Outsourcing of Innovation

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Abstract: There has been a great deal of recent work on the outsourcing of production by firms. In these models, the usual motivation for outsourcing is based on the cost advantage of subcontracting as opposed to in-house production. This paper looks at a particular kind of outsourcing activity, namely outsourcing of research and development activities. We consider cost reducing research and development and consider a firm which decides whether to outsource the project to a research firm or do the research in-house. We use a principal-agent framework and consider fixed and performance based contracts. We solve for the optimal contract. Among the major findings are: (1) Allowance for performance-based contracts increases the chance of outsourcing and improves welfare. (2) Even an informed principal who foresees the leakage of information may still find it optimal to design a contract in such a way as to allow the leakage to occur. This is a second best outcome when leakage cannot be monitored or verified. (3) Comparative statics exercises can yield misleading results if one fails to account for the market adjustment effects (e.g. entry and exit of firms) as the exogenous variable changes. This is illustrated by the effects of a change in the outside option of the agent. (4) Stronger protection of trade secrets encourages R&D outsourcing and improves welfare.

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1 Introduction

There is recent evidence that outsourcing research and development (R&D) activities is on the increase. For example, R&D magazine (January, 2001 issue) reports that according to a recent survey of their readers, "...a significant portion of total R&D would be outsourced. ...[I]t is estimated that 25% of all R&D will be performed on contract with outside performers." There is other anecdotal evidence of outsourcing of R&D such as software development outsourced to India. However, to our knowledge, there has not been any paper formally modeling the theoretical foundations of R&D outsourcing. Our paper fills that gap.

The outsourcing of production by firms has been considered by many authors (for example, Grossman and Helpman, 2002, and papers cited therein). The motivation for outsourcing of production is mainly based on consideration of the cost advantage of subcontracting as opposed to in-house production. Despite the lack of a formal theory, it has been pointed out by Milgrom and Roberts (1992, Chapter 16) that the difficulty of writing and monitoring a contract would make R&D outsourcing difficult to do, even when there is a cost advantage of subcontracting out the R&D activities of the firm. In this paper, we tackle these difficulties by considering a very simple outsourcing problem using a principal-agent framework following the lead of Grossman and Hart (1983) and Myerson (1983). While this approach differs from that used to analyze production outsourcing we feel that it is an appropriate way to think about outsourcing R&D.

We begin by supposing that there are a group of firms in the output market, that we assume to be monopolistically competitive. The principal in our problem is the owner of a firm that produces output for this monopolistically competitive market. There is an unlimited supply of workers who can work as in-house researchers for the principal at a competitive wage W. We assume that there are two types of workers, cooperative and non-cooperative. Cooperative workers are able to cooperate with other research workers, non-cooperative workers are not. These cooperative workers have the capability to form a research subcontracting firm. We assume, because of agglomeration and knowledge spillover effects, that these research firms have a comparative advantage in R&D activities. They can innovate faster (or maybe more cheaply) than the principal's in-house employees and in addition there may be economies of scale in research for these contractors. We assume that non-cooperative workers do not have the ability to work in a research firm. The research firm is the agent in our problem.

For the principal, research is required to reduce costs. We use a principal-agent framework to analyze whether or not the production firm should hire the research subcontracting firm to do its R&D or whether it should do it in-house. We assume that a subcontracting firm consists of several partners, each of whom deals with the R&D of one principal. Information sharing between partners is possible. This is why information leakage can occur.

Would R&D outsourcing always be the equilibrium outcome if the research firm can do research more cheaply and more quickly? Our answer is a surprising "No". The reason is the information leakage problem. Useful information about the firm is obtained by the subcontractor. This could lead to (i) the research firm selling information to the production firm's competitors which would lead to erosion of the market share of the production firm or (ii) entry of the subcontractor into the industry. As the subcontractor works with many firms and gradually learns about the industry, it can eventually enter as a competitor. Because of the information problem, R&D may not be outsourced even when it is efficient to do so.

Most of our major findings are therefore related to the information leakage problem, which distinguishes R&D outsourcing from production outsourcing. First, the optimal outsourcing contract may or may not be performance-based. In the first case, lump-sum cum revenue-sharing contract is the equilibrium outcome, and there is no information leakage. In the second case, the equilibrium is a lump-sum contract, and there will be information leakage. The allowance for revenue-sharing between the principal and the agent increases the likelihood of R&D outsourcing because it eliminates information leakage. Since outsourcing is efficiency-enhancing, allowing for the possibility of revenue-sharing as part of a contractual arrangement is welfare improving. Second, a related point, is that even an informed principal who foresees the leakage of information may still find it optimal to design a contract in such a way as to allow the leakage to occur. This is the second best outcome when the principal cannot monitor or verify leakage. Third, an increase in the outside option of the researcher in general makes the cooperative outsourcing agreement more likely to reach. This result runs counter to the one obtained without accounting for entry and exit in the output market. The result arises because increases in this outside option induce adjustments in the output market, which enlarges the potential gains from cooperation. This indicates that principal-agent models that ignore the market adjustment effects can yield misleading results. Finally, since information leakage reduces the chance of outsourcing R&D, which is efficiency-enhancing, any measure that reduces the gains of the agent from appropriating the principal's proprietary information or reduces the losses of the principal from appropriation would increase welfare. Increased protection of trade secrets is one of such measures.

2 The Basic setup

We consider an environment in which firms engaged in production activities are capable of doing cost-reduction innovations in house. In a monopolistically competitive product market, firms are faced with a downward sloping inverse demand curve $p(x)$. Thus, the value of sales is $xp(x)$.[1] The inception date of the research output is I and the length of product cycle is T. Without discounting the future, the present-discounted value of sales over the entire product cycle is: $xp(x)T$.[2]

We consider two possible ways in which R&D activities can be done, the first via an outsourced subcontractor or secondly, with in-house researchers.[3] We identify three important features of these activities that can easily be identified in practice, for example in industries

[1] While we focus primarily on the simple case abstracting from uncertainty, the implications of demand uncertainty will be discussed in the concluding section.

[2] With discounting, T is replaced by $\int_0^T e^{-rt}dt$, where r is the discount rate. This would not fundamentally change the results.

[3] One may regard in-house R&D as that examined in the conventional literature, such as Grossman and Helpman (1991) and Aghion and Howitt (1992).

such as pharmaceuticals and apparel.

1. (*Adaptability of the outsourced R&D to the production firm's environment*) In-house R&D has no adaptability problem, since in-house researchers knows the firm's operating environment. But outsourced R&D needs to be adapted to the host firm's operating environment, which takes time.[4] Therefore, adaptability is a disadvantage of outsourcing, as outsourcing delays the arrival of customized innovations.

2. (*Specialization of the subcontractor*) Since the subcontractor enjoys increasing returns to knowledge accumulation as well as increasing returns to scale, it is more efficient in the sense that it can develop the same innovation faster than in-house researchers at a given cost. Therefore, the speed of development is an advantage of outsourcing. Moreover, there is saving in the unit production cost from outsourced innovation as opposed to in-house R&D since specialization allows the subcontractor to produce higher-quality research outputs than in-house researchers. This is also an advantage of outsourcing. Both factors imply that outsourcing shortens the innovation time for a given cost or effort.

