This is satisfied because the cut-off point is determined ex post efficiently. Therefore, $I_2^* \geq I_1^*$. Strict inequality holds when $\theta_c \in (\underline{\theta}, \bar{\theta})$.

(2) $I_2 \leq I_1$:

Similarly, this hypothesis is true because of the underlying supermodular structure (with respect to I and x) and because for any I and I',

$$g'(I)\int_{\theta_c}^{\bar{\theta}} \theta x(\theta,I')f(\theta)d\theta$$
$$\leq g'(I)E\{\theta x(\theta,I')\}.$$

Therefore, $I_2 \leq I_1$. Strict inequality holds when $\theta_c \in (\underline{\theta}, \bar{\theta})$.

Q.E.D.

***Proof of Lemma* 6:** Again using the monotone comparative static results from Milgrom and Shannon, the proof is obvious since, for any I and I',

$$g(I)[\int_{\underline{\theta}}^{\theta_c} s\theta y(\theta,I')f(\theta)d\theta + \int_{\theta_c}^{\bar{\theta}} (\theta - H(\theta))x(\theta,I')f(\theta)d\theta] - I$$

is supermodular in I and s; while

$$g(I)\int_{\theta_c}^{\bar{\theta}} (\theta - H(\theta))x(\theta,I')f(\theta)d\theta - I$$

is submodular I and s (recall θ_c is non-decreasing in s).

Q.E.D.

***Proof of Proposition* 3:** The proof involves several steps.

(1) $I_2(0) > I_2^*(0)$ and $I_2(1) < I_2^*(1)$:

When $s = 0$, $\theta_c = \underline{\theta}$. Thus second sourcing is exactly the same as sole sourcing. Thus, $I_2(0) = I_1$ and $I_2^*(0) = I_1^*$. Since $I_1 > I_1^*$, $I_2(0) > I_2^*(0)$. Now, consider the second inequality. When $s = 1$, $\theta_c = \overline{\theta}$. Then, the left hand side of equation (16) vanishes. Thus, $I_2(1) = 0$. Next, since $y(\theta, I) > x(\theta, I)$ $\forall I$, $\forall \theta < \theta_c$, $\theta_c = \underline{\theta}$ implies that $I_2^*(1) > I_1$. By the Inada condition for $g(I)$, $I_1 > 0$. Hence, $I_2(1) < I_2^*(1)$.

(2) $\exists\, s^* \in (0, 1)$ such that for $s < s^*$, $I_2 > I_2^*$ and for $s > s^*$, $I_2 < I_2^*$:

Obvious from (1) and Lemma 6.

(3) $\Gamma_2(I_2(0);\, 0) = \Gamma_1(I_1)$ and $\Gamma_2(I_2(1);\, 1) < \Gamma_1(I_1)$:

The first equality is obvious. As for the second one: Since $s = 1$ implies $I_2(1) = 0$, $\Gamma_2(I_2(1);\, 1) > 0$, $\Gamma_2(I_2(1);\, 1) = \Gamma_0 = 0$. From the regularity condition that $H \equiv (1 - F)/f$ is non-increasing and that $\underline{\theta} - H(\underline{\theta}) > 0$, $\Gamma_1(I_1) > \Gamma_0 = 0$, proving the result.

(4) $\Gamma_2(I_2(s);\, s)$ is strictly increasing in s for any $s \in (s(\underline{\theta}), s^*)$:

Using the Envelope theorem for x and y,

$$\frac{d\Gamma_2(I_2(s);s)}{dx} = \frac{\partial\Gamma_2}{\partial I_2}\frac{dI_2}{ds} + \frac{\partial\Gamma_2}{\partial s} > 0 \quad \forall s \in (s(\underline{\theta}), s^*).$$

Note $\partial\Gamma_2 / \partial s > 0$, and from Lemma 6 $dI_2/ds < 0$ $\forall\, s \in (s(\underline{\theta}), s^*)$. Finally from (2) and the global second order condition for equation (11), $\partial\Gamma_2 / \partial I_2 < 0$. $\forall\, s \in (s(\underline{\theta}), s^*)$.

(5) $\exists\, s_c \in (s^*, 1)$ such that for $s \le s_c$ ($s \in (s(\underline{\theta}), s_c)$) implies that $\Gamma_2(I_2(s);\, s) \ge (>)\, \Gamma_1(I_1)$; For s sufficiently close to 1, $\Gamma_2(I_2(s);\, s) < \Gamma_1(I_1)$:

(3) and (4) imply that $\Gamma_2(I_2(s^*);\, s^*) > \Gamma_1(I_1)$. This, together with (3) and the continuity of $\Gamma_2(I_2(s);\, s)$ in s proves the results.

Q.E.D.

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