Technological Change and the Boundaries of the Firm

by

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In this paper, we analyze a firm's choice between buying an input from a subcontractor and making the input itself. A fundamental tradeoff is present. The subcontractor is known to have lower innate production costs than the firm. However, the firm is better able to monitor and therefore to control its own production activities.

We characterize the firm's profit-maximizing behavior when faced with this tradeoff. We also analyze how the firm's choice between subcontracting and internal provision is influenced by technological change. Thus, for instance, we examine whether a typical producer is more or less likely to subcontract its printing needs when powerful, inexpensive desk-top publishing systems become available to both the professional printer and the amateur. Technological progress takes various forms in our model, including a symmetric reduction in innate production costs for the firm and the subcontractor, a symmetric increase in the efficacy of cost-reducing effort by the two parties, and a symmetric decrease in the costs of their effort. We find that under these forms of technological progress, the likelihood of internal provision by the firm increases. Another empirical prediction of our model is that technological change which results in the employment of more highly skilled labor will be correlated with increased internal provision.

The expanded incidence of internal provision follows from the interplay of two effects: a *relative efficiency effect* and a *control effect*. The former effect refers to the differential impact technological progress has on the firm and on the subcontractor. The differential impact arises because the firm and the subcontractor supply different levels of cost-reducing effort and have different total costs of production in equilibrium. The control effect refers to the influence of technological progress on the costs of controlling the subcontractor's activities. Technological progress can either increase or decrease control costs, depending upon the nature of the subcontractor's alternative profit opportunities.

Two settings are contrasted: one where the subcontractor's potential earnings in alternative endeavors are independent of his capabilities in the firm's employ, and another where these earnings increase with his capabilities in producing for the firm. In this latter case where the subcontractor's skills are transferable, we find that technological progress may actually reduce the welfare of the firm and the welfare of society as a whole. The welfare loss arises because technological progress can increase control costs by more than it reduces production costs, even when technological progress does not affect the subcontractor's opportunity profit. In the former case where the subcontractor's skills are idiosyncratic, the welfare of the firm increases with technological progress because control costs are reduced. In this case, though, observable production costs under subcontracting will often exceed those under internal provision, despite the innate cost advantage of the subcontractor.

Our analysis proceeds as follows. The model we employ, which is essentially the standard procurement model due to Laffont and Tirole (1986) is described in Section I. The firm's choice between subcontracting and internal provision is analyzed in Section II for the case where the subcontractor's skills are idiosyncratic. The corresponding analysis for the case of transferable skills is presented in Section III. Conclusions are drawn in Section IV, where we suggest extensions of our simple model. The proofs of all results are contained in the Appendix.

I. The Model.

The firm's problem is to provide for the delivery of a fixed quantity of an essential input. The value of this input is V. The firm can either supply the input itself or obtain the input from a subcontractor. The subcontractor has an innate cost advantage relative to the firm. If he were to produce the good without exerting any cost-reducing effort, the subcontractor could do so at cost $t^C c$. $c \in [\underline{c}, \bar{c}]$ is the realization of a random cost variable. $t^C > 0$ is one of three technological parameters that will be varied in the comparative static exercises below. Lower values of t^C correspond to settings where innate production costs, $t^C c$, are systematically lower, as when technological progress is realized. Reductions in t^C lower the innate production costs of both the subcontractor and the firm. These costs for the firm are $t^C[\bar{c} + \Delta]$, where $\Delta > 0$ represents the minimum possible innate cost advantage of the subcontractor. The cost advantage may be due, for example, to economies of scale or a longer tenure in supplying the good in question. (See Michael Porter (1980)).[1]

The subcontractor alone knows the realization of the cost parameter, c. The firm's beliefs about c are represented by the density function $f(c)$. This density is assumed to have strictly positive support on the interval $[\underline{c}, \bar{c}]$. The corresponding distribution function is denoted F(c). Following much of the incentive literature, we assume $\frac{F(c)}{f(c)}$ is a nondecreasing function of c, and $\frac{1-F(c)}{f(c)}$ is a nonincreasing function of c.

Both the firm and the subcontractor can reduce final production costs through the expenditure of personally costly effort, e. Each unit of effort reduces observable final production costs, C^O, by t^E units. Thus, for the subcontractor, $C^O = t^C c - t^E e$. Increases in t^E reflect technological progress that increases the impact of each unit of cost-reducing effort. The firm and the subcontractor both incur cost or disutility $t^D D(e)$ in supplying e units of effort. Reductions in t^D reflect a third type of technological progress in which the cost to the firm and the subcontractor of supplying a unit of cost-reducing effort is diminished. The marginal cost of delivering effort is assumed to increase at a nondecreasing rate, i.e., $D'(e) > 0$, $D''(e) > 0$, and $D'''(e) \geq 0$. It will be useful to define direct costs $C(c, e, t)$ as the sum of observable production costs and the disutility of cost-reducing effort. t denotes the vector (t^C, t^E, t^D).

The firm is presumed better able to monitor the supply of effort under internal provision than under subcontracting. This assumption is most natural when the firm is a single entrepreneur. A sole entrepreneur may know precisely how much effort she supplies even though she cannot monitor perfectly the effort of a subcontractor. More generally, a firm may be better able to monitor effort supply under internal provision than under subcontracting if, for example, internal provision entails production at the firm's own facilities, while subcontracted production occurs elsewhere. Physical proximity can enhance monitoring capabilities. Furthermore, if internal provision involves the transfer of existing personnel within the firm, familiarity with the abilities and working habits of one's own employees can facilitate the firm's monitoring abilities under internal provision.[2]

For simplicity, we assume the effort supply is observed perfectly by the firm under internal provision, whereas the effort supply is unobservable to the firm under subcontracting. Therefore, although the subcontractor's final production costs, C^O, are observable to the firm, the firm cannot discern the portion of final costs due to cost-reducing effort, e, and the portion due to innate cost, c.[3] Thus, while subcontracting entails an innate cost advantage it also involves a strong informational disadvantage.[4]

A formal representation of the firm's "make-or-buy" decision requires some additional notation. Let $P(\hat{c})$ represent the payment the subcontractor receives from the firm when his observed costs are $C^O(\hat{c})$. These payments and observed costs are indexed by the subcontractor's report, $\hat{c} \in [\underline{c},\overline{c}]$, of his innate cost parameter. Presuming the firm pays directly for the observed final production costs, $C^O(\cdot)$, the subcontractor's profit when he is called upon to produce after reporting his innate cost to be $\hat{c}$ although it is truly c is

$$(1) \qquad \pi(\hat{c}|c) = P(\hat{c}) - t^D D(\frac{1}{t^E}[t^C c - C^O(\hat{c})]).$$

The argument of $D(\cdot)$ in (1) is the level of effort required to realize total cost $C^O(\hat{c})$ when the subcontractor's innate cost parameter is c.