3. (*Information leakage*) Useful information about "design for manufacturing" (DFM) is obtained by the subcontractor.[5] The research firm might have an incentive to appropriate the proprietary information of the output firm by (i) selling it to the potential competitors of the production firm; (ii) entering into the industry as a competitor, with the help of the information she obtained from the output firm, including the R&D and the operation. Both of these would lead to erosion of the market share of the production firm and they can prevent R&D from being outsourced even when the advantages in point (2) above outweigh the disadvantages in point (1).

[4] Although we do not model this effect explicitly, one could easily incorporate it by following the technology adoption setup in Chen and Shimomura (1998) and Chen et al. (2002).

[5] For a discussion of design for manufacturing, the reader is referred to Allen (2002).

Throughout the paper, we focus on the case in which the overall arrival time under outsourcing is earlier than under in-house research. We normalize by setting $I = 0$ for outsourcing and $I = L$ for in-house R&D, where L is the net delay of arrival of the innovation under in-house R&D. That is, we impose:

Assumption 1: $L > 0$.

While lower adaptability of outsourced R&D or higher in-house innovative capability tends to lower L, the specialization effect of R&D outsourcing tends to increase L.

Point (3) above reflects a typical agency problem, that could conceivably be mitigated by intellectual property rights (IPR) protection. Moreover, we make the following assumption:

Assumption 2: Leakage of the principal's proprietary information cannot be monitored or verified.

Because of this assumption, it is not meaningful to write a contract to require the agent not to leak information, since it is not enforceable. To understand the basic incentives in this environment we use a very simple model of the leakage problem. Denote the binary-choice *action* of leakage by ϕ where $\phi = 0$ indicates no leakage and $\phi = 1$ indicates leakage occurs. Further, consider that the demand faced by the firm depends on whether there is a leakage of information. Specifically, we assume that informational leakage causes a fractional reduction in a production firm's market share, or, more formally,

Assumption 3: *Under R&D outsourcing, the goods demand is given by*

$$X(p;\delta) \equiv \begin{cases} x(p) & \text{if } \phi = 0 \\ \delta x(p) & \text{if } \phi = 1 \end{cases}, \textit{ where } \delta \in (0,1).$$

In other words, the market share declines with information leakage at the rate $1 - \delta$, which also captures the severity of information leakage. The type of research that suffers from very low δ once leakage occurs, is called the "core competency" of the firm. Without outsourcing,

$\phi = 0$. The entire schedule of market share facing the particular production firm is plotted in Figure 1. For convenience of exposition, however, we shall make use of the inverse demand function $p(x)$ more often in the rest of the paper.

The R&D we consider is cost reduction R&D. We assume that the unit production cost resulting from in-house R&D is c and that from outsourcing is $(1-\lambda)c$ (where λ is the unit cost reduction due to the higher quality of outsourced R&D). If outsourcing takes place then production firms and research firms must agree on a "royalty fee" schedule for the outsourcing contract. The royalty contract (m, μ) specifies a fixed payment independent of the sales (m) and a percentage fee based on the value of sales (a fraction μ). The competitive wage faced by a researcher, the agent, is assumed to be W. It can be treated as a fixed R&D cost from the point of view of the principal. Therefore, the gross profit to the host firm without outsourcing is $\Pi_0 = x[p(x) - c](T - L) - W$ and that with outsourcing is

$$\Pi(\mu, m) = \begin{cases} x\left[p(x)(1-\mu) - (1-\lambda)c\right]T - m & \text{when } \phi = 0 \\ \delta x\left[p(x)(1-\mu) - (1-\lambda)c\right]T - m & \text{when } \phi = 1 \end{cases}.$$

Note that the x and $p(x)$ in each regime is to be chosen optimally by the principal in each circumstance, treating all other variables and parameters as given.

3 R&D Outsourcing

We next turn to an analysis that uses a principal-agent framework to determine whether or not the production firm should hire the research firm to do its R&D. The production firm is the principal who designs the royalty contract (m, μ) which the agent may or may not accept. The research firm is the agent and decides, whether to accept the contract or not. Once accepted, the agent also must decide for a given royalty contract, whether to leak the information to the host firm's competitors. Since we want to focus on the information leakage problem, we assume that a match has been made between a firm (principal) and a research firm (agent). Please refer to the game tree in Figure 1a.

To ensure subgame perfection, we solve this problem backward. More specifically, to solve this problem we first solve for the agent's optimal ϕ given the contract offered by the principal, (m, μ). Then, given this function of ϕ we can solve for the optimal contract (m, μ). Once we solve this we show that the information leakage problem results in less outsourcing. We are also interested in whether there is a distortion in the sense that resources are misallocated between in-house research and outsourced research. We begin by looking at the agent's decision problem.

3.1 Decision by the Agent

We assume that the agent, a research firm, consists of several partners, each of whom deals with the R&D of one principal. Information sharing between partners occurs in the normal course of the research process. This is why information leakage is a possibility. Therefore, an agent compares her wage as an employee of the principal and her income earned as a partner of a subcontractor minus any setup cost for becoming a partner of a subcontracting firm. Assuming that the setup cost is trivial compared with the income earned in either option, she would choose the one that yields her higher income. Because there is no uncertainty, she does not have to evaluate risks. In a more sophisticated model with risks and uncertainty, we need to take into account risk aversion. So, at this stage of the game, we assume that the agent does better as a subcontracting partner. Given that a match between a production firm and research firm exists we turn to the question of whether the research firm decides to leak the information or not

Define the pre-sharing revenue of the principal per period (without information leakage) as $R = xp(x)$. Given an outsourcing contract (m, μ), the principal maximizes its profit by choosing x, given μ and m. Since the optimally chosen x is a function of μ, the variable R will also be a function of μ. Typically, R is a decreasing function of μ. (This is true if the output demand curve faced by the principal has a constant elasticity, as shown in the appendix.) Let us assume from now on a constant-elasticity output demand curve of the form $x = Ap^{-\epsilon}$ faced by the principal. Let B be the benefit of information leakage accrued to the agent from selling information and entering the output market as a competitor. To simplify the analysis, suppose that the value of the information leakage to the subcontractor is a fraction $\beta \in (0, 1-\delta)$ of the present discounted value of the principal's revenue before leakage. This assumption guarantees that the principal's revenue loss is always more than the agent's gains when the agent appropriates proprietary information. Then, B, the benefit of information leakage is:

$$B = \beta RT \tag{1}$$

When there is no leakage, the revenue-sharing allows the agent to gain μRT (in addition to the lump sum payoff m); with leakage, it becomes $\delta\mu RT$. Therefore, when the agent leaks information about the principal it loses revenue because the leakage lowers the principal's market share and hence its revenue. The agent's expected value is therefore given by:

$$V(\phi) = [1 - \phi(1-\delta)]\,\mu RT + m + \phi B \tag{2}$$

or equivalently,

$$V(\phi) = \begin{cases} \mu RT + m & \text{when } \phi = 0 \\ \delta\mu RT + m + \beta RT & \text{when } \phi = 1 \end{cases}$$

