Information expropriation and moral hazard in optimal second-source auctions

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Received August 1991, final version received February 1993

Government mandated technology transfers from the developer of a product to a second source offer a potential gain of reduced information rents and procurement costs. To provide appropriate incentives, technology must sometimes be transferred even when the second source is less efficient than the first. Additionally, when developer moral hazard exists with respect to investments in cost-reducing technology, the optimal auction will make the developer's success in the auction more sensitive to the developing firm's announced costs.

1. Introduction

Amidst shrinking budgets and increasingly expensive technology, the U.S. government has begun to pursue more vigorously the use of competition to reduce the costs of its defense procurements. Witness the enactment of the Competition in Contracting Act of 1984, which reoriented the procurement process around competition and dramatically narrowed the use of sole-source procurement strategies. It is commonly recognized that this new emphasis has had a strong effect on increasing the use of competition in procurement, and in particular, second sourcing.¹

Several approaches exist for introducing competition into the acquisition process. When an accurate and complete description of the developing firm's technology (known as a data package) exists, the government may choose merely to advertise the procurement competition to interested and qualified...

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*Earlier portions of this research were presented at the PA&E Workshop on the Economics of Defense Acquisition held at the RAND Corporation in August 1988 and the Pew Foundation Conference on Defense Procurement in September 1989 in Cambridge, Massachusetts. Financial support from a National Science Foundation Graduate Fellowship, the RAND Corporation, and the Olin Foundation is gratefully acknowledged. The author thanks Joel Demski, Kent Osband, David Sappington, Jean Tirole, and two anonymous referees for helpful comments. The usual disclaimer applies.

¹Gansler (1989) provides an interesting overview of many of the more salient issues involved in defense procurement.
bidders, offering a fixed-price contract to the lowest bidder. When an adequate data package does not exist, or when the item to be produced is very complex, the government may choose to make an 'educational' contract with a second source; such a contract typically consists of the purchase of small quantities of the item (called 'learning buys') at a higher relative cost, thereby providing the second source with production experience and absorbing some of its initial production setup costs.

Both of these methods require the transfer of data from the developer to a second source - a result which can be accomplished in various ways. The developer's contract may contain negotiated terms for license fees, or the firm may be required by law to turn over all data to the government for use in the competitive procurement. (In the United States, a firm must turn over to the government all data when either public funds have entirely funded the development or the government has Government Purpose License Rights in the project's data.) This approach is known as directed licensing, whereby the developer licenses its technology to the second source.

Three policy questions of increasing complexity emerge concerning the licensing of technology to a second source. First, putting aside the developer's incentives for investment in cost-reducing technology, when (if ever) should the government introduce a second source rather than remain with the developer? Second, when the second source has the added option of using its own designs and technologies, rather than the developer's data package, an additional question arises: When should the government choose to have the developer license the second source rather than allow the second source to produce using its own technology? That is, how should the government approach the problem of choosing among the developer, licensing a second source, and selecting a second source but directing it to use its own technology. Third, turning to the problem of moral hazard, when the cost of the product depends in part on the unobservable investments of the developer during initial stages of product design, how should the government respond with its technology transfer policy? Ostensibly, second sourcing may have the deleterious effect of reducing ex ante investment by the developer.

We begin by examining a simple model of second-sourcing in which a tradeoff exists between inefficiently transferring technology and reducing the profits of the firms (and hence reducing the price of procurement). It is possible that introducing such a cost inefficiency is optimal for the buyer if it can also reduce the rents which firms receive from their private information. As in Baron and Myerson (1982) and Laffont and Tirole (1986), the buyer's goal is to balance the introduction of inefficiencies with the reduction of these 'information rents' so as to obtain the lowest possible expected price. Our approach differs from these previous works as we consider the role of competition via second-sourcing as the rent-reducing inefficiency.

In sections 2 and 3 we consider the situation where the buyer can commit
to a take-it-or-leave-it offer, but all contracts are constrained to be ex post profitable. The model consists of one buyer (the government) and two sellers (a developer and a second source). The government has three procurement alternatives: choose the developer to produce, choose the second source to produce using its own technology, or choose the second source to produce using technology transferred from the developer. When second sources do not have their own technology to produce, as is a common situation in defense procurement, the government's options are more restricted, but the analysis is easily incorporated below. At the contracting stage all parties have symmetric information, and the government commits to specific rules for an auction it will later conduct. The sellers determine their costs and bid accordingly; the rules establish who will produce and how much each seller will receive as a function of the bids.

A rule which optimally transfers technology induces both the developer and the second source to report their costs truthfully while leaving each with less rents from their private information. Intuitively, the existence of a second source allows the buyer to compete away some of these information rents via an auction, where the licensing option can be thought of as the addition of a third seller. Although this additional bidder may have higher costs, it also has less of an informational stake in the transferred technology: if the production costs using the transferred technology are less related to the second source's own costs and more related to the developer's costs, its requisite information rent for truth-telling will be significantly lowered. Consequently, informational rent-reducing gains from technology transfer exist.

Although a policy of transferring information-laden technology may reduce rents, we might suspect such a policy would have perverse effects upon the developer's initial incentive to invest. In section 4, this paper endogenizes the developer's investment decision and derives the optimal auction in the moral hazard environment. The results indicate that the solution to the moral hazard problem entails a change in the probability of choosing production by the developer as a function of the project's reported production cost using the developer's technology. The probability of licensing is more sensitive to the developer's announced cost when moral hazard considerations are present.

This paper has important policy ramifications. First, with respect to our earlier policy questions regarding the optimal transfer rule, we find that a

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2This ex post individual rationality constraint is also known as limited liability in the contracts literature. See Sappington (1983).

3The idea of transferring the information-inherent component of one agent to another so as to reduce information rents is not entirely new to the literature. Riordan and Sappington (1989), for example, make use of such transfers in their examination of defense procurement second-sourcing.
commitment to transferring technology for some bids may reduce expected procurement costs, even when moral hazard is present. Second, this paper provides a caveat for the common empirical practice of evaluating the gains from licensing by comparing the post-transfer cost of production with the estimated cost of production by the developer. Such a comparison ignores the ex ante gains in reduced information rents which result from the government's commitment to breakout technology for bad bids and it ignores the costs of reduced incentives for initial development.

The contributions of this paper, however, are not restricted to defense procurement. On a more general level, this paper considers the transfer of information-inherent 'property' from one agent to another so as to reduce information rents. Such a strategy achieves rent reductions by expropriating the agent's hidden information – transferring property in which the information is embodied to a competing agent with a lower informational stake in the property. Providing that an alternative agent can utilize the asset, an optimal transfer has the potential for reducing the principal's acquisition costs.