To induce the subcontractor to produce for the firm, he must be guaranteed at least his reservation profit level, $\overline{\pi}(c)$. $\overline{\pi}(c)$ is the most profit the subcontractor with innate cost parameter c could expect to earn if he employed his resources elsewhere. Two cases will be considered: the case of "transferable skills", where $\overline{\pi}'(c) < 0 \ \forall \ c \in [\underline{c},\overline{c}]$ (see Figure 1); and the case of "idiosyncratic skills", where $\overline{\pi}'(c) = 0 \ \forall \ c \in [\underline{c},\overline{c}]$. When the subcontractor's skills are transferable, his potential expected earnings in other sectors increase with his innate ability in the firm's employ.[5] When the subcontractor's skills are idiosyncratic, his expected earnings in other sectors are independent of his ability in working for the firm, perhaps because the task in question is unique. In this case of idiosyncratic skills (the case usually explored in the agency literature)[6], we will normalize $\overline{\pi}(c)$ to zero, the presumed reservation profit level of the firm.

We now summarize the timing in the model. First, the subcontractor learns the realization of c. Second, the firm commits to a menu of payment and observed cost pairs $\{P(\cdot), C^o(\cdot)\}$ that will govern eventual compensation if subcontracting takes place. These pairs are indexed by the subcontractor's public report of c. The firm also specifies the set, S, of reported innate cost realizations for which subcontracting will occur. Similarly, the firm specifies the complementary set of reports, S^-, for which internal provision will take place. Third, the subcontractor makes a report, $\hat{c} \in [\underline{c}, \overline{c}]$, of his innate cost realization. If internal provision is then undertaken, the efficient level of effort, $e^* \equiv \underset{e}{\operatorname{argmax}}\{t^E e - t^D D(e)\}$, is directed, and production takes place. The subcontractor receives no payment in this case, and he is free to pursue alternative endeavors. If subcontracting occurs, the subcontractor undertakes the level of effort required to realize cost $C^o(\hat{c})$. He then carries out production, and receives payment $P(\hat{c})$ upon delivery of the input.[7]

Formally, the firm's problem [FP] is the following:

$$\underset{P(\cdot),e(\cdot),S,S^-}{\text{Maximize}} \quad \int_S \{V - P(c) - [t^C c - t^E e(c)]\} f(c)\, dc$$
$$+ \int_{S^-} \{V - [t^C[\overline{c} + \Delta] - t^E e^* + t^D D(e^*)]\} f(c)\, dc$$

subject to:

(2) $$\pi(c|c) \geqq \overline{\pi}(c) \qquad \forall \quad c \in S;$$

(3) $$\pi(c|c) \geqq \pi(\hat{c}|c) \qquad \forall \quad c,\ \hat{c} \in S; \text{ and}$$

(4) $$\overline{\pi}(c) \geqq \pi(\hat{c}|c) \qquad \forall \quad c \in S^- \text{ and } \hat{c} \in S;$$

where e(c) is the equilibrium effort level supplied by the subcontractor with innate cost realization $c \epsilon S$.

The individual rationality constraints (2) ensure the subcontractor receives at least his reservation profit level whenever he is called upon to produce. The incentive compatibility constraints, (3) and (4), ensure the subcontractor will truthfully report his innate cost realization, $c \epsilon S$, and $c \epsilon S^-$, respectively.[8]

II. Idiosyncratic Skills.

In this section, we analyze the solution to [FP] for the case where the subcontractor's skills are idiosyncratic, i.e., where $\bar{\pi}(c) = 0 \ \forall \ c \ \epsilon \ [\underline{c},\bar{c}]$. Our main finding, that each of the various forms of technological progress in isolation leads the firm to undertake internal provision more often, is recorded in Proposition 1. The following lemmas are helpful in understanding Proposition 1.

Lemma 1. Suppose $\bar{\pi}(c) = 0 \quad \forall \ c \ \epsilon \ [\underline{c},\bar{c}]$. Then at the solution to [FP]:

$S = \{c|c \ \epsilon \ [\underline{c},c^I]\}$ and $S^- = \{c|c \ \epsilon \ (c^I,\bar{c}]\}$, where $c^I \ \epsilon \ [\underline{c},\bar{c}]$.

Lemma 1 simply states that in equilibrium the firm will subcontract production when c is small ($c \leq c^I$) and undertake internal provision when c is large ($c > c^I$) . (See Figure 2.) The solution to [FP] is said to be an interior solution if both subcontracting and internal provision can occur in equilibrium (i.e., if $c^I \ \epsilon \ (\underline{c},\bar{c})$). This will be the case if the subcontractor's cost advantage over the firm is not too pronounced (i.e., if Δ is sufficiently small).

At the margin (i.e., at c^I), the firm equates the total costs of internal provision with the total costs of subcontracting (as reflected in equation (6) of Lemma 2 below). Total costs are the sum of direct costs and control costs. For the firm, there are no control costs, so total costs are $C^T(\bar{c} + \Delta, e*, t) =$

$t^C[\overline{c} + \Delta] - t^E e^* + t^D D(e^*)$. For the subcontractor, direct costs are $t^C c - t^E e + t^D D(e)$, and control costs are $\frac{t^C t^D}{t^E} D'(e(c)) \frac{F(c)}{f(c)}$.[9]

Lemma 2. Suppose $\overline{\pi}(c) = 0 \;\; \forall\, c \in [\underline{c},\overline{c}]$. Then at an interior solution to [FP]:

(5) $t^E - t^D D'(e(c)) - \frac{t^C t^D}{t^E} D''(e(c)) \frac{F(c)}{f(c)} = 0$, so $e(c) < e^*(c) \quad \forall\, c \in (\underline{c}, c^I]$;

(6) $t^C c^I - t^E e(c^I) + t^D D(e(c^I)) + \frac{t^C t^D}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)} = C^T(\overline{c} + \Delta, e^*, t)$; and

(7) $t^D D(e^*) > t^D D(e(c^I)) + \frac{t^C t^D}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)}$.