So, when the agent appropriates proprietary information there are two effects on her income. First, her income goes up due to the direct payment from the principal's rivals who pay for the information, and also due to her ability to enter the output market as a competitor. Second, since information leakage erodes the principal's market share the agent's payment from the principal is reduced since it is a function of the principal's revenue.[6]

We can express the agent's value when information is leaked using (2):

$$V(1) = V(0) + \Delta(\mu) \tag{3}$$

where $\Delta(\mu) \equiv [\beta - (1-\delta)\mu]RT$ is the agent's valuation differential between leaking and not leaking. It is strictly decreasing in μ as long as R decreases with μ, which is true when the

[6]See Shell (1973) for a discussion of the importance of market share for inventive activities.

demand faced by the principal is constant elasticity. The relationship between $\Delta(\mu)$ and μ is therefore negative and is depicted in Figure 2. Let μ_C be the critical value such that $\Delta(\mu_C) = 0$. (In fact, $\mu_C = \frac{\beta}{1-\delta}$.) Thus, for any $\mu > \mu_C$, $\Delta(\mu) < 0$ which means the value of not leaking is higher than the value of leaking. In this case, the performance-dependent royalty payment is high enough to discourage leakage of information. On the other hand, for $\mu < \mu_C$, the agent would leak information leading to an erosion of the market share of the host production firm. The agent will be indifferent when $\mu = \mu_C$. Summarizing, we have, in equilibrium,

$$\phi(\mu) = \begin{cases} 0 & \text{if } \mu > \mu_C \\ 1 & \text{if } \mu < \mu_C \end{cases} \tag{4}$$

3.2 The Optimal Outsourcing Contract

In this subsection we determine what type of contract the principal (i.e. the production firm) will offer the agent (i.e. the research firm). As mentioned above, we assume that the royalty contract has two components, a fixed payment m and a payment contingent on sales $\mu p(x)x$. So, the two parameters (m, μ) define the contract. It is useful to define $Q(\mu)$, the principal's gross profit (excluding setup cost) before they make the fixed payment to the research firm.

$$\begin{aligned} Q(\mu) &\equiv [1-\phi(1-\delta)]\, x\,[p(x)(1-\mu)-(1-\lambda)c]\, T \\ &= \begin{cases} x\,[p(x)(1-\mu)-(1-\lambda)c]\, T & \text{when } \phi = 0 \\ \delta x\,[p(x)(1-\mu)-(1-\lambda)c]\, T & \text{when } \phi = 1 \end{cases} \end{aligned} \tag{5}$$

Then it follows that for any particular response by the agent $\phi(\mu)$, the principal's gross profit under outsourcing with a royalty contract (μ, m) is:

$$\begin{aligned} \Pi(\mu, m) &= Q(\mu) - m \\ &= \begin{cases} x\,[p(x)(1-\mu)-(1-\lambda)c]\, T - m & \text{when } \phi = 0 \\ \delta x\,[p(x)(1-\mu)-(1-\lambda)c]\, T - m & \text{when } \phi = 1 \end{cases} \end{aligned} \tag{6}$$

which is decreasing in μ and discontinuous at $\mu = \mu_C$. Figure 3 plots $Q(\mu)$ against μ. Clearly, $Q(\mu)$ is decreasing in μ and discontinuous at $\mu = \mu_C$. It is shown in the appendix that the slope of $Q(\mu)$ is steeper when $\mu > \mu_C$ (line segment BA in Figure 3 and slope of $Q(\mu)$ is RT) than when $\mu < \mu_C$ (line segment DC in Figure 3 and here the slope of $Q(\mu)$ is δRT). So, profits, including the fixed payment, are always decreasing in the contingent payment μ, and jump up at the critical point where $\mu = \mu_C$. This occurs because as μ increases towards μ_C, $Q(\mu)$ is falling but at $\mu = \mu_C$, ϕ switches from 1 to 0 meaning that μ has reached a high enough value that it does not pay the research firm to leak information.

The next element in determining the optimal contract is to consider the production firm's willingness to trade off between μ and m. Let Π_0 denote the gross profit of the firm under in-house R&D (excluding the fixed setup cost). For a given value of Π_0, we can define an iso-profit curve for each production firm, given by,

$$\Pi(\mu, m) = \Pi_0 \tag{7}$$

The curve defines combinations of μ and m that leave the principal indifferent between outsourcing and conducting in-house R&D. We can then use (7) to find how (μ, m) vary along the iso-profit curve with gross profit equal to Π_0 (see Figure 4.) An iso-profit curve closer to the origin is associated with a higher value of gross profit under in-house R&D. Totally differentiating (6) with respect to μ and m, we can show (in the appendix) that

$$\left|\frac{d\mu}{dm}\right|_{\Pi_0}^{\mu>\mu_C} = \frac{1}{RT} < \frac{1}{\delta RT} = \left|\frac{d\mu}{dm}\right|_{\Pi_0}^{\mu<\mu_C} \quad \text{at } \mu = \mu_C,$$

that is, the iso-profit curve is flatter if $\mu > \mu_C$ (segment AB in Figure 4) than if $\mu < \mu_C$ (segment CD in Figure 4) at least in the neighborhood of $\mu = \mu_C$.

If the principal does not outsource the R&D then it has to pay the in-house researcher a wage of W. The gross profit of the principal is therefore given by

$$\Pi_0 \equiv x_0^{IH}[p(x_0^{IH}) - c](T - L) - W \tag{8}$$

where x_0^{IH} is the optimal output of the firm when it conducts in-house R&D.[7] Zero profit condition under free entry and monopolistic competition market structure implies that $\Pi_0 =$

[7]Specifically, x_0^{IH} is the value of x that maximizes $x[p(x) - c]$. See the appendix for a derivation x_0^{IH}.

k_0, where k_0 is the reservation value which may also be thought of as the fixed entry/setup cost facing the principal. Voluntary participation by the principal in R&D outsourcing requires that the principal's payoff from R&D outsourcing be at least as high as her payoff under in-house R&D. This implies the inequality $\Pi(\mu, m) \geq \Pi_0$. That is, the participation constraint requires:

Assumption 4: $\Pi(\mu, m) \geq x_0^{IH}[p(x_0^{IH}) - c](T - L) - W = k_0$.

Later in the paper, we shall show that any change in W, T, L or c would affect entry or exit of firms in the output market, which would affect whether R&D will be outsourced in equilibrium.

4 Outsourcing Versus In-House R&D

We next focus on the decision to outsource innovation versus doing the cost reduction innovation in-house.