2. The model

We present a model of a risk-neutral buyer with full-commitment ability and two risk-neutral sellers who are subject to limited liability. For exposition, we initially consider the problem of a buyer (the government) who must procure an item from one of two potential sellers (firms). The government desires to procure a single object at the lowest possible cost. It proposes a take-it-or-leave-it contract to both sellers: the primary seller (firm 1) and the secondary seller (firm 2). The contract commits the buyer to deal with the sellers in a pre-specified manner after the sellers have announced their costs, and must guarantee both sellers non-negative income. Each firm either accepts or rejects the contract. Following their decision, they discover their production costs. The government does not observe costs either ex ante or ex post. After learning their costs, firms make announcements (i.e. 'bids') to the government, who chooses which firm will produce; in the case that the second source is chosen, the government additionally chooses whether or not to transfer the developer's technology. We assume the government's valuation is sufficiently large that it always chooses to procure the item. Monetary payments are made in accordance with the initial contract.

We may think of the contract that the buyer offers as a commitment to use a specific auction mechanism. In this way we analyze the problem of

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4Laffont and Tirole (1986) and McAfee and McMillan (1986) consider contexts where the government can observe costs ex post, but is unable to observe the firms' effort levels. The approach taken here differs from theirs because cost remains unobservable, but similar gains from technology transfers could be realized under alternative models with contractible costs.
choosing the optimal contract as one of optimal auction design. In particular, we will consider truthful revelation mechanisms, using techniques similar to those found in Myerson (1981).

Each firm's cost, $c_i$, is independently distributed according to the continuous probability density, $f_i(c_i) > 0$, on a compact set which we take to be $[0, 1]$ without loss of generality. $F_i(c_i)$ is the corresponding cumulative distribution function, and we make the common regularity assumption that $F_i(c_i)/f_i(c_i)$ is non-decreasing in $c_i$.\(^5\)

The total cost to firm 2 of producing with firm 1's technology, i.e. the total cost of production under licensing, is given by the function $\ell(c_1, c_2)$, which includes the cost of transfer, if any. We will further assume that $\frac{\partial\ell(c_1, c_2)}{\partial c_2} = \ell_2$, a constant; that is, $\ell(c_1, c_2)$ is linear in $c_2$. This implies the second source's marginal cost effect on the licensed production is independent of the developer's cost, allowing us to separate the information effects from each other. We also assume that $1 > \ell_2 \geq 0$ and $\frac{\partial\ell(c_1, c_2)}{\partial c_1} < 1$. Consequently, the second source has less informational stake in the transferred technology than its own technology.

The cost distributions and $\ell$ are common knowledge to the buyer and the sellers. We will often consider a particular situation with linear licensing costs:

$$\ell(c_1, c_2) = \lambda c_1 + (1 - \lambda)c_2 + \gamma,$$

for $1 > \lambda > 0$. With linear licensing costs, a proportion $\lambda$ of the technology is transferable to firm 2 for a fixed transfer cost $\gamma$. In the extreme case of perfectly and costlessly transferable technology, we have $\ell(c_1, c_2) = c_1$.

Finally, based upon cost reports, the government chooses from one of three possible production alternatives: (i) primary production; (ii) secondary production; or (iii) technology transfer or licensing (i.e. secondary production with technology transfer). For tractability, we do not include the logical fourth possibility of transferring technology from the secondary firm to the primary firm. It is important to note that in this framework, seller 2 can be required to produce using seller 1's technology, even when it is inferior to seller 2's own technology. In the defense procurement context, this assumption is plausible as technologies are easily verified. When second sources do not have their own designs to produce, the government's options are restricted to (i) and (iii) above, but the analysis incorporates this case by assuming that $c_2$ is sufficiently large and $\ell_2$ is sufficiently small.

Along with the production decision, the government determines payments

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\(^5\) This regularity assumption is commonly referred to as the monotone likelihood ratio property (MLRP). Among others, the uniform, normal, logistic, chi-squared, exponential, and Laplace distributions satisfy this property.
to each firm based upon their cost reports. A crucial constraint is that the government must guarantee non-negative profits for both producers for all possible realizations of cost: no policy can be enforced ex post which would unduly harm a truthful seller. Here we assume that no firm can be forced to accept a loss, which prevents the government from effectively buying the project from the sellers for the expected minimum cost of the production among them. By law, corporate bodies are protected from liability beyond the value of their assets. Our assumption is stronger, but justified for several reasons. First, the assumption approximates a firm that is extremely risk averse beyond a certain level of losses. Given that managers are sensitive to excessive losses, it is plausible that the firms' behavior may be risk neutral over a moderate range but risk averse for dramatic losses. Additionally, from a purely descriptive perspective it is doubtful that the government could force a defense company to continue production when it suffers excessively large losses. Boards of Contracts Appeal (BCAs), the neutral tribunals which have jurisdiction over government contract disputes, frequently grant equitable adjustments to contracts which impose excessive sacrifices upon firms. To this extent, a limit exists to the losses which a contractor can be forced to bear.

We do not allow the government's payment to the primary firm to depend upon any ex post discoveries made by the licensed firm after a transfer. If the buyer could do this, the first-best solution would be approximated by employing the secondary firm with an arbitrarily small probability to check the truth-telling of the developer, and then punishing this firm sufficiently hard whenever untruthful reports occur. This paper considers the more subtle issue involved when payments cannot be conditioned on an ex post report of another agent. Such a restriction appears realistic in the defense procurement context; otherwise we would have to allow a time delay (perhaps years) between the auction and the agent's action (e.g. defense production) before enough verifiable evidence could be marshalled to levy a punishment against the primary agent.

3. The optimal contract

In this model the buyer commits to deal with the sellers in a predetermined manner after learning their reported costs. Using these reports, the buyer determines who produces the object, whether technology is transferred, and how much each firm shall be paid. The Revelation Principle states that without loss of generality, we may restrict our attention to direct revelation mechanisms. The class of mechanisms which we will consider is given by $\mathcal{M} = \{\{\phi_t(c_1,c_2)\}_{t=0}^2, \{t_j(c_1,c_2)\}_{j=1}^2\}$, where, for given reported costs, $\phi_t$ is the probability that production alternative $i$ is chosen by the buyer, and $t_j$ is the transfer to firm $j$. The production alternatives, $i=0,1,2$, correspond to
licensed production, firm 1 (developer) production, and firm 2 (second source with own technology) production, respectively.