Equation (5) reflects the standard conclusion that induced effort under subcontracting is inefficiently small in order to limit the subcontractor's rents.[10] Equation (7) reveals that the effort supplied by the marginal subcontractor is sufficiently small that the sum of his effort costs and control costs is less than the effort costs of the firm under internal provision. This fact, together with equation (6) implies that the observable costs of the subcontractor may exceed those of the firm, i.e.,

(8) $t^C c^I - t^E e(c^I) > t^C[\overline{c} + \Delta] - t^E e^*$.

These observations facilitate the analysis of the effects of technological change on the firm's make-or-buy decision. Lemma 3 describes a benchmark change in which all technological parameters are varied in identical fashion, as when inflation increases all costs symmetrically.[11] Such change simply rescales the firm's problem, and therefore has no effect on the incidence of subcontracting.

Lemma 3. Let $\lambda t \equiv (\lambda t^C, \lambda t^E, \lambda t^D)$ where $\lambda > 0$ is a constant. Then at an interior solution to [FP], $\frac{dc^I}{d\lambda} = 0$.

When each of the components of technological change is considered in isolation, a different pattern emerges.

Proposition 1. Suppose $\overline{\pi}(c) = 0 \ \ \forall\ c \in [\underline{c}, \overline{c}]$ and $D'''(e)$ is sufficiently small for all $e \geqq 0$. Then at an interior solution to [FP], technological progress in any of its three forms (i.e., a reduction in either t^C or t^D or an increase in t^E):

(i) leads the firm to undertake internal provision more often (i.e., $-\frac{dc^I}{dt^C} < 0$, $-\frac{dc^I}{dt^D} < 0$ and $\frac{dc^I}{dt^E} < 0$); and

(ii) increases the expected welfare of the firm (i.e., $-\frac{dW^I}{dt^C} > 0$, $-\frac{dW^I}{dt^D} > 0$, and $\frac{dW^I}{dt^E} > 0$, where W^I is the value of the objective function at the solution to [FP] in the case of idiosyncratic skills).

Our comparative static exercises hold constant the distribution of c. Therefore, because c^I declines with technological progress, the probability that the firm undertakes internal provision $(1 - F(c^I))$ increases, and the probability of subcontracting $(F(c^I))$ decreases with technological progress. This is the precise meaning of such phrases as "internal provision occurs more often". The expanded incidence of internal provision arises because the relative efficiency effect of each form of technological progress outweighs the associated control effect in this environment.

To illustrate, consider technological progress that reduces innate production costs. A reduction in t^C reduces control costs under subcontracting at the rate $\frac{t^D}{t^E} D'(e(c)) \frac{F(c)}{f(c)}$. Intuitively, the critical information asymmetry under subcontracting becomes less pronounced as t^C declines because a given differential in innate costs, δ, translates into a smaller effective innate cost differential, $t^C\delta$. Thus, the control effect favors more subcontracting. The relative efficiency effect, on the other hand, favors more internal provision because a reduction in t^C reduces the innate costs of the firm $t^C[\bar{c} + \Delta]$ more than it reduces the innate costs of the marginal subcontractor $(t^c c^I)$.[12]

On balance, the relative efficiency effect dominates. Notice from equation (6) that

$$(9) \quad t^C[(\bar{c} + \Delta - c^I) - \frac{t^D}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)}]$$

$$= [t^E e^* - t^D D(e^*)] - [t^E e(c^I) - t^D D(e(c^I))] > 0 .$$

The left hand side of the inequality in (9) reflects the difference between the relative efficiency effect and the control effect of a reduction in t^C. This difference is positive because effort is chosen efficiently under internal provision while an inefficiently small level of effort is induced under subcontracting.

Corresponding arguments explain the other conclusions in part (i) of Proposition 1. For example, reductions in the cost of effort reduce control costs under subcontracting at the rate $\frac{t^C}{t^E} D'(e(c)) \frac{F(c)}{f(c)}$. Control costs decline with t^D because a given innate cost differential can be offset through the provision of effort at lower cost. Therefore, the critical information asymmetry under subcontracting is again less problematic, so subcontracting is favored. In contrast, the relative efficiency effect favors more internal provision. This is because the firm exerts more effort than does the marginal subcontractor, so a reduction in t^D reduces effort costs more for the firm than for the marginal subcontractor (i.e., $D(e^*) > D(e(c^I))$). On balance, the relative efficiency effect dominates because of the pronounced effort distortion under subcontracting. This fact is apparent from inequality (7), which can be rewritten as

$$(10) \quad D(e^*) - D(e(c^I)) > \frac{t^C}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)} .$$

Part (ii) of Proposition 1 reports that the firm's expected welfare increases with each of these types of technological progress. This conclusion holds because the technological progress reduces both production costs and control costs in the case of idiosyncratic skills.

Because each of the three types of technological progress in isolation leads to more internal provision, combinations of these forms of technological progress will have the same qualitative effect. Thus, for example, when technological advances both lower the innate costs of operation and increase the impact of labor input on final production costs, internal provision will occur more often. Predictions are also possible concerning technological change that provides reductions in one component of total cost at the expense of other components, as reported in Corollary 1.

Corollary 1. Under the conditions of Proposition 1, the firm will undertake internal provision more often if:

(i) both t^E and t^C increase proportionately (i.e.,

$$\frac{dc^I}{d\lambda} < 0 \quad \text{when } t = (\lambda t^C, \lambda t^E, t^D) \text{); or}$$

(ii) both t^E and t^D increase proportionately (i.e.,

$$\frac{dc^I}{d\lambda} < 0 \quad \text{when } t = (t^C, \lambda t^E, \lambda t^D) \text{).}$$

Corollary 1 suggests that technological change which results in the employment of more highly skilled labor may be correlated empirically with expanded internal provision. Property (i) of the Corollary considers technological change that increases innate costs and the effectiveness of a unit of effort in symmetric fashion. For example, new capital equipment may embody advanced computer technology that raises expected capital costs but accommodates more highly skilled labor. Such technological change leads to more internal provision, as the predominant effect is the increase in innate labor productivity.