First, we characterize the indifference curve of the agent in (m, μ) space. The indifference curve is the locus of pairs of (m, μ) for which $V(\phi) = V_0$ (a constant). Note that, unlike the iso-profit locus of the principal, there is no discontinuity of the indifference curve where $\mu = \mu_C$ (ϕ switches from 0 to 1). This follows directly from (3), which shows that $V(0) = V(1)$ when $\mu = \mu_C$. Next, we compare the slopes of the indifference curve for $\mu > \mu_C$ and when $\mu < \mu_C$. Using (2), we totally differentiate $V(\phi) = V_0$ with respect to m and μ. Then, it can be shown (in the appendix) that

$$\left|\frac{d\mu}{dm}\right|_{V_0}^{\mu>\mu_C} = \frac{1}{RT - \mu T\left|\frac{dR}{d\mu}\right|} < \frac{1}{\delta RT - \delta\mu T\left|\frac{dR}{d\mu}\right| - \beta T\left|\frac{dR}{d\mu}\right|} = \left|\frac{d\mu}{dm}\right|_{V_0}^{\mu<\mu_C} \text{ at } \mu = \mu_C.$$

That is, the indifference curve is flatter when $\mu > \mu_C$ than when $\mu < \mu_C$, at least at $\mu = \mu_C$. That means the indifference curve is kinked outward at $\mu = \mu_C$. Please refer to Figure 5. Moreover, the indifference curve has higher utility in the northeast direction. To solve for the equilibrium (m, μ) combination, we need to make one more assumption:

Assumption 5: *The principal does not have any bargaining power, and so all the surplus accrues to the agent.*

This will be the case, for example, when there is limited supply of potential agents. This could occur because there are few researchers who have a high ability to cooperate with other researchers to form a subcontracting firm but a large number of output firms. This assumption makes the solution to our problem straightforward since, given the various contracts offered by the principal, the agent selects the one she most prefers.[8] Therefore, the agent solves[9]

$$\max_{\mu,m} \quad V(\mu,\ m) \quad \text{s.t.} \quad \Pi(\mu,\ m) = \Pi_0$$

It can be shown in the appendix that

$$\left|\frac{d\mu}{dm}\right|_{V_0} > \left|\frac{d\mu}{dm}\right|_{\Pi_0} \qquad \text{for any given } \mu.$$

That is, the indifference curve is always steeper than the iso-profit curves for any given μ. We can also conclude that the iso-profit curves and the indifference curves are convex in each of the zones $\mu < \mu_C$ and $\mu > \mu_C$.

We can immediately identify two cases, Case I and Case II. Which Case occurs depends on how much the indifference curve is steeper than the iso-profit line. If the indifference curve is much steeper than the iso-profit line then we have Case I shown in Figure 5. Otherwise, we have Case II shown in Figure 6.

In Case I, $\left|\frac{dR}{d\mu}\right|$ is large, meaning that the pre-sharing revenue of the principal is greatly reduced by an increase in revenue-share of the agent. Here the agent must be given a larger increment in revenue-share to compensate for each dollar reduction in lump-sum payment. We call this trade-off the marginal rate of substitution of the agent. On the other hand,

[8] When the principal has some bargaining power, one may derive an optimal contract maximizing the joint surplus in a way similar to Burdett and Mortensen (1981) or Laing, et al. (1995). The main findings concerning the different roles of μ and m in alleviating the agency problem remain unchanged.

[9] Thus, the optimal contract obtained is an optimal incentive contract in the sense of Harris and Raviv (1979) and Milgrom (1988).

for each dollar reduction in lump-sum payment, the principal is willing to give up more revenue-share. This trade-off is the “price” faced by the agent. Consider the scenario in which leakage occurs, $\phi = 1$. In Case I, the marginal rate of substitution is much greater than the price at each μ, and so the agent is less willing to substitute μ for m. Thus, we have a corner solution under outsourcing as shown in Figure 5, and the agent would rather take a pure lump-sum contract from the principal. In Case II, $\left|\frac{dR}{d\mu}\right|$ is relatively small. Therefore, the marginal rate of substitution of the agent is not much higher than the price for each μ. So, the agent is more willing to substitute μ for m. Thus, we have an interior solution, as shown in Figure 6, where we have a mixed contract with a positive lump sum payment and a positive share of revenue. Note that, as mentioned before, the curves in these diagrams are not really straight lines, but are shown that way for simplicity only.

Each case has two subcases, that depend on the wage rate relative to the lump-sum equivalent that the agent can extract from the principal under R&D outsourcing.

(i) Case I: Agents are less willing to substitute μ for m

(IA) When $W < \overline{OE}$, i.e. the wage is less than the lump-sum equivalent of the researcher's payoff under outsourcing, we have Case IA, as shown in Figure 5. In this case, there is outsourcing, since the wage of the researcher when she works in-house is less than her payoff when she subcontracts research work from the principal. *The outsourcing contract entails a lump sum payment without revenue sharing.* As a result, *there is leakage of information* of the principal by the agent. Given this outsourcing contract, the agent strictly prefers leaking, since the payoff from leakage is equal to βRT. The principal, on the other hand, prefers no leakage, but can do nothing to prevent it, because it is impossible to monitor or verify leakage, according to Assumption 2. (Improved protection of trade secret can only reduce β, but not make it zero.)

(IB) When $W > \overline{OE}$, we have Case IB, as shown in Figure 5. In this case, there is always in-house R&D, because the wage the agent earns from working as the principal's employee is higher than the payoff she gets if she works as a subcontractor of the principal.

(ii) Case II: Agents are more willing to substitute μ for m

(IIA) When $W < \overline{OE}$, there is outsourcing with *a mixed contract* (m, μ) such that μ is set equal to μ_C and m is set positive. *There will be no information leakage.* Under this contract, the agent is indifferent between leaking and not leaking information, but the principal strictly prefers no leakage, since the loss from leakage is strictly positive. In other words, if the agent leaks information, the principal would be better off switching to in-house R&D the next period. Since the agent does not want this to happen, it has incentive to refrain from leaking.

(IIB) When $W > \overline{OE}$, there is in-house R&D.

Assumption 4 says that, under in-house R&D, the quantity demanded x_0^{IH} faced by the principal is determined by W and other parameters, as given by,

$$\Pi_0(x_0^{IH}) = x_0^{IH}[p(x_0^{IH}) - c](T - L) - W = k_0. \tag{9}$$

This equation signifies that, for a given demand schedule and competitive wage, the expected profit of the principal must be such that there is no incentive to enter into or exit from the output market. When parameters such as W, T, L and c change so that the resulting Π_0 is temporarily above (below) the fixed cost, there would be entry into (exit from) the output market to lower (raise) x_0^{IH} to the appropriate level to restore the equality.

On the other hand, we can obtain the relationship between the distance $\overline{OD}$ in Figures 5 and 6 and Π_0 from the iso-profit line (7). Note that $(\overline{OD}, 0)$ lies on the iso-profit line corresponding to $\Pi(m, \mu) = \Pi_0$ in Figure 5. We can interpret $\overline{OD}$ as the lump sum amount that the principal has to pay the agent in a outsourcing contract with zero revenue share for the agent, so as to keep the principal's profit equal to Π_0. At $\mu = 0$, we know that $\phi = 1$ from (4). Let x_0 and $p(x_0)$ be the output and price chosen optimally by the principal under

R&D outsourcing with a lump-sum contract. Thus, setting $\mu = 0$ and $\Pi(\mu, m) = \Pi_0$ in (5) and (6), we obtain

$$\Pi_0 = \delta x_0 \left[p(x_0) - (1-\lambda)c\right] T - \overline{OD}$$

which implies that

$$\overline{OD} = \delta x_0 \left[p(x_0) - (1-\lambda)c\right] T - \Pi_0. \tag{10}$$

The above equation says that the maximum lump-sum amount that the principal is willing to pay the agent in a outsourcing contract is lower if the principal's outside option (gross profit under in-house R&D) is higher, since the latter is the principal's "fall-back income".