3.1. The first best

Before examining the optimal contract under limited liability and asymmetric information, we note the properties of the full-information contract. Under the full information contract

(i) the most efficient form of production is chosen:

\[ \phi_0(c_1, c_2) = \begin{cases} 1, & \text{if } \ell(c_1, c_2) \leq \min \{c_1, c_2\} \\ 0, & \text{otherwise} \end{cases} \]

\[ \phi_1(c_1, c_2) = \begin{cases} 1, & \text{if } c_1 < \min \{c_2, \ell(c_1, c_2)\} \\ 0, & \text{otherwise} \end{cases} \]

\[ \phi_2(c_1, c_2) = \begin{cases} 1, & \text{if } c_2 < \min \{c_1, \ell(c_1, c_2)\} \\ 0, & \text{otherwise} \end{cases} \]

(ii) the buyer pays the producer realized cost:

\[ t_1(c_1, c_2) = \begin{cases} c_1, & \text{if } \phi_1(c_1, c_2) = 1 \\ 0, & \text{otherwise} \end{cases} \]

\[ t_2(c_1, c_2) = \begin{cases} c_2, & \text{if } \phi_2(c_1, c_2) = 1 \\ \ell(c_1, c_2), & \text{if } \phi_0(c_1, c_2) = 1 \\ 0, & \text{otherwise} \end{cases} \]

(iii) the firms make zero profit.

Because there is full information, the limited-liability constraint is not binding, as zero profits may be guaranteed for all outcomes. The firms will be willing to accept the above contract, and the buyer obtains the object at minimum (in this case, actual) cost. Any contract yielding a lower expected price must necessarily violate individual rationality. Note that if \( \ell(c_1, c_2) > \min \{c_1, c_2\} \) for all \( c_1, c_2 \), then licensing is never optimal under full information. We will see below that even when licensing would never be optimal under full information, licensing may be a desirable strategy by the buyer in environments of asymmetric information.

3.2. Asymmetric information and limited liability

Under the assumption that the other firm is truthful, payoffs to each firm as a function of reported and true costs are
\[ \pi_1(\hat{c}_1, c_2 | c_1) \equiv t_1(\hat{c}_1, c_2) - \phi_1(\hat{c}_1, c_2)c_1, \]
\[ \pi_2(c_1, \hat{c}_2 | c_2) \equiv t_2(c_1, \hat{c}_2) - \phi_2(c_1, \hat{c}_2)c_2 - \phi_0(c_1, \hat{c}_2)\ell(c_1, c_2), \]
where a caret denotes the reported type. Because neither firm knows the other's cost when it must make its report, it is useful to consider the expected payoffs for each firm:

\[ \pi(\hat{c}_1 | c_1) = \int_0^1 \left( t_1(\hat{c}_1, c_2) - \phi_1(\hat{c}_1, c_2)c_1 \right) dF_2(c_2), \tag{2} \]
\[ \pi(\hat{c}_2 | c_2) = \int_0^1 \left( t_2(c_1, \hat{c}_2) - \phi_2(c_1, \hat{c}_2)c_2 - \phi_0(c_1, \hat{c}_2)\ell(c_1, c_2) \right) dF_1(c_1). \tag{3} \]

The mechanism-design problem facing the buyer is given below as program P1:

\[
\min \int_0^1 \int_0^1 \left[ t_1(c_1, c_2) + t_2(c_1, c_2) \right] dF_1(c_1) dF_2(c_2) \tag{4}
\]
subject to

\[ \pi_j(c_j | c_j) \geq \pi_j(\hat{c}_j | c_j), \quad \forall c_j, \hat{c}_j, \tag{5} \]
\[ \pi_j(c_1, c_2 | c_j) \geq 0 \quad \forall c_1, c_2. \tag{6} \]

The objective function is the expected value of the payments paid by the government for the procurement. This is minimized subject to constraints (5) and (6). The constraints in (5) ensure Bayesian truth-telling. The constraints in (6) represent the limited-liability constraints for all states of nature; note that this is not an expectation over payments, but actual payment.

Following Mirrlees (1971), Myerson (1981), and others, we simplify the truth-telling and limited-liability constraints, and incorporate them into the objective function to ascertain the nature of the optimal auction to obtain our first result. All results are proved in the appendix.

**Proposition 1.** The set of \( \{ \phi_i(c_1, c_2) \}_{i=0}^{l=2} \) which solve P1 is the same as that which solves program P2 below using point-wise minimization over the production alternatives at every point \((c_1, c_2)\):

\[
\min_{\phi_0, \phi_1, \phi_2} \left\{ \phi_1 \left[ c_1 + \frac{F_1(c_1)}{f_1(c_1)} \right] + \phi_2 \left[ c_2 + \frac{F_2(c_2)}{f_2(c_2)} \right] + \phi_0 \left[ \ell(c_1, c_2) + \ell_2 \frac{F_2(c_2)}{f_2(c_2)} \right] \right\}. \tag{7} \]
Optimal payments which correspond to the solution of P2 are given by

\[ t_1(c_1, c_2) = \int_{c_1}^{c_2} \phi_1(c_1, c_2) \, dc_1 + \phi_1(c_1, c_2) c_1, \]  
\[ t_2(c_1, c_2) = \int_{c_2}^{c_1} [\phi_2(c_1, c_2) \ell' + \phi_2(c_1, c_2)] \, dc_2 + \phi_2(c_1, c_2) c_2 + \phi_0(c_1, c_2) \ell(c_1, c_2). \]

Note that when \( \ell(c_1, c_2) = c_2 \), Proposition 1 reduces to the standard auction result which may involve handicapping if the cost distributions differ, such as in Myerson (1981). When firm \( i \) is chosen to produce, the transfers given in (8) and (9) indicate that the losing firm receives nothing [this is because \( \phi_{-i}(c_1, c_2) = 0 \) and the integrand in the losing bidder's transfer function is zero given the monotonicity of the optimal choice functions]. The transfer to the winner covers the costs of production and an additional rent term, which indirectly depends upon the report of the loser through the affect of the report on the integrand. The government could alternatively pay each bidder their expected information rents, thereby removing this interdependence of payments on reports, but under such a payment scheme the loser would typically receive some rents as well as the winner.