Property (ii) of Corollary 1 considers technological change that increases the cost and the effectiveness of effort in symmetric fashion. To illustrate, the least-cost means of production may again come to involve more sophisticated capital equipment. In this case, though, suppose the expected cost of the capital itself is not changed, but the capital requires more highly skilled labor to operate effectively. Also suppose such labor is more costly to secure, but its productivity is higher. Technological change of this sort will lead to more internal provision, as the predominant effect again is the increase in labor productivity.[13,14]

III. Transferable Skills.

We now turn to the case of transferable skills, where the subcontractor's opportunity profit is higher the lower is his innate cost, i.e., where $\bar{\pi}'(c) < 0 \ \forall\ c$, as depicted in Figure 1. To focus on the case that is most distinct from the case of idiosyncratic skills, we presume that the subcontractor's opportunity profit rises sufficiently rapidly as c falls that the binding problem for the firm is always to limit the subcontractor's incentive to *understate* the realization of c. Such understatement by the subcontractor amounts to a claim that his alternative opportunities are more lucrative than they truly are, and therefore that he requires more generous compensation to work for the firm. With $|\overline{\pi}'(c)|$ sufficiently large, the firm's total costs of production (including opportunity cost) are larger the smaller is the realization of c. Consequently, the firm will employ the subcontractor only for the larger realizations of c (i.e., for $c > c^T$), as reported in Lemma 4 below. Lemma 4 also refers to the "second order conditions", which are the restrictions required to ensure that the firm's total costs of production vary inversely with c and that the firm's problem is concave and has an interior solution.[15]

Lemma 4. Suppose $\overline{\pi}'(c) < 0 \quad \forall \; c \in [\underline{c},\overline{c}]$ and the second order conditions are satisfied. Then at the solution to [FP],

$$S = \{c \mid c \in (c^T,\overline{c}]\} \text{ and } S^- = \{c \mid c \in [\underline{c},c^T]\}\text{ , where } c^T \in (\underline{c},\overline{c}).$$

As in the case of idiosyncratic skills, the marginal subcontractor here is identified by the equality of total production costs under subcontracting and under internal provision.[16] In contrast to the case of idiosyncratic skills, though, increases in induced effort here reduce control costs under subcontracting. Consequently, the subcontractor is induced to provide more than the efficient level of effort ($e(c) > e^*$).[17] On balance, the sum of effort costs and control costs for the marginal subcontractor is smaller than the effort costs of the firm, as reported in Lemma 5.

Lemma 5. Suppose the conditions of Lemma 4 hold. Then at the solution to [FP]:

$$(11) \quad t^E - t^D D'(e(c)) + \frac{t^C t^D}{t^E} D''(e(c)) \frac{1-F(c)}{f(c)} = 0 \text{ , so } e(c) > e^*(c) \quad \forall \; c \in [c^T, \overline{c});^{18}$$

$$(12) \quad t^D D(e^*) > t^D D(e(c^T)) - \frac{t^C t^D}{t^E} D'(e(c^T)) \frac{1 - F(c^T)}{f(c^T)} \text{ .}$$

These lemmas facilitate the proof of:

Proposition 2. Suppose the conditions of Lemma 4 hold. Then at the solution to [FP], each of the three forms of technological progress (i.e., a reduction in either t^C or t^D or an increase in t^E) leads the firm to undertake internal provision more often (i.e., $-\frac{dc^T}{dt^C} > 0$, $-\frac{dc^T}{dt^D} > 0$, and $\frac{dc^T}{dt^E} > 0$).

Although the main qualitative conclusions of Propositions 1 and 2 are the same, the explanation for the two sets of results is very different. Most importantly, technological progress in each of its three forms *increases* control costs under subcontracting in the case of transferable skills. Reductions in t^C or t^D, like increases in t^E, make it less costly for the subcontractor to exaggerate his alternative profit opportunities, $\overline{\pi}(\cdot)$. The subcontractor can only exaggerate $\overline{\pi}(c)$ by simultaneously understating innate production costs, c. A given exaggeration of $\overline{\pi}(\cdot)$ (i.e., a given understatement of innate costs, δ) will obligate the subcontractor to deliver less effort to compensate for the implicit understatement of production costs ($t^C\delta$) the smaller the level of t^C. Similarly, when effort becomes less costly to supply or when the impact of effort on final production costs increases, it is less onerous for the subcontractor to cover up for any understatement of innate costs. Consequently, when t^C or t^D declines or when t^E increases, it becomes more difficult for the firm to limit the subcontractor's incentive to exaggerate his alternative profit opportunities. The associated increase in control costs makes internal provision more attractive to the firm.[19]

With transferable skills, the relative efficiency effect may enhance or counteract the control effect, depending upon the type of technological progress.

When technological progress reduces innate costs, the relative efficiency effect, like the control effect, leads to more internal provision, since innate costs are higher for the firm than for the subcontractor. When technological progress increases the impact of effort on final costs or reduces the cost of such effort, the relative efficiency effect alone leads to more subcontracting because the marginal subcontractor exerts more cost-reducing effort than does the firm. However, the difference in effort supply under subcontracting and internal provision is not so pronounced as to outweigh the countervailing control effect, as inequality (12) suggests. Therefore, more internal provision results under each form of technological progress.

Of course, combinations of the various forms of technological change might occur simultaneously. For the sake of completeness, we record without further comment the less obvious outcomes of such combinations, which parallel the predictions of Corollary 1.

Corollary 2. Under the conditions of Lemma 4, the firm will undertake internal provision more often if:

(i) both t^E and t^C increase proportionately (i.e.,

$$\frac{dc^I}{d\lambda} > 0 \quad \text{when } t = (\lambda t^C, \lambda t^E, t^D)); \text{ or}$$

(ii) both t^E and t^D increase proportionately (i.e.,

$$\frac{dc^I}{d\lambda} > 0 \quad \text{when } t = (t^C, \lambda t^E, \lambda t^D)).$$

Despite these strong parallels across regimes concerning the impact of technological change on the firm's make-or-buy decision, an important difference emerges when the firm's welfare is considered. Because control problems under subcontracting are exacerbated by technological progress in the case of transferable skills, the firm's expected welfare may actually decline when technological progress occurs. To illustrate this point, consider the following simple setting.

Example: $D(e) = \frac{1}{2}e^2$; $t = (1, 1, 1)$; $f(c) = \begin{cases} 1/\bar{c} & \text{for } c \in [0, \bar{c}] \\ 0 & \text{otherwise} \end{cases}$.

Proposition 3. Suppose $\bar{\pi}'(c) < 0$ and $|\bar{\pi}'(c)|$ is sufficiently large $\forall$ $c \in [\underline{c}, \bar{c}]$. Also suppose Δ is sufficiently large and $\bar{\pi}(\underline{c})$ is sufficiently small that $S = \{c | c \in [\underline{c}, \bar{c}]\}$ in the solution to [FP]. Then in the Example, technological progress that reduces innate costs:

(i) reduces the expected welfare of the firm (i.e., $-\frac{dW^T}{dt^c} < 0$ $\forall$ $\bar{c} > 0$, where W^T is the value of the objective function in the solution to [FP] for the case of transferable skills); and

(ii) reduces total expected surplus if the control problem under subcontracting is sufficiently pronounced (i.e., $-\frac{dZ^T}{dt^c} < 0$ whenever $\bar{c} > 3/2$, where Z^T is the sum of W^T and the equilibrium expected rents for the subcontractor with transferable skills).