On the other hand, (9) implies that

$$W = x_0^{IH}[p(x_0^{IH}) - c](T - L) - \Pi_0 \tag{11}$$

That is, free entry and exit in the output market dictates that a higher wage must be accompanied by exit of output firms so as to restore normal profits for the firms, given zero profit condition $\Pi_0 = k_0$.

From equations (10) and (11), we obtain

$$\overline{OD} - W = \left\{\delta x_0 \left[p(x_0) - (1-\lambda)c\right] T - x_0^{IH}[p(x_0^{IH}) - c](T - L)\right\} \tag{12}$$

From the appendix, it can be derived that

$$x_0 = x_0^{IH}(1-\lambda)^{-\epsilon} \qquad \text{and} \qquad p(x_0) = p(x_0^{IH})(1-\lambda).$$

Therefore,

$$\overline{OD} - W = x_0^{IH}[p(x_0^{IH}) - c]\left\{\delta(1-\lambda)^{1-\epsilon}T - (T - L)\right\}.$$

We next use these results to analyze the two cases.

4.1 Case I Results

We begin by considering Case I depicted in Figure 5. In this case $\overline{OD} = \overline{OE}$. That is, the maximum lump-sum-equivalent that the principal is willing to give up to maintain its gross profit of Π_0 is equal to the maximum lump-sum-equivalent that the agent can extract from the principal under outsourcing. Note that this makes sense: when only lump-sum payment contract can be sustained, the agent extracts the maximum lump-sum that the principal is willing to give up, because of Assumption 5. As shown in Figure 5, when $\overline{OE} - W$ is positive, there will be outsourcing of R&D; when $\overline{OE} - W$ is negative, there will be in-house R&D.

Now, let us examine the effects of changes in the various parameters on who would carry out R&D in equilibrium. It is clear from (9) that an increase in δ or λ has no effect on any parameters in the equation, and therefore they would have no effect on entry or exit in the monopolistically competitive output market. Hence, they do not affect the number of firms in the output market and do not affect x_0^{IH} or $p(x_0^{IH})$. From (12), it is clear that an increase in δ or λ would increase $\overline{OD} - W$, which tends to switch the firm from in-house to outsourced R&D. The intuition for this result is that an increase in δ means that less market share is lost from leakage and increasing λ means that there is more saving in production cost from outsourcing, so increases in either of these should lead to more outsourcing.

The effect of an increase in L is slightly harder to analyze, but still quite clear. An increase in L, which measures the delay in arrival of the innovation when doing R&D in-house, would initially lead to a decrease in Π_0, according to (8). This would lead to exit of firms from the output market. When there are fewer firms in the output market, the demand curve faced by each firm would shift out. This translates into a larger A when the demand faced by each firm is constant-elasticity of the form $x = Ap^{-\epsilon}$. It turns out that $p(x_0^{IH})$ would stay the same while x_0^{IH} would increase.[10] From (12), it is clear that $\overline{OD} - W$ increases.

[10] $x_0 = (\alpha/c)^\epsilon A$, and $p_0 = c/\alpha$, as shown in the appendix. Since p_0 is independent of A, it is unaffected by entry/exit. It should also be noted that if demand is linear of the form $p = B - bx$, it can be easily shown that $x_0 = (B - c)/(2b)$ and $p(x_0) = (B + c)/2$. Entry (exit) implies that b increases (decreases) Therefore, price is also independent of entry and exit.

Therefore, an increase in L tends to encourage a switch from in-house to outsourced R&D.

Next consider an increase in W. According to (9), an increase in W would, in equilibrium, lead to the exit of firms in the output market and an increase in x_0^{IH} without affecting $p(x_0^{IH})$, if demand has a constant elasticity. From (12), it is clear that $\overline{OD} - W$ increases. However, the sign of $\overline{OD} - W$ would not be affected since the equilibrium output price is unaffected by entry and exit in the output market, as explained in the last footnote. Therefore, an increase in W has little effect on who would carry out R&D in equilibrium. Similarly, an increase in the fixed cost of entry k_0 would yield the same result. It increases the equilibrium value of Π_0, which then has the same effect as an increase in W, as shown in (9) and (12).[11]

In the current setting, an increase in W causes entry into the output market, which not only increases x_0^{IH}, but also x_0. In the end, W has no effect on $\overline{OD} - W$, and therefore it has no effect on the mode of R&D. In fact, an even more counter-intuitive result is that increases in W would actually make it more likely for outsourcing to occur if there is a non-trivial fixed cost in setting up a subcontractor by the workers. Interestingly, if changes in W do not cause adjustments in the output market, we have the opposite result: (10) implies that increases in W would reduce $\overline{OD} - W$, which would reduce the likelihood of outsourcing. This is because W is the outside option of the agent in the negotiation on the outsourcing contract, and an increase in W lowers the potential gains from the cooperative contract. *This result indicates that principal-agent models that fail to capture the market adjustment effect can generate misleading results.*

According to (9), an increase in T leads to a decrease in x_0^{IH} in such a way as to keep $x_0^{IH}(T - L)$ unchanged, since $p(x_0^{IH})$ would stay unchanged as A decreases due to entry of new firms in the output market. Therefore, $x_0^{IH}T$ has to decrease in equilibrium. From (12), it is clear that $\overline{OD} - W$ decreases. However, the effect on the sign of $\overline{OD} - W$ can be quite different. Assume the demand faced by each firm is constant-elasticity of the form $x = Ap^{-\epsilon}$

[11] If there is a fixed setup cost for an agent to become a partner of a subcontracting firm, then an increase in W would tend to switch the equilibrium to R&D outsourcing, since it is the magnitude, and not just the sign, of $\overline{OD} - W$ that matters now.

and $\epsilon = 1/(1-\alpha)$. We show later that, if $\delta < (1-\lambda)^{\epsilon-1}$, an increase in T could eventually switch the sign of $\overline{OD} - W$ from positive to negative, favoring in-house R&D. Therefore, an increase in T would tend to tip the balance towards in-house R&D in equilibrium if δ, λ or α is sufficiently small. In other words, if the advantage of outsourcing is not too great, a longer T, which allows the principal adopting in-house R&D to earn profits for longer period of time, can make in-house R&D more worthwhile. If $\delta > (1-\lambda)^{\epsilon-1}$, however, outsourcing is always the equilibrium outcome, since no value of T would ever make the sign of $\overline{OD} - W$ negative — the advantages of outsourcing are too great to be overcome by any increase in T to enhance the benefits of in-house R&D.[12]