To understand the mechanics of this solution to the optimal auction, define the following variables as the virtual costs of each production alternative:

\[ J_i(c_1, c_2) \equiv c_i + \frac{F_i(c_i)}{f(c_i)}, \quad i = 1, 2, \]

\[ J_0(c_1, c_2) \equiv \ell(c_1, c_2) + \frac{F_2(c_2)}{f_2(c_2)}. \]

Thus, the solution to P2 amounts to selecting the alternative with the minimum virtual cost. It will also be useful for a graphical analysis to define the following state-space partition over the set of all possible realizations of cost, where \( \Omega^i \) is the set of \( (c_1, c_2) \) such that alternative \( i \) has the lowest virtual cost. That is, \( \Omega^i \equiv \{(c_1, c_2) \mid J_i(c_1, c_2) \leq \min_k J_k(c_1, c_2)\} \). The following corollary flows directly from the definitions and the optimization of P2 in Proposition 1.

**Corollary 1.** The optimal auction consists of setting \( \phi_i(c_1, c_2) = 1 \) iff \( (c_1, c_2) \in \Omega^i \).
The sets \( \Omega^0 \), \( \Omega^1 \) and \( \Omega^2 \), represent cost realizations where licensing, developer production, and second-source production are chosen, respectively. Note that it is never strongly optimal to randomize between alternatives. The payments which implement the choices in \( P_2 \) are determined using standard techniques. In all but the worst states, the above payment scheme pays positive rents to the firm chosen to produce, while the other firm receives nothing.

3.3. The value of technology transfers

The commitment to use technology transfers under some cost realizations reduces ex ante information rents by relaxing firm 2's incentive compatibility constraints. Firm 2 can 'less easily' say that it has high costs, because the buyer can always transfer firm 1's technology for it to produce.

To understand the intuition behind the optimal auction, consider the following polar case: \( \ell(c_1, c_2) = c_1 \). That is, firm 1's technology is completely and costlessly transferred under licensing to firm 2. For symmetry in this case, also assume technology can be transferred from firm 2 to firm 1, completely and costlessly. Now a buyer may offer the following contract to extract fully the rent: if \( c_1 \leq c_2 \), transfer firm 1's technology to firm 2 and have firm 2 produce the project using firm 1's technology for payment \( c_1 \); if \( c_1 > c_2 \), vice versa. Under this scheme, neither firm has an incentive to lie and the buyer completely extracts the information rents. Moreover, this scheme does not require firms to know each other's cost at the time of bidding.

Returning to our one-way technology transfer environment, transfers of technology under the optimal contract are ex ante optimal whenever \((c_1, c_2) \in \Omega^0\). An interesting question regards the determination of this region. Essentially the buyer trades off the costs of inefficient licensing against the gain in reduced information rents. This is easily seen in the following proposition.

Proposition 2. The ex ante expected gain to the buyer from a policy of optimal licensing is given by

\[
\int_{\Omega^0} \left( \frac{F_1(c_1)}{f_1(c_1)} - \ell(c_2) \right) dF_1(c_1) dF_2(c_2) + \int_{\Omega^0} (1 - \ell(c_2)) \frac{F_2(c_2)}{f_2(c_2)} dF_1(c_1) dF_2(c_2) - \int_{\Omega^0} \ell(c_1, c_2) - c_1 dF_1(c_1) dF_2(c_2) - \int_{\Omega^0} \ell(c_1, c_2) - c_2 dF_1(c_1) dF_2(c_2),
\]

where \( \Omega^0 \) is the licensing region where alternative \( i \) would have been chosen if licensing were not available, i.e. \( \Omega^0_i = \{ (c_1, c_2) | J_0(c_1, c_2) < J_i(c_1, c_2) \leq J_{-i}(c_1, c_2) \} \), \( i = 1, 2 \).
Proposition 2 identifies two effects. The first two terms represent the gain to the buyer from information rent reductions. The last two terms represent the cost inefficiencies to the buyer from deciding on an inefficient production technique. The optimal contract can be reformulated as one in which $\Omega^0$ maximizes the sum of the terms. If no $\Omega^0$ exists such that the sum is positive, the optimal contract does not entail licensing for any realization of costs. This suggests a corollary.

Corollary 2. If $\ell(c_1, c_2) = \lambda c_1 + (1 - \lambda) c_2 + \gamma$, $\lambda \in (0, 1)$, and the sellers' cost distributions are symmetric on $[\xi, \bar{c}]$, then an optimal auction will transfer technology with positive probability if

$$\lambda > \gamma f(\bar{c}).$$

If costs are distributed uniformly on $[\xi, \bar{c}]$, then the optimal contract will utilize transfers if $\lambda(\bar{c} - \xi) > \gamma$.

This result is in contrast to the result in Riordan and Sappington (1989) who find in their model without limited-liability constraints and without commitment that second-sourcing is rarely optimal. Because Riordan and Sappington do not assume limited liability, the firms compete away expected information rents at the initial symmetric information stage, so there is no information-rent problem. The gains from technology transfer in their model do not derive from reductions in information rents, but from production enhancement: the government introduces less distortion in its decision of whether to produce at all if a second source exists as an alternative. This latter effect is absent in the present model because we have assumed, for tractability, that the government always procures the object – otherwise, we would find an additional positive term in Proposition 2, providing another gain from technology transfers.

3.4. An example

Consider the following linear cost model with uniform distributions on $[0, 1]$. That is, let $F_i(c_i) = c_i$, $i = 1, 2$, and let $\ell(c_1, c_2) = \lambda c_1 + (1 - \lambda) c_2 + \gamma$. Thus the virtual costs are given by $J_0(c_1, c_2) = \lambda c_1 + 2(1 - \lambda) c_2 + \gamma$ and $J_i(c_1, c_2) = 2c_i$, $i = 1, 2$. For the initial case, we make the further simplifying assumptions that $\lambda = \frac{1}{2}$ and $\gamma = 0$. The optimal partition over $[0, 1]$ is graphed in fig. 1(a) as the projection of the minimum virtual cost onto the cost space.

The diagram indicates that when cost reports are relatively close, licensing is chosen. Intuitively, if the cost reports are relatively close, the licensing cost does not differ significantly from either the developer or second-source
production, so there is little cost inefficiency from licensing. If firm 2 has a relatively low cost, it is expensive for the buyer to make the second source use the inefficient licensed technology rather than its own. Similarly, if firm 1 has a relatively low cost, it is productively inefficient to license technology to firm 2, since firm 1 is a superior producer. As costs become close, the losses in production inefficiencies shrink to zero and are offset by the gains from reduced information rents.