For simplicity, Proposition 3 focuses on the case where the subcontractor's innate cost advantage is sufficiently pronounced that the firm will always subcontract production. This case facilitates the demonstration that the firm may prefer a higher-cost environment by abstracting from the lower costs of internal provision that accompany a reduction in innate production costs. Of course, the qualitative conclusions drawn in Proposition 3 will continue to hold when production is subcontracted sufficiently often.

The firm's expected loss from technological progress (reported in property (i) of Proposition 3) occurs because the increase in the subcontractor's information rents when t^c declines outweighs any potential gains to the firm from reductions in the subcontractor's innate production costs.[20] Property (*ii*) of Proposition 3 reports that the firm's expected losses from the technological progress outweigh the subcontractor's gains when control costs are large, due to a pronounced information advantage ($\bar{c}$ - $\underline{c}$) of the subcontractor.

IV. Extensions.

In closing, we comment briefly on possible empirical tests of our model, and mention some extensions of our analysis that warrant consideration. To begin, consider how one might test the empirical predictions of our model. International comparisons of firms in the same industry would be one approach. Differences in relative prices and technological opportunities across countries might lead firms that are otherwise identical to adopt different technologies. The relation between these technologies and the extent of internal provision could then be examined. Of course, one must be wary of other institutional differences across firms (such as government regulations, organizational structure, and management style) that could complicate the comparison. Alternatively, one might examine the behavior of a single firm over time as technological progress is realized. Although this approach avoids difficult inter-firm comparisons, it introduces dynamic incentive issues that have not been modeled explicitly here. Such modeling seems worthwhile.

Three additional extensions of the model should also be pursued. First, different formulations of the production technology should be examined. For example, innate production costs (c) and effort (e) need not be separable. When they are not, the efficient effort level, e*, can vary with the level of innate costs. In such cases, even technological progress that affects only innate production costs may affect the efficient effort level, thereby complicating the calculus considered above. Technically, there are important linearities in the model that should be relaxed.

Second, different formulations of technological progress warrant consideration. To best identify and contrast the key effects of different forms of technological change, our analysis focused on symmetric variations in three types of technological change. Asymmetric variations are likely in practice. An explicit analysis of these asymmetries would proceed along the lines developed here.

Third, our analysis might be extended to incorporate *ex ante* competition among potential subcontractors. Such competition would reduce the expected rents of the selected contractor; but the work of Laffont and Tirole (1987), McAfee and McMillan (1987), and Riordan and Sappington (1987) suggests that this subcontractor would face the same incentive contract identified in our analysis.

In conclusion, it should be emphasized that other factors must be analyzed to obtain a more complete understanding of a firm's choice between internal provision and subcontracting. For example, incomplete contracting (e.g., Williamson (1985)) and residual rights of control (Sanford Grossman and Oliver Hart (1986)) are important to consider. So, too, are the dynamic issues of commitment (e.g., Williamson (1975) and Tirole (1986)) and renegotiation (e.g., Laffont and Tirole (1990)).[21, 22]

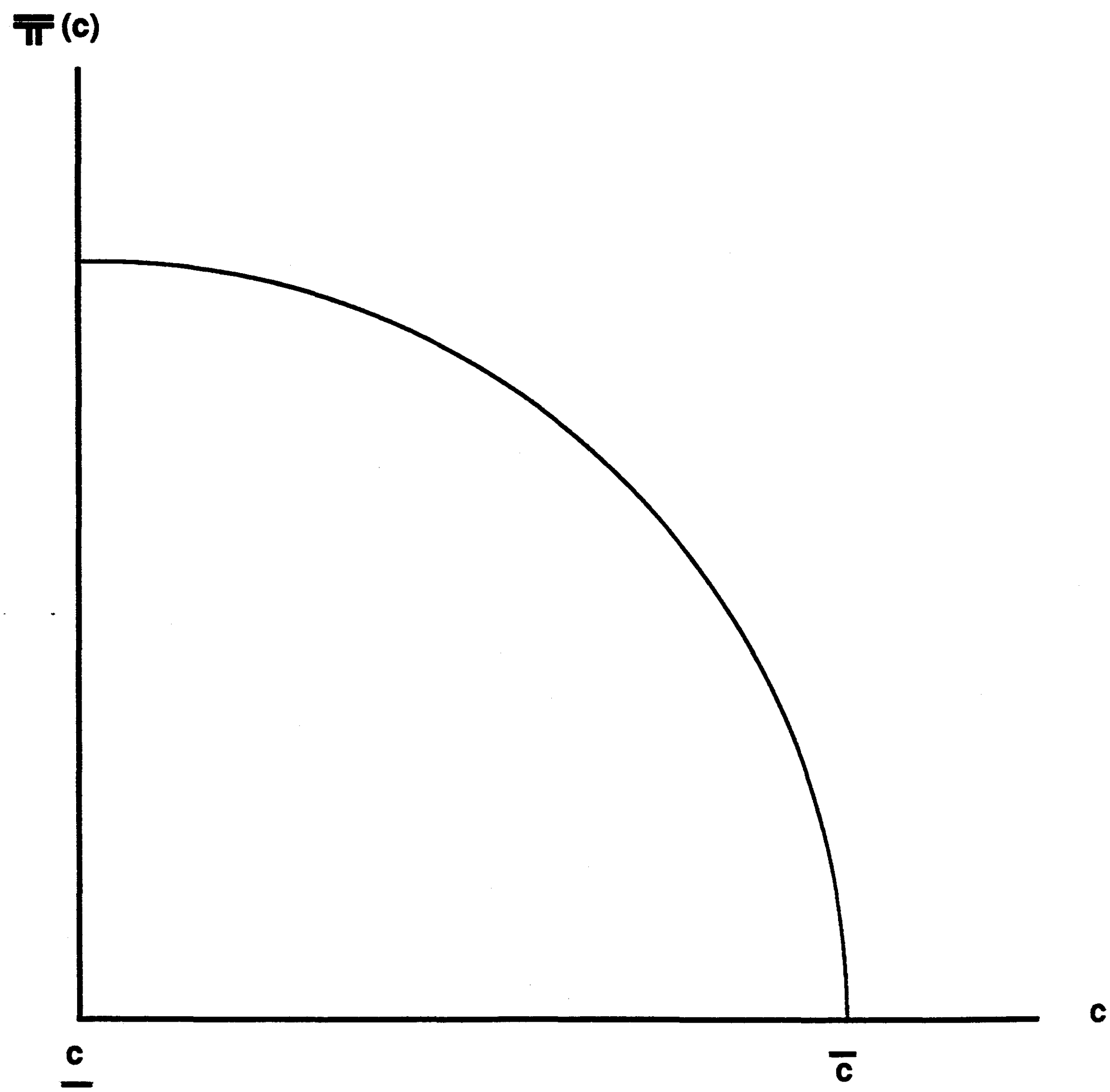

Figure 1. Reservation Profits with Transferable skills.