We summarize our findings in the following proposition:

Proposition 1: *Under Assumptions 1-5 and Case I, the institutional arrangement for R&D exhibits the following features:*

(i) *a decrease in the cost of information leakage (higher δ), an decrease in production cost as a result of research outsourcing (higher λ), or a more significant shortening of the innovation time from outsourcing vis-a-vis in-house R&D (higher L) tend to switch the firm from conducting in-house R&D to outsourcing it;*

(ii) *an increase in the length of product cycle (higher T) tends to switch the principal to in-house R&D even when the setup cost of becoming a partner of a subcontractor is trivial, as long as δ and λ are sufficiently small, i.e., when the advantages of outsourcing are not too great;*

(iii) *as long as $\delta > (1-\lambda)^{\epsilon-1}$, R&D is always outsourced in equilibrium;*

(iv) *an increase in the competitive wage for researchers (higher W) has little effect on who carries out R&D in equilibrium if the setup cost of becoming a partner of a subcontracting firm is trivial.*

[12] If there is a fixed set-up cost for an agent to become a partner of a subcontracting firm, then an increase in T would unambiguously push the equilibrium towards in-house R&D, since it is the magnitude, and not just the sign, of $\overline{OD} - W$ that matters now.

The fact that changes in W have no effect on who carries out R&D in equilibrium is quite surprising, since one would expect an increase in the wage to induce agents to become employees rather than partners in subcontracting firms. This argument is not correct because it ignores the fact that an increase in W leads to the exit of firms from the output market and shifts the demand curve out for each firm that stays. This increases the profit of each principal if outsourcing fees stay the same. Therefore, the agents can extract more surplus from the principal in an outsourcing contract. Thus, both $\overline{OD}$ and W increase. In other words, though the subcontractor gets a higher wage while working as the principal's employee, she also gets more fees from the principal through outsourcing. It turns out that an increase in W affects $\overline{OD}+\Pi_0$ and $W+\Pi_0$ equi-proportionally. Thus, it would not change the sign of $\overline{OD}-W$, and so it would not change who carries out R&D in equilibrium.

To try and get an understanding for how the various parameters affect the outsourcing decision we adopt a particular functional form for demand and solve for the critical value of each of the key variables. Hence, we can determine the threshold values of δ, λ and L/T that result in outsourcing being the equilibrium outcome. Assume the demand faced by each firm is constant-elasticity of the form $x = Ap^{-\epsilon}$ with $\epsilon = 1/(1-\alpha)$. Using results from the appendix we can easily show from (12) that

$$\overline{OD} - W = \left(\frac{\alpha}{c}\right)^{\frac{\alpha}{1-\alpha}} A(1-\alpha)\left\{\delta(1-\lambda)^{\frac{-\alpha}{1-\alpha}}T - (T-L)\right\}. \tag{13}$$

Now we can use this expression to solve for the threshold values (δ, L/T) that drive $\overline{OD}-W$ to zero for given λ and α:

$$\delta = (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right) \tag{14}$$

The threshold values of δ and L/T must be between 0 and 1. When L/T is large, the threshold value of δ is small. In other words, when the delayed arrival disadvantage of in-house R&D is strong, the loss of profit from leakage $(1-\delta)$ can be higher and the principal will still choose R&D outsourcing. Thus, the (δ , L/T) locus is downward sloping. The horizontal intercept is at $L/T = 1$. In Figure 7a we graph the relationship between δ and

L/T. The solid line indicates pairs of critical values of δ and L/T for which outsourcing and in-house R&D generate equal payoffs to the agent. Points above the solid line give parameter values for which R&D outsourcing occurs while points below the line indicate in-house R&D.

Changes in the cost reduction parameter λ affect the equilibrium in a straightforward way. When λ approaches zero, the advantage in cost reduction by outsourcing vanishes and the only advantage of outsourcing is more rapid delivery of the cost reduction technology. Figure 7b illustrates the $\lambda = 0$ case. One can see that lower λ means that the boundary between the two regimes shifts up. This means that the set of parameters for which outsourcing takes place shrinks and in-house R&D is more likely to be the equilibrium. This makes sense since, with lower λ, there are fewer advantages of outsourcing.

When λ is close to one, innovation reduces production cost to almost zero, and so the cost advantage of outsourcing reaches the maximum. As one can see from Figure 7c, all values of parameters will support R&D outsourcing as the equilibrium as λ approaches one.

If δ is sufficiently large or L sufficiently close to T, in equilibrium R&D is always outsourced even when λ is zero. That is, if the leakage disadvantage of R&D outsourcing is sufficiently small or the innovation speed disadvantage of in-house R&D is sufficiently large, outsourcing can be supported as an equilibrium even if there is no saving in unit production cost from outsourcing R&D as opposed to in-house R&D.

4.2 Case II Results

In Case II depicted in Figure 6, $\overline{OD} < \overline{OE}$. That is, the maximum lump-sum-equivalent that the principal is willing to give up so as to maintain its gross profit of Π_0 is smaller than the maximum lump-sum-equivalent that the agent can extract from the principal under outsourcing. In other words, the agent can extract more than the maximum lump-sum that the principal is willing to give up, thanks to the possibility of a mixed contract with positive μ and m. Since there is outsourcing iff $\overline{OE} - W > 0$, a sufficient but not necessary condition for outsourcing is that $\overline{OD} - W > 0$. In other words, we have weaker conditions than

Proposition 1 for outsourcing to be the equilibrium outcome:

Proposition 2: *The set of parameters that support outsourcing in Case I will also support outsourcing in Case II. However, even with the set of parameters that support in-house R&D in Case I, outsourcing may arise as an equilibrium outcome in Case II, due to the possibility of writing a mixed contract.*

That is, when outsourcing does not entail a lump-sum contract, there exists some wage level which is higher than the maximum lump-sum the principal is willing to pay the agent, but the agent is still willing to subcontract R&D from the principal. This is because the agent is able to extract a mixed contract from the principal which yields a higher payoff to the agent than the wage. Therefore, allowing for a performance-based component in the outsourcing contract can increase the chance of outsourcing.

Although β has no effect on who carry out R&D in Case I, it has an effect in Case II. Moreover, starting from Case I, the regime will eventually switch to Case II as β decreases. From (3), we can deduce that $\mu_C = \beta/(1-\delta)$. Since a reduction in β reduces μ_C, it extends line AB in Figure 6 further down and to the right. Moreover, line BE in Figure 6 is also flatter, according to the derivation in the appendix. Therefore, $\overline{OE}$ is longer, which makes $\overline{OE} - W > 0$ more likely. Thus a decrease in β makes R&D outsourcing more likely. In the extreme case when $\beta \to 0$, so that $\mu_C \to 0$, and line AB in Figure 6 approaches the m-axis, getting arbitrarily close to the point where $m = x_0 \left[p(x_0) - (1-\lambda)c\right] T$. This is the lump-sum equivalent of a mixed contract in equilibrium. Since $W = x_0^{IH}[p(x_0^{IH}) - c](T-L) - \Pi_0$, and the former expression is greater than the latter, we can conclude that there must be R&D outsourcing when $\beta \to 0$, i.e. when there is very little for the agent to gain from appropriating information from the principal. Moreover, there will be no information leakage in equilibrium. Hence, we can state

Proposition 3: *A reduction in* β makes R&D outsourcing more likely. When $\beta \to 0$, R&D outsourcing must be the equilibrium.