We would expect the introduction of a fixed cost for transfer to increase the productive inefficiencies associated with licensing, and consequently to shrink the state space associated with licensing. To see the effect of a transfer cost, consider fixed licensing costs of \( y = \frac{d}{3} \) as in Fig. 1(b). The licensing region has decreased substantially. As Corollary 2 predicts, if \( \ell(c_1, c_2) = \lambda c_1 + (1 - \lambda)c_2 + \lambda \) and costs are symmetrically and uniformly distributed on \([0, 1]\), then there is no gain to licensing when \( y \geq \lambda \). As \( y \) increases to \( \lambda = \frac{1}{3} \), the optimal licensing area shrinks to zero. More generally, Proposition 2 indicates that an increase in \( \ell(c_1, c_2) \) (holding \( \ell_2, \epsilon_1 \), and \( c_2 \) fixed) will reduce the probability of licensing and, if the increase is sufficiently large, will eliminate its use altogether. Mathematically, the costs of licensing (the latter terms in Proposition 2) increase while the benefits (the former terms) remain unchanged.

4. Moral hazard

We naturally expect that in some situations where the initial agent (the

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**Fig. 1.** Optimal auctions: \( \Omega_0 = \text{license}, \Omega_1 = \text{developer production}, \Omega_2 = \text{second-source production}. \)

(a) \( \lambda = \frac{1}{3}, \gamma = 0 \); (b) \( \lambda = \frac{1}{3}, \gamma = \frac{1}{3} \).
developer) must make unobservable investments in reducing the marginal cost, \( c_1 \), of the final product, a policy of expropriating information via technology transfer would induce significant moral hazard. If the buyer can freely transfer the design to a second source to produce, the primary agent may have less incentive to reduce the marginal cost of production.

4.1. The problem of moral hazard

This section extends the previous analysis by incorporating moral hazard on the part of the primary agent. We model this extension by assuming that the primary agent (the developer) may make cost-reducing investments. The question we ask is: Will the buyer find it optimal to favor the developer for cost-reducing investments in the award of the production contract, and if so, how?

As before, the approach we take is one of full commitment by the buyer and limited-liability constraints for the sellers. Initially, the buyer proposes a contract to the two sellers which is accepted if it guarantees each non-negative profit. Following the offer, the developer chooses cost-reducing investment, \( e \). This investment stochastically shifts (in a first-order sense) the distribution of the developer's production costs, \( c_1 \), and thereby improves the licensed cost of production as well. After investments have been made, costs of production are drawn by each firm from known distributions, with each firm's actual cost being observed only by that individual firm. The sellers then report their costs to the government. The government follows the agreed-upon contract and awards the production decision and payments conditional on the cost announcements.

The resulting optimal contract is found to be a variation of the classical optimal auction design which awards production to the most favorable virtual type. Under moral hazard, we find that the developer's virtual type has an additional term which decreases in production cost in a manner closely akin to the sharing rule in Holmström (1979). This suggests that in the stochastic cost-investment model, we would expect a discriminating auction to be utilized which may additionally favor the developer depending upon the resulting cost realizations.

4.2. The model with moral hazard

The cost to firm 2 of producing with firm 1's technology is as before. The cumulative distribution function for the developer's cost is now given by \( F_1(c_1 | e) \), and it is assumed that effort leads to a first-order stochastic improvement in the distribution on costs. For tractability, we will assume \( F_1(c_1 | e) \) satisfies the Concave Distribution Function Condition (CDFC),
\( \frac{\partial^2 F_1(c_1 | e)}{\partial e^2} \leq 0 \), which ensures us that the first-order approach to the principal–agent problem is valid.\(^6\)

The cost to the developer for value-enhancing effort is given by \( \psi(e) \), where \( \psi(e) \) is increasing, strictly convex, \( \psi''(e) > 0 \), \( \psi(0) = \psi'(0) = \psi''(0) = 0 \), and \( \psi(1) = \infty \).

For simplicity in analyzing the moral hazard case we assume that the government chooses from one of two possible production alternatives: (i) licensed production; or (ii) developer production; we ignore production by the second source using its own technology. Along with the production decision, the government determines payments to each firm based upon their cost reports. Again the crucial constraint is that the government must guarantee non-negative profits for both producers for all possible realizations of cost.

4.3. The optimal contract under moral hazard

The class of mechanisms considered is given by \( \mathcal{M}' = \{ \{ \phi_i(c_1, c_2) \}_{i=0}^{1}, \{ t_i(c_1, c_2) \}_{i=0}^{1} \} \), analogous to before. The production alternatives, \( i=0,1 \), correspond to licensed production and developer production, respectively.

The choice of investment. Consider first the investment decision. Given the assumptions regarding the distribution of costs, the developer’s choice of effort solves

\[
\max_{e \in [0,1]} \int \int \pi_1(c_1, c_2) dF(c_2) dF_1(c_1 | e) - \psi(e).
\]

We can more simply characterize the solution to this program in the following lemma.

Lemma 1. A necessary and sufficient condition for the agent’s optimal effort decision is

\[
\int \int \left\{ \phi_1(c_1, c_2) \frac{\partial F_1(c_1 | e)}{\partial e} \right\} dF_1(c_1 | e) dF_2(c_2) = \psi'(e).
\]

\(^6\)In addition to CDFC, a monotone likelihood ratio condition is usually required in pure moral hazard settings in order to ensure that the agent’s payoffs are monotonic in outcome. See Grossman and Hart (1983) and Rogerson (1985) for proofs of this proposition. (We use concavity in distributions rather than convexity as in Grossman and Hart, because higher costs are considered undesirable in our model.) With adverse selection, incentive compatibility requires that \( \pi(c_1) \) be non-increasing, and so we do not need an additional MLRP condition for sufficiency in the first-order approach. We may, however, have to solve the buyer’s program subject to monotonicity of \( \pi \) in costs.
General solution to the contracting problem. Having characterized the effort chosen by the developer for a given contract we compute the buyer's optimal contract in the presence of moral hazard. To do so we simply append to the buyer's problem the additional condition from Lemma 1 to endogenize the investment decision. Call this program P3, and let \( \mu \) represent the Lagrange multiplier associated with the investment constraint. Proposition 3 below provides the equivalence of P3 with a simple point-wise minimization problem.