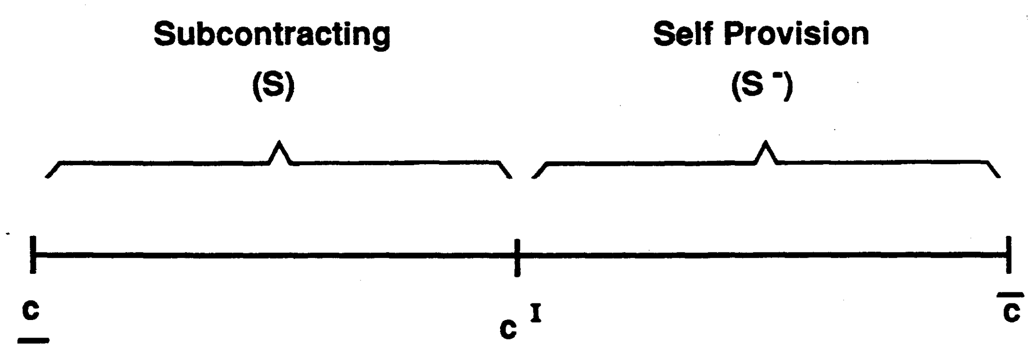

Figure 2. Idiosyncratic skills.

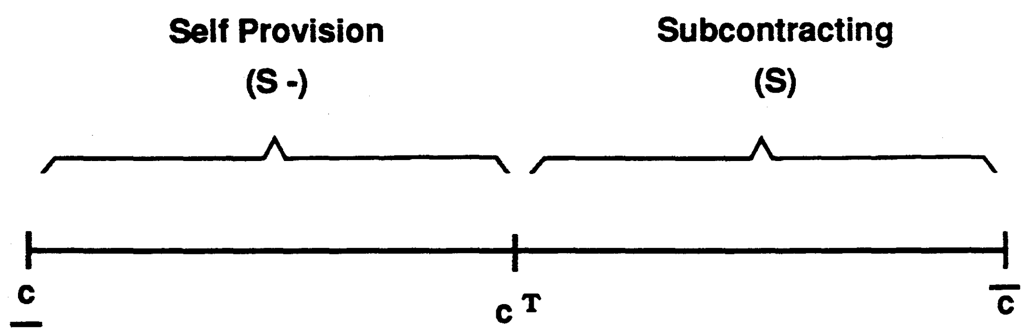

Figure 3. Transferable skills.

FOOTNOTES

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1. Notice our focus on technological change that affects the underlying technologies of the firm and the subcontractor in symmetric fashion. In particular, a given percentage change in t^c alters the innate costs of the firm and the subcontractor by the same percentage.

2. Internal provision can also provide expanded access to and control of bookkeeping accounts. To the extent that cost-reducing effort entails purchased inputs, control of bookkeeping procedures can provide more accurate accounts of delivered effort levels. For an expanded treatment of such "loss of control" under subcontracting, see Oliver Williamson (1985). Interesting formal models of this phenomenon include those of Michael Riordan (1988) and Riordan and Williamson (1985). Also see Keith Crocker (1983). A related model is Riordan and Sappington's (1987), where there are two tasks to perform. In their model, the correlation in the agent's productivity across tasks determines whether the principal prefers to subcontract or perform the second task herself.

3. C^{o} could also be interpreted as the level of delivered quality, where effort enhances quality. In this interpretation of our model, quality would be observable, but the total cost incurred by the subcontractor would be unobservable to the firm.

4. One could readily construct models in which nontrivial agency problems existed under internal provision as well as under subcontracting. To illustrate, the firm might have better information about its costs than the costs of the subcontractor, but the information might not be perfect. Formally, models of this sort would be similar to the auction models of Jean-Jacques Laffont and Jean Tirole (1987), R. Preston McAfee and John McMillan (1987), and Riordan and Sappington (1987). Conceptually, such models would incorporate the same basic tradeoff between innate cost advantages and control disadvantages under subcontracting that we analyze here in particularly stark form.

5. Notice that the subcontractor's expected profits in alternative employment may increase with his innate ability even though no other potential employer has better knowledge of the subcontractor's ability than does the firm. In the presence of asymmetric knowledge, optimal incentive schemes generally have the property that "agents" with higher ability earn larger profits. Thus, the assumption that $\overline{\pi}'(c) < 0 \ \forall \ c$ simply amounts to an assumption that the subcontractor's skills across various tasks are positively correlated.

6. For example, see Laffont and Tirole (1986). It should be apparent that, except for the technological parameters we introduce, our model with idiosyncratic skills is nearly identical to Laffont and Tirole's model.

7. In Section IV, we briefly address an alternative contracting arrangement in which potential contractors bid for the right to serve the firm.

8. By the revelation principle (e.g., Roger Myerson (1979)), this formulation is without loss of generality.

9. An intuitive derivation of this expression for control costs is as follows. Suppose a contractor with innate cost $c - \varepsilon$ decides to produce at final cost $C^{O}(c)$, which is the cost intended for the subcontractor with innate cost c. The latter subcontractor must expend effort $e(c) = \frac{1}{t^{E}}[t^{C}c - C^{O}(c)]$, while the former subcontractor need only expend effort $e(c-\epsilon) = \frac{1}{t^{E}}\left[t^{C}[c-\epsilon] - C^{O}(c)\right]$ to realize final cost $C^{O}(c)$. The additional profit earned by the subcontractor with innate cost $c-\varepsilon$ is:

$$\Delta\pi = t^{D}\left\{D(e(c)) - D(e(c-\epsilon))\right\}$$

$$= t^{D}\left\{D(\frac{1}{t^{E}}[t^{C}c - C^{O}(c)]) - D(\frac{1}{t^{E}}[t^{C}(c-\epsilon) - C^{O}(c)]\right\}.$$

Dividing both sides of this equation by ε and letting ε become arbitrarily small, one obtains $\pi'(c) = \frac{t^{C}t^{D}}{t^{E}}D'(e(c))$, indicating the rate at which the profit of the subcontractor must increase as c declines because of the essential information asymmetry. Notice that for any given c, all subcontractors with innate costs less than c can extract the information rents that accrue to the subcontractor with innate cost c. Therefore, total information rents or control costs accrue at the rate $\frac{t^{C}t^{D}}{t^{E}}D'(e(c))F(c)$. Finally, this expression is divided by $f(c)$ in the text to normalize for the probability that the agent is of type c.