4.3 Non-trivial setup cost for subcontractor

As discussed above, if the setup cost for being a partner of a subcontractor is non-trivial, effects of W or T on the equilibrium outcome would be sharper. We state the result in the following proposition:

Proposition 4: *Under Assumptions 1-5 with a non-trivial setup cost for an agent to become a subcontractor, the institutional arrangement for R&D possesses the same features in part (i) of Proposition 1; moreover, the following properties can be established:*

(i) *an increase in the competitive wage for researchers (higher W) tends to favor R&D outsourcing in equilibrium;*

(ii) *an increase in the length of product cycle (higher T) tends to favor in-house R&D in equilibrium.*

Notice that result (i) is especially interesting since it is opposite to what one would expect if W did not affect entry and exit in the output market. This would be the case, for example, when entry into the output market is blockaded, so that the principal can earn super-normal profit. In that case, (10) indicates that increases in W would *reduce* $\overline{OD} - W$, thus making in-house R&D more likely.

5 Welfare Implications

Having worked out the conditions in which the production firm favors R&D outsourcing, we now inquire whether R&D outsourcing or in-house research results in higher economic welfare. In the absence of informational leakage problems, The fact that the research firm can do research faster and better implies that R&D outsourcing is more efficient than in-house research and thus is associated with higher welfare. Information leakage causes the production firm to under-outsource R&D compared to the social optimum.

This suggests a role for policy. Can appropriate policies alleviate the social inefficiency resulting from the information leakage problem? Suppose that the government has no direct control over the actions of research firms. For any given unit production cost and competitive research wage, consider a policy of tighter protection of trade secrets. Such a policy would generate two effects: (i) it reduces the principal's loss associated with information leakage (i.e., higher δ), and (ii) it reduces the agent's benefit from leaking information (i.e., lower β). Propositions 1 and 3 say that both effects increase the chance of R&D outsourcing. Therefore, stronger protection of trade secret improves welfare.

We summarize these results in Proposition 5.

Proposition 5: *Under Assumptions 1-5, a stronger protection of trade secret reduces the principal's losses and the agent's gains from information leakage and so it improves social efficiency.*

6 Concluding Remarks

This paper is among the first to explore the economics of R&D outsourcing. We believe a principal-agent framework is appropriate for this purpose because the central issue in R&D outsourcing is the possibility of leakage of trade secrets and the subsequent erosion of the competitive advantage of the principal. Here, a very simple model reveals a rich array of principles. We highlight a few interesting findings. First, the optimal outsourcing contract may or may not be performance-based. In the first case, lump-sum cum revenue-sharing contract is the equilibrium outcome, and there is no information leakage. In the second case, the equilibrium is a lump-sum contract, and there will be information leakage. The allowance for revenue-sharing between the principal and the agent increases the likelihood of R&D outsourcing because it eliminates information leakage. Since outsourcing is efficiency-enhancing, allowing for the possibility of revenue-sharing as part of a contractual arrangement is welfare improving. Second, a related point, is that even an informed principal who foresees the leakage of information may still find it optimal to design a contract in such a way as to allow the leakage to occur. This is the second best outcome when the principal cannot monitor or verify leakage. Third, an increase in the outside option of the researcher in general makes the cooperative outsourcing agreement more likely to reach. This result runs counter to the one obtained without accounting for entry and exit in the output market. The result arises because increases in this outside option induce adjustments in the output market, which enlarges the potential gains from cooperation. This indicates that principal-agent models that ignore the market adjustment effects can yield misleading results. Finally, since information leakage reduces the chance of outsourcing R&D, which is efficiency-enhancing, any measure that reduces the gains of the agent from appropriating the principal's proprietary information or reduces the losses of the principal from appropriation would increase welfare. Increased protection of trade secrets is one of such measures.

What happens if we introduce demand uncertainty? If both the principal and the agent have linear value functions, our findings remain the same. Suppose we allow the agent to be risk averse. Then under the same competitive wage, the principal must provide an outsourcing contract with higher compensation in order to maintain the agent's indifference. The resulting increase in the compensation cost therefore discourages the principal from outsourcing R&D. That is, demand uncertainty might reduce R&D outsourcing.

7 Appendix

This appendix proves that the slope of the agent's indifference curve is always steeper than that of the iso-profit line of the principal at any given μ. Now, the principal's output is x. Its pre-sharing revenue per period with no leaking of trade secret is defined as $R \equiv xp(x)$. Suppose also that the demand curve faced by the principal is constant-elasticity of the form $x = Ap^{-\epsilon}$ where A and ϵ are both constants. Define $\epsilon = 1/(1-\alpha)$. We can easily show that $R = x^{\alpha}A^{1-\alpha}$.

When there is **in-house R&D**, total gross profit $\Pi_0 = x[p(x) - c](T - L) - W = (R - cx)(T - L) - W$, where T, L and W are treated as parametric by the principal. Therefore, profit-maximization implies $\frac{d\Pi_0}{dx} = 0$, which in turn implies that

$$\begin{aligned} x_0^{IH} &= \left(\frac{\alpha}{c}\right)^{\epsilon} A \\ p_0^{IH} &\equiv p(x_0^{IH}) = \frac{c}{\alpha} \\ R_0^{IH} &\equiv x_0^{IH} p_0^{IH} = \left(\frac{\alpha}{c}\right)^{\epsilon-1} A. \end{aligned}$$

Under R&D outsourcing, (5) and (6) imply that the principal's total net profit is

$$\Pi(\mu, m) = \begin{cases} -m + x\left[p(1-\mu) - (1-\lambda)c\right]T & \text{when } \phi = 0 \\ -m + \delta x\left[p(1-\mu) - (1-\lambda)c\right]T & \text{when } \phi = 1 \end{cases}$$

In both cases of $\phi = 0$ and $\phi = 1$, profit-maximization by the principal yields the same x, p, and R as a function of μ. In choosing the optimal x, the principal treats m, μ, λ, c and T as parametric. Profit-maximization implies $\frac{d\Pi}{dx} = 0$, which in turn implies that

$$\begin{aligned} x &= \left[\frac{(1-\mu)\alpha}{c(1-\lambda)}\right]^{\epsilon} A \\ p &= \frac{c(1-\lambda)}{(1-\mu)\alpha} \\ R &= \left[\frac{(1-\mu)\alpha}{c(1-\lambda)}\right]^{\epsilon-1} A \end{aligned}$$

where $\frac{dR}{d\mu} = -A\left(\frac{\alpha}{1-\alpha}\right)\left[\frac{\alpha}{c(1-\lambda)}\right]^{\frac{\alpha}{1-\alpha}}(1-\mu)^{\frac{2\alpha-1}{1-\alpha}} < 0$. This explains why $\Delta(\mu)$ decreases with μ in (14). Note that x_0 and $p_0 \equiv p(x_0)$ can be obtained by setting $\mu = 0$.