Proposition 3. Assume that \( \frac{F_1(e|c_1)}{f_1(c_1|e)} \) is non-decreasing in \( c_1 \), \( \frac{F_1(e|c_1)}{f_1(c_1|e)} \) is non-increasing in \( e \), and

\[
\frac{\partial}{\partial e} \left( \frac{F_1(c_1|0)}{f_1(c_1|0)} \right) = 0.
\]

The set of \( \{ \phi_i(c_1, c_2) \}_{i=0}^1 \) which solves P3 is the same as that which solves

\[
\min_{\phi_i} \left\{ \phi_1 \left[ c_1 + \frac{F_1(c_1|\hat{e})}{f_1(c_1|\hat{e})} + \mu \frac{F_{1,e}(c_1|\hat{e})}{f_1(c_1|\hat{e})} \right] + \phi_0 \left[ \epsilon(c_1, c_2) + \epsilon_2 \frac{F_2(c_2)}{f_2(c_2)} \right] \}
\]

using point-wise maximization, where \( \hat{e} \) is the buyer's expectation of firm 1's effort (which is correct in equilibrium) and \( \mu > 0 \). The level of effort, \( \hat{e} \), induced by the buyer satisfies (10), and a set of optimal transfers are given by

\[
t_1(c_1, c_2) = \int_{c_1}^1 \phi_1(c_1, c_2) dF_2(c_2) + \phi_1(c_1, c_2)c_1 + \psi(\hat{e}),
\]

\[
t_2(c_1, c_2) = \int_{c_2}^1 \phi_0(c_1, c_2)\epsilon_2 dF_1(c_1|\hat{e}) + \phi_0(c_1, c_2)\epsilon(c_1, c_2).
\]

The assumptions for Proposition 3 regarding the monotonicity of \( \frac{F_1(e|c_1)}{f_1} \) in \( c_1 \) and \( \frac{F_1}{f_1} \) in \( e \) are satisfied if \( e \) has more effect on reducing higher cost levels and the developer cannot increase information rents (i.e. the inverse hazard rate) by increasing investment.

The solution to the principal's problem has the same nature as the optimal auction without moral hazard, except that the state-space partition over firm production has been changed in an important way – it now depends more importantly upon the realization of the developer's cost. Consider the developer's virtual cost to the buyer:

\[
\tilde{J}_1(c_1, c_2) = c_1 + \frac{F_1(c_1|e)}{f_1(c_1|e)} + \mu \frac{F_{1,e}(c_1|e)}{f_1(c_1|e)}.
\]

There is an additional term in the virtual cost that was not present before
which is very similar to the optimal sharing rule in Holmström (1979). This new term represents an additional reward for cost reduction that the developer receives through departures from bidding parity in the auction for production. This additional term serves to increase the sensitivity of the developer's virtual cost by increasing the marginal effect of a reduction in \( c_1 \) and thereby increasing \( \phi_1(c_1) \). Of course, the buyer realizes the developer did not shirk under the optimal scheme, but nevertheless the buyer must commit to 'over'-punish the developer for high costs if she wishes to maximize surplus from an ex ante point of view.

The additional term in the virtual cost of the developer reflects the interdependence of the moral hazard and adverse selection problems in this model. Rewards for low costs are accomplished by appropriately tilting the incentive scheme. Unlike Holmström, in our case rewards are made by changing the probability of winning the auction rather than through lump-sum payments since \( c_1 \) is not contractible.

5. Conclusions

The immediate implications of our analysis suggest that a policy of technology transfer is a useful device for reducing information rents in defense procurement. Indeed, it may be optimal to switch to a possibly inefficient bidder, ex post, in order to reduce rents, ex ante. Additionally, no information of the developer needs to be known by the second source for such a transfer to yield benefits for the government.

Although the contributions of this paper are not restricted to defense procurement, transferring information is not always possible in other auction contexts. For example, in the traditional private-values auction the auctioneer cannot transfer the subjective valuation of a painting from one bidder to another. Nonetheless, in many contexts, such as defense procurement, the transfer of information is a real possibility because such information is embodied in tangible assets. As another example, following Laffont and Tirole (1988), consider managerial takeover in this framework. Suppose that the incumbent managerial team secures profit for its stockholders following a particular profit plan. Later, a raider appears who may be employed to take over the current management team and either institute its own profit strategies, or continue with its predecessors' plans (i.e. plans are transferable). In such a situation, takeovers may discipline incumbent management via threatened expropriation of managerial rents.\(^7\)

\(^7\)In the context of managerial incentives, Scharfstein (1988) examines the disciplinary role of a corporate raider who is informed of the firm's true value, and finds such an informed raider both induces incumbent managers to work harder and reduces their information rents. His model is
Related to our work is that of Riordan and Sappington (1989). They consider a model of effort-enhanced value, in their no-commitment, unlimited-liability environment. Because the buyer cannot commit, the developer can expect the buyer to behave opportunistically after investment is sunk. Under this framework, the inability to commit not to use a second source leads to inefficient investment in most plausible cases. If commitment were possible, the government could promise to purchase the product at a price equal to its valuation and let the potential sellers bid away the expected information rents ex ante in the competition for the development contract at the symmetric information stage. In this paper, the limited-liability constraint implies any gain from information rent reduction is a direct gain to the buyer. The tradeoffs involved are very different.

Laffont and Tirole (1988) also consider a dynamic adverse selection–moral hazard framework. They find that if investment is completely transferable from the developer to the second source, the buyer would do best to commit to favor the developer at the competition for determining the producer. The results are similar in that bidding parity is disposed of to provide incentives for value-enhancing, transferable investment.

Appendix

Proof of Proposition 1. The proof of Proposition 1 proceeds with three lemmas. Lemma A.1 establishes necessary and sufficient conditions for truth-telling (5) and interim individual rationality (IIR), a weaker constraint than (6); the IIR constraint is given by

\[ \pi_{j}(c_{j} | c_{j}) \geq 0, \quad \forall c_{j}, j = 1, 2. \]

Lemma A.2 establishes that the modified program of minimizing (4) over these new conditions is equivalent to solving P2 point-wise. Finally, Lemma A.3 shows that a particular solution to the modified program is 'equivalent' to the solution of P1.

For notational convenience, we will sometimes denote a function that has had expectations taken over one argument, as a function of only the single remaining argument. For example, \( \phi_{1}(c_{1}) = \int_{0}^{1} \phi_{1}(c_{1}, c_{2}) dF_{2}(c_{2}) \), etc.