10. See, for example, Laffont and Tirole (1986).

11. In this interpretation, c might be viewed as the cost of capital inputs and labor (e) might serve as a perfect substitute for capital inputs in the production process. When capital inputs become more expensive, each unit of labor reduces observed costs by a greater amount. Thus, inflation or deflation that affects all input prices symmetrically will have the impact considered in Lemma 3.

12. Of course, this conclusion follows from our multiplicative representation of technological progress. It is straightforward to verify that in an additive formulation where innate costs are $c + t^c$, changes in t^c do not affect c^I.

13. Notice that only symmetric variations in the parameters are considered in Corollary 1. With asymmetric variations, different qualitative conclusions could emerge. For example, if the costs of effort are increased more then the impact of effort on final costs, more subcontracting could result.

14. Property (ii) of Corollary 1 also has the following interpretation, suggested to us by Paul Milgrom. Suppose the costs of effort are given by $\alpha D(e/\alpha)$. Because $D(\cdot)$ is convex, increases in α reduce the costs of supplying e. An increase in α can be thought of as an increase in the number and a concomitant reduction in the scale of independent processes employed to reduce production costs. With $z = e/\alpha$, $e - \alpha D(e/\alpha) = \alpha[z - D(z)]$, so an increase in α corresponds to a symmetric increase in the cost

and effectiveness of effort.

15. Technically, the second order conditions will be satisfied if: (1) the expression in (A5) in the Appendix is a strictly concave function of c^T; (2) this expression is strictly increasing in c^T at $c^T = \underline{c}$ and strictly decreasing at $c^T = \overline{c}$; and (3) $|\overline{\pi}'(c)|$ is sufficiently large $\forall$ c. Property (3) is required to ensure $|\overline{\pi}'(c)| > |\pi'(c)|$ $\forall$ c (where $\pi(c) \equiv \pi(c|c)$) so that the subcontractor's reservation profit schedule is everywhere more steeply sloped than his equilibrium profit schedule. Conditions sufficient to ensure the second order conditions hold are:

(a) $f(c) = \dfrac{1}{\overline{c} - \underline{c}}$ $\quad \forall\, c \in [\underline{c}, \overline{c}]$;

(b) $D''(e) = d > 0$, a constant, $\forall$ e;

(c) $-\overline{\pi}'(c) = k > 0$, a constant, $\forall$ c;

(d) $t = (1, 1, 1)$;

(e) $\overline{\pi}(\overline{c}) < \Delta$; and

(f) $$k > \text{maximum}\left\{[1 + d[\overline{c} - \underline{c}]],\ \frac{\Delta - \overline{\pi}(\overline{c})}{2[\overline{c} - \underline{c}]} - \frac{1}{2}\int_{\underline{c}}^{\overline{c}} [2 + d[\overline{c} - \underline{c}]]\, \frac{1}{\overline{c} - \underline{c}}\, dc\right\}.$$

16. Control costs in the case of transferable skills are $-\dfrac{t^D t^C}{t^E} D'(e(c)) \dfrac{1-F(c)}{f(c)}$. An intuitive explanation of this expression follows in straightforward fashion from the explanation provided above for the case of idiosyncratic skills.

17. For a detailed explanation of this phenomenon, see Lewis and Sappington (1989). For an interesting related analysis, see Paul Champsaur and Jean-Charles Rochet (1989). Briefly, effort in excess of the efficient level

makes it less attractive for the subcontractor to exaggerate his alternative profit opportunities by understating c.

18. As a referee has observed, the solution to [FP] may involve regions over which the subcontractor is paid more than one dollar for each additional dollar of realized cost. Consequently, the subcontractor may have an incentive to inflate realized production costs, perhaps by adopting an inefficient production technology. Ideally, one should carefully model the subcontractor's ability to produce with other than the least cost technology. (For an analysis along these lines, see Lewis (1991).) Implicit in our treatment of this interpretation of the model is the (strong) assumption that the firm can detect and punish such use of inefficient production technologies. Notice, however, that such considerations are less germane when C^o is interpreted as quality rather than cost.

19. We have adopted the simplifying assumption here that technological progress does not affect the alternative profit opportunities of the subcontractor. When, for example, reductions in t^c increase opportunity profits, the costs of subcontracting are increased even further.

20. A corollary of this observation is that in an auction setting with many potential subcontractors, each with private information about its own innate costs, the optimal auction will not necessarily award the production contract to the subcontractor with the lowest expected innate costs. With transferable skills, the lowest c realization is not necessarily associated with the lowest total costs of production. Hence, the firm may prefer to award the contract to a "less efficient"

contractor, but one with lower expected total costs (including opportunity costs).

21. It would also be interesting to imbed the model we have analyzed in a setting where firms are oligopolists in an output market. In such a setting, the choice between internal provision and subcontracting may take on an added dimension. In particular, to the extent that there are sunk costs associated with establishing a supply relationship, an oligopolist may be able to commit herself to higher or lower production costs through her decision to subcontract production of inputs or to produce them internally. (See Y. Joseph Lin (1988).) Such commitment can be of value to the oligopolist because of its effect on the behavior of rivals.

22. A complete analysis of the make-or-buy decision would also have to address possible differences in the likelihood that the proprietary nature of information will be jeopardized under subcontracting versus internal provision.

APPENDIX

Proof of Lemma 1. The lemma follows immediately from the fact that the subcontractor's total costs of production increase monotonically with c, while the firm's production costs are independent of c.