Lemma A.1. Incentive compatibility (IC) and interim individual rationality (IIR) hold if and only if

\[ \text{closely analogous to this paper in that the firm value (known by the incumbent managers) transfers completely to the raider if there is a takeover. This paper suggest that while a raider is more effective in reducing information rents if she knows the incumbent's information, there is nonetheless a positive role for uninformed raiders in reducing information rents. There is no requirement that the alternative agent have any ex ante knowledge of the primary agent's cost realization for information rents to be reduced.} \]
\[
\pi_1(c_1 \mid c_1) = \pi_1(1 \mid 1) + \int_{c_1}^{1} \phi_1(c_1) \, dc_1, \quad (11)
\]

\[
\pi_2(c_2 \mid c_2) = \pi_2(1 \mid 1) + \int_{c_2}^{1} \left[ \phi_2(c_2) + \phi_0(c_2) \ell_2 \right] \, dc_2, \quad (12)
\]

\[
\phi_1(c_1) \geq \phi_1(c_1'), \quad \forall c_1' > c_1, \quad (13)
\]

\[
\phi_2(c_2) + \phi_0(c_2) \ell_2 \geq \phi_2(c_2') + \phi_0(c_2') \ell_2, \quad \forall c_2' > c_2, \quad (14)
\]

\[
\pi_i(1 \mid 1) \geq 0, \quad i = 1, 2. \quad (15)
\]

**Proof.** *Necessity.* Consider firm 1. IC and the definition of \(\pi_1(\hat{c}_1 \mid c_1)\) imply

\[
\pi_1(c_1 \mid c_1) \geq \pi_1(\hat{c}_1 \mid c_1) = \pi_1(\hat{c}_1 \mid \hat{c}_1) - \phi_1(\hat{c}_1)(c_1 - \hat{c}_1).
\]

Rearranging and reversing the roles of \(c_1\) and \(\hat{c}_1\) yields

\[-\phi_1(c_1)(c_1 - \hat{c}_1) \geq \pi_1(c_1 \mid c_1) - \pi_1(c_1 \mid \hat{c}_1) \geq -\phi_1(\hat{c}_1)(c_1 - \hat{c}_1),
\]

which implies (13). Without loss of generality, take \(c_1 > \hat{c}_1\), divide by \((c_1 - \hat{c}_1)\), and take the limit as \(c_1 \to \hat{c}_1\) to obtain

\[
\frac{d\pi_1(c_1 \mid c_1)}{dc_1} = -\phi_1(c_1).
\]

Since \(\pi_1(c_1)\) is monotonic, it is Riemann integrable, thus implying (11). Finally, IR clearly implies (15). A similar series of arguments establishes the necessity of (12), (14), and (15) for firm 2.

**Sufficiency.** Again consider firm 1. By definition of \(\pi_1(\hat{c}_1 \mid c_1)\), we have

\[
\pi_1(\hat{c}_1 \mid \hat{c}_1) = \pi_1(\hat{c}_1 \mid c_1) - \phi_1(\hat{c}_1)(\hat{c}_1 - c_1).
\]

Condition (11) implies

\[
\pi_1(c_1 \mid c_1) = \pi_1(\hat{c}_1 \mid c_1) + \int_{\hat{c}_1}^{c_1} \left[ \phi_1(\hat{c}_1) - \phi_1(s) \right] \, ds.
\]

But by condition (13), the integral is non-negative, giving us incentive compatibility for firm 1. A similar series of arguments establishes the incentive compatibility for firm 2 using (12), (14), and (15). Individual rationality follows immediately for both firms from conditions (11), (12) and (15). \(\square\)

**Lemma A.2.** The set of \(\{\phi_i(c_1, c_2)\}_i\) which solves the modified IIR program is
the same as that which solves P2 below using point-wise minimization over \( \{ \phi_i \}_{i=0}^2 \):

\[
\min_{\phi_i} \left\{ \phi_1 \left( c_1 + \frac{F_1(c_1)}{f_1(c_1)} \right) + \phi_2 \left( c_2 + \frac{F_2(c_2)}{f_2(c_2)} \right) + \phi_0 \left( \ell(c_1, c_2) + \ell_2 \frac{F_2(c_2)}{f_2(c_2)} \right) \right\}.
\]

**Proof.** The modified program is formally given by

\[
\min \int_0^1 \int_0^1 \{ \tau_1(c_1, c_2) + \tau_2(c_1, c_2) \} \, dF_1(c_1) \, dF_2(c_2)
\]

subject to IC and IIR. Substituting out \( \tau_i(c_1, c_2) \) in the objective function yields as the minimand

\[
\int_0^1 \int_0^1 \left\{ \pi_1(c_1, c_2) + \pi_2(c_1, c_2) + \phi_1(c_1, c_2)c_1 + \phi_2(c_1, c_2)c_2 + \phi_0(c_1, c_2) \ell(c_1, c_2) \right\} \, dF_1(c_1) \, dF_2(c_2).
\]

Integrating by parts and using Lemma A.1 we can simplify this expression to obtain the following objective function:

\[
\min \int_0^1 \int_0^1 \left\{ \phi_1(c_1, c_2) \left( c_1 + \frac{F_1(c_1)}{f_1(c_1)} \right) + \phi_2(c_1, c_2) \left( c_2 + \frac{F_2(c_2)}{f_2(c_2)} \right) + \phi_0(c_1, c_2) \ell(c_1, c_2) + \pi_1(1 \mid 1) + \pi_2(1 \mid 1) \right\} \, dF_1(c_1) \, dF_2(c_2).
\]

We want to minimize this subject to conditions (13)–(15). Rather than minimize subject to the monotonocity constraints, we will ignore them for now, and check our solution for their satisfaction.

Choosing the optimal \( \phi_i(c_1, c_2) \) while ignoring the monotonocity constraints for the above integrand amounts to point-wise minimization of the bracketed expression over \( \{ \phi_i \}_{i=1}^1 \).

To complete the lemma, we must show that the monotonocity conditions (13) and (14) hold. It is sufficient for monotonocity that \( \phi_1(c_1, c_2) \) is non-increasing in \( c_1 \), and that both \( \phi_2(c_1, c_2) \) and \( \phi_0(c_1, c_2) \) are non-increasing in \( c_2 \). Given \( \ell_1 < 1 \), and given our assumptions regarding the cost distributions, this is indeed the case. \( \square \)

Finally, we show a solution to the relaxed IIR problem satisfies limited liability.
Lemma A.3. The following payments implement the optimal \( \{ \phi_i(c_1, c_2) \}_i \) for the relaxed IIR program and satisfy the limited liability constraints:

\[
t_1(c_1, c_2) = \int_{c_1}^{c_2} \phi_1(s) \, ds + \phi_1(c_1, c_2)c_1,
\]

\[
t_2(c_1, c_2) = \int_{c_1}^{c_2} \{ \phi_2(s) + \phi_0(s)c_2 \} \, ds + \phi_2(c_1, c_2)c_2 + \phi_0(c_1, c_2)c_2\phi'(c_1, c_2).
\]

Proof. Substituting the above payments into (11) and (12) in the text demonstrates that the payments maintain incentive compatibility by Lemma A.1. Also, the payments clearly meet the limited liability constraint, as the integrals in the above expressions are never negative for any cost realization. Finally, there do not exist any other payments with lower expected value to the buyer. This last point is evident from Lemma A.2. \( \Box \)

The transfers are determined directly from Lemma A.3.

Proof of Proposition 2. The result follows from noting that the gain from licensing is the expected reduction in virtual cost from licensing over a standard optimal auction without technology transfer. Since chosen virtual costs are only changed over \( \Omega^0 \), we take expectations over this space. The expression immediately follows. \( \Box \)

Proof of Lemma 1. The first-order condition for the solution is

\[
1 \int_0^1 \int_0^1 \pi_1(c_1, c_2) f_1,c_1(c_1 \mid e) \, dc_1 \, dF_2(c_2) - \psi'(e) = 0.
\]

A sufficient condition for a maximum is that

\[
1 \int_0^1 \int_0^1 \pi_1(c_1, c_2) f_1,c_1(c_1 \mid e) \, dc_1 \, dF_2(c_2) - \psi''(e) < 0,
\]

for all \( e \). Integrating this expression by parts, and noting that Lemma A.1 from above implies \( \partial \pi_1(c_1, c_2)/\partial c_1 = -\phi_1(c_1, c_2) \), yields an equivalent condition:

\[
1 \int_0^1 \pi_1(c_1, c_2) F_1,c_1(c_1 \mid e) \, dc_1 \, dF_2 + 1 \int_0^1 \phi_1(c_1, c_2) F_1,c_1(c_1 \mid e) \, dc_1 \, dF_2 - \psi''(e) < 0,
\]

where \( e \) subscripts denote partial derivatives with respect to \( e \). CDFC and the strict convexity of \( \psi(e) \) assures us that the second-order condition for a
maximum holds, thus (16) is both necessary and sufficient. Integrating by parts yields
\[ \int_0^1 \int_0^1 \frac{\partial \pi_1(c_1, c_2)}{\partial c_1} F_1(e|c_1|e) \, dF_1(c_1|e) \, dF_2(c_2) - \psi'(e) = 0. \]

Substituting from Lemma A.1 gives us the desired result. □

**Proof of Proposition 3.** The normal hazard problem amounts to minimizing the expected cost of the buyer’s expected payments, subject to the investment constraint given in (10). We can now summarize the new program as P3.

\[
\min \int_0^1 \int_0^1 \left\{ \sum_{i=0}^1 \phi_i(c_1, c_2) \tilde{J}_i(c_1, c_2) - \psi(e) \right\} \, dF_1(c_1|e) \, dF_2(c_2),
\]

subject monotonicity in \( \phi_1(c_1) \) and \( \phi_0(c_2) \) and to (10), where the \( \tilde{J}_i(c_1, c_2) \) are the virtual types for the moral hazard problem as defined in the text. As before, we ignore the monotonicity constraints and check that our solution satisfies them.

Given our assumption that \( \psi(1) = \infty \), we know by (10) that \( e < 1 \). Let \( \mu \) be the Lagrange multiplier associated with the constraint in (10) and suppose for the moment that \( \mu > 0 \). Minimizing the Lagrangian taking the optimal choice of \( \phi_i(c_1, c_2) \) as given, effort is chosen such that either

\[
\mu \left\{ \int_0^1 \int_0^1 \left( \frac{F_1(c_1|e|\hat{e})}{f_1(c_1|\hat{e})} \right) f_1(c_1|\hat{e}) \, dc_1 \, dF_2(c_2) \right\} + \int_0^1 \int_0^1 \frac{\partial}{\partial e} \left( \frac{F_1(c_1|e|\hat{e})}{f_1(c_1|\hat{e})} \right) f_1(c_1|\hat{e}) \, dc_1 \, dF_2(c_2)
\]

\[
= \psi(\hat{e}) - \int_0^1 \int_0^1 \sum_{i=0}^1 \phi_i(c_1, c_2) \tilde{J}_i(c_1, c_2) f_1(c_1|\hat{e}) \, dc_1 \, dF_2(c_2),
\]

where \( \tilde{J}_1(c_1, c_2) = c_1 + (F_1(c_1|e)/f_1(c_1|e)) + \mu (F_1.e(c_1|e)/f_1(c_1|e)) \) and \( \tilde{J}_0(c_1, c_2) = \ell(c_1, c_2) + \ell(F_2(c_2)/f_2(c_2)), \) or \( e = 0 \). By our assumptions on \( F \) and \( \psi \), the marginal benefit from \( e \) is positive at \( e = 0 \), and so we know \( e \in (0, 1) \) and (18) holds.

Now, given that \( e \) is optimally set at \( \hat{e} \) and given the value of \( \mu > 0 \), we may solve for the optimal \( \phi_i(c_1, c_2) \). Bringing the investment constraint within the objective function yields
\[
\int_0^1 \left\{ \sum_{i=0}^1 \phi_i(c_1,c_2) \hat{J}_i(c_1,c_2) \right\} dF_1(c_1 \mid \hat{e}) dF_2(c_2) - \mu \psi'(\hat{e}) - \psi(\hat{e}).
\]

But the solution to the minimum of this expression is identical as the pointwise minimum of

\[
\min_{\phi_i} \left\{ \phi_1 \left[ c_1 + \frac{F_1(c_1 \mid \hat{e})}{f_1(c_1 \mid \hat{e})} + \mu \frac{F_1,c(c_1 \mid \hat{e})}{f_1(c_1 \mid \hat{e})} \right] + \phi_0 \left[ \ell(c_1,c_2) + \ell_2 \frac{F_2(c_2)}{f_2(c_2)} \right] \right\}.
\]

The problem is therefore as in the proposition. Provided that \( \mu > 0 \), the virtual costs are appropriately monotone in costs so as to satisfy the additional monotonicity constraints. Finally, \( \mu > 0 \) holds since the developer will ignore the positive externality that effort has on reducing licensed costs. Thus, the purchaser will always prefer more effort than the developer is willing to provide, and the constraint must bind with a positive multiplier.

References