Proof of Lemma 2 and Proposition 1. Proceeding as in Laffont and Tirole (1986), it is readily shown that the firm's problem can be rewritten as:

$$\underset{e(\cdot),\,c^I}{\text{Maximize}} \int_{\underline{c}}^{c^I} \left\{ V - [t^C c - t^E e(c)] - t^D D(e(c)) - \frac{t^C t^D}{t^E} D'(e(c)) \frac{F(c)}{f(c)} \right\} f(c)dc$$

$$\text{(A1)} \qquad + [1 - F(c^I)] \left\{ V - [t^C(\overline{c} + \Delta) - t^E e^*] - t^D D(e^*) \right\}.$$

Pointwise maximization with respect to e(c) yields equation (5). Also, differentiating (A1) with respect to c^I yields

$$G^I(c^I, t) \equiv \left\{ t^C[\overline{c} + \Delta] - t^E e^* + t^D D(e^*) \right.$$

$$\text{(A2)} \qquad \left. - [t^C c^I - t^E e(c^I) + t^D D(e(c^I)) - \frac{t^C t^D}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)} \right\} = 0.$$

Under the maintained assumptions, (A1) is a concave function of c^I and $G^I(\underline{c}, \cdot) > 0 > G^I(\overline{c}, \cdot)$. Therefore, the optimal value of c^I is determined by equation (6). Furthermore, from (A2):

$$\text{(A3)} \qquad \frac{dc^I}{dt^C} \triangleq \frac{\partial}{\partial t^C} G^I(\cdot) \triangleq \frac{1}{t^C} \{t^E e^* - t^D D(e^*) - [t^E e(c^I) - t^D D(e(c^I))]\} > 0.$$

Furthermore, from (A1) we have:

$$\frac{\partial W^I}{\partial t^C} = - \int_{\underline{c}}^{c^I} \left[c + D'(e(c)) \frac{F(c)}{f(c)} \right] f(c)dc - [1 - F(c^I)][\overline{c} + \Delta] < 0.$$

The proofs for variations in t^E and t^D are analogous, and so are omitted. Details can be found in Lewis and Sappington (1989), which is available upon request from the authors.

What remains is to prove inequality (7). The inequality follows directly from equation (6), given that inequality (8) holds. From (A2),

$$\frac{dc^I}{dt^D} \overset{s}{=} D(e^*) - D(e(c^I)) - \frac{t^C}{t^E} D'(e(c^I)) \frac{F(c^I)}{f(c^I)}$$

$$\overset{s}{=} t^C c^I - t^E e(c^I) - \left[t^C[\bar{c} + \Delta] - t^E e^*\right]. \tag{A4}$$

Inequality (8) follows from (A4) because $\dfrac{dc^I}{dt^D} > 0$. ■

Proof of Lemma 3. The proof follows from logic analogous to that used to derive (A3). ■

Proof of Corollary 1. Letting $t^C = t^E = t$, straightforward calculations corresponding to those that underlie (A3) reveal

$$\frac{dc^I}{dt} = \bar{c} + \Delta - c^I - [e^* - e(c^I)]$$

$$= -\frac{t^D}{t}\left[D(e^*) - D(e(c^I)) - D'(e(c^I)) \frac{F(c^I)}{f(c^I)}\right]$$

$$\overset{s}{=} -\frac{dc^I}{dt^D} < 0.$$

The proof of (ii) is analogous. ■

Proof of Lemma 4. The proof follows from straightforward arguments by contradiction, employing unconstrained versions of the firm's problem as in (A5) below. ■

Proof of Lemma 5 and Proposition 2. Proceeding as in the proof of Proposition 1, the firm's problem can be rewritten as:

$$\underset{e(\cdot),c^T}{\text{Maximize}} \int_{c^T}^{\bar{c}} \left\{ V - [t^C c - t^E(e(c)] - t^D D(e(c)) - \bar{\pi}(c^T) + \frac{t^C t^D}{t^E} D'(e(c)) \frac{1 - F(c)}{f(c)} \right\} f(c)dc$$

$$\text{(A5)} \qquad + F(c^T) \left\{ V - [t^C(\bar{c} + \Delta) - t^E e*] - t^D D(e*) \right\} .$$

Pointwise maximization with respect to e(c) yields equation (11). Differentiating (A5) with respect to c^T yields

$$G^T(c^T,t) \equiv f(c^T) \left\{ t^C c^T - t^E e(c^T) + t^D D(e(c^T)) + \bar{\pi}(c^T) - \frac{t^C t^D}{t^E} D'(e(c^T)) \frac{1-F(c^T)}{f(c^T)} \right.$$

$$\text{(A6)} \qquad \left. - [t^C(\bar{c} + \Delta) - t^E e* + t^D D(e*)] \right\} - \bar{\pi}'(c^T)[1-F(c^T)] = 0.$$

From (A6),

$$\text{(A7)} \qquad \frac{dc^T}{dt^C} \overset{s}{=} \frac{\partial}{\partial t^C} G^T(\cdot) \overset{s}{=} c^T - [\bar{c} + \Delta] - \frac{t^D}{t^E} D'(e(c^T)) \frac{1 - F(c^T)}{f(c^T)} < 0 .$$

Again, the corresponding analysis for variations in t^E and t^D are omitted, but can be found in Lewis and Sappington (1989).

Finally, inequality (12) is immediate since from (A6),

$$\frac{dc^T}{dt^D} \overset{s}{=} D(e(c^T)) - D(e^*) - \frac{t^C}{t^E} D'(e(c^T)) \frac{1 - F(c^T)}{f(c^T)} . \qquad \blacksquare$$

The proof of Corollary 2 is analogous to the proof of Corollary 1, and so is omitted.

Proof of Proposition 3. From (A5),

$$\text{(A8)} \qquad \frac{\partial W^T}{\partial t^C} = \int_{\underline{c}}^{\bar{c}} \left[D'(e(c)) \frac{1-F(c)}{f(c)} - c \right] f(c)\,dc .$$

For the Example, $D'(e(c)) = e(c)$ and $\frac{1-F(c)}{f(c)} = \bar{c} - c$. Therefore, since $e(c) = 1 + \bar{c} - c$ from equation (11), (A8) provides

$$\frac{\partial W^T}{\partial t^C} = \int_0^{\bar{c}} \{ [1 + \bar{c} - c] \} \frac{1}{c} dc = \frac{1}{3}(\bar{c})2 > 0 \;\; \forall \, \bar{c} > 0 .$$

Under the conditions of the Proposition,

$$\text{(A9)} \qquad \frac{dZ^T}{dt^C} = \int_{\underline{c}}^{\bar{c}} \left\{ c - [1 - D'(e(c))] \frac{de(c)}{dt^C} \right\} f(c)\,dc ,$$

where $\frac{de(c)}{dt^C} = - \frac{1-F(c)}{f(c)}$, using equation (11). Hence substitution into (A9) and integration reveals

$$\frac{dZ^T}{dt^C} = \frac{1}{2}\bar{c} - \frac{1}{3}\bar{c}^2 < 0 \quad \text{if } \bar{c} > \frac{3}{2}.$$

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