Now, recall from (2) that,

$$V(\phi) = \begin{cases} R\mu T + m & \text{when } \phi = 0 \\ \delta R\mu T + m + \beta RT & \text{when } \phi = 1 \end{cases}$$

from which we obtain, for $\phi = 0$,

$$\left|\frac{d\mu}{dm}\right|_{V_0} = \left|\frac{dV(0)/dm}{dV(0)/d\mu}\right| = \frac{1}{RT + \mu T\frac{dR}{d\mu}} = \frac{1}{RT - \mu T\left|\frac{dR}{d\mu}\right|} \tag{A1}$$

Also, (5) and (6) imply that

$$\Pi(\mu, m) = \begin{cases} -m + x\left[p(1-\mu) - (1-\lambda)c\right]T & \text{when } \phi = 0 \\ -m + \delta x\left[p(1-\mu) - (1-\lambda)c\right]T & \text{when } \phi = 1 \end{cases}$$

Invoking envelope theorem, since $\partial\Pi/\partial x = 0$ due to profit maximization, for $\phi = 0$,

$$\frac{d\Pi}{d\mu} = \frac{\partial\Pi}{\partial\mu} + \frac{\partial\Pi}{\partial x}\cdot\frac{\partial x}{\partial\mu} = \frac{\partial\Pi}{\partial\mu} = -RT$$

Therefore, for $\phi = 0$,

$$\left|\frac{d\mu}{dm}\right|_{\Pi_0} = \left|\frac{d\Pi/dm}{d\Pi/d\mu}\right|_{\phi=0} = \frac{1}{RT} \tag{A2}$$

Comparing (A1) and (A2), for $\phi = 0$,

$$\left|\frac{d\mu}{dm}\right|_{V_0} = \frac{1}{RT - \mu T\left|\frac{dR}{d\mu}\right|} > \frac{1}{RT} = \left|\frac{d\mu}{dm}\right|_{\Pi_0} \quad \text{for a given } \mu.$$

That is, the indifference curve is always steeper than the iso-profit curve for any given μ for $\phi = 0$.

We can similarly prove from (2), (5) and (6) that, for $\phi = 1$,

$$\left|\frac{d\mu}{dm}\right|_{V_0} = \frac{1}{\delta RT - \delta\mu T\left|\frac{dR}{d\mu}\right| - \beta T\left|\frac{dR}{d\mu}\right|} > \frac{1}{\delta RT} = \left|\frac{d\mu}{dm}\right|_{\Pi_0} \quad \text{for a given } \mu.$$

That is, the indifference curve is always steeper than the iso-profit curve for any given μ for $\phi = 1$.

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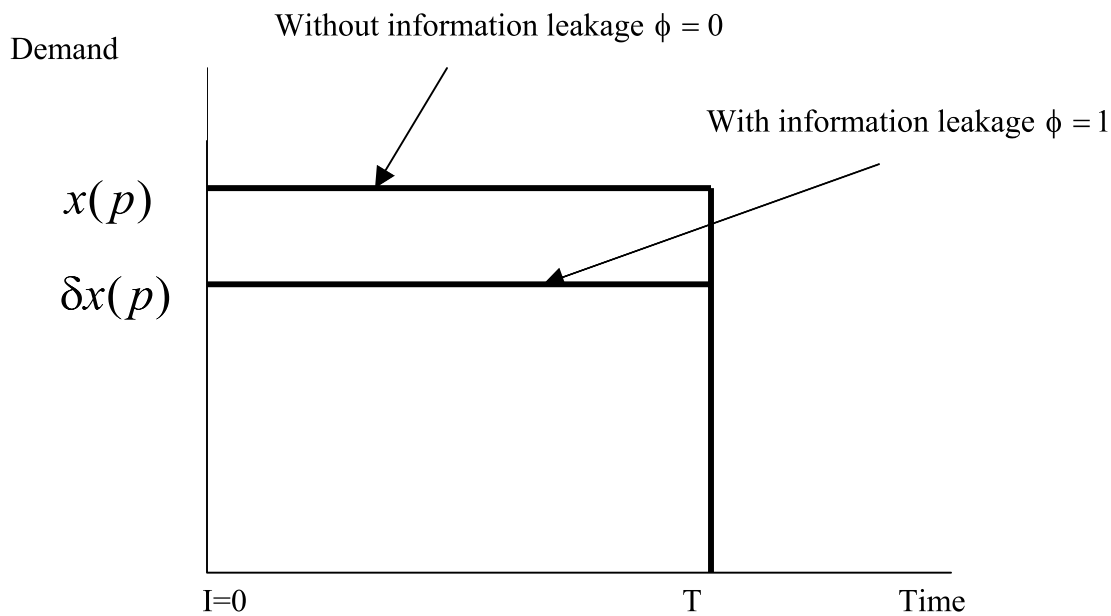

Figure 1. Demand faced by production firm under R&D outsourcing, with or without information leakage.

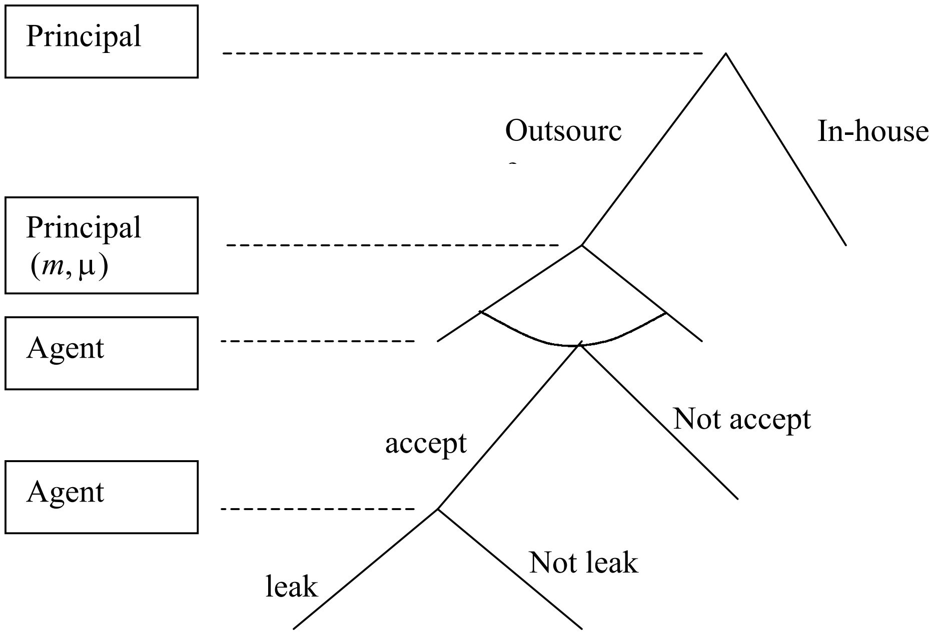

Figure 1a. The Game Tree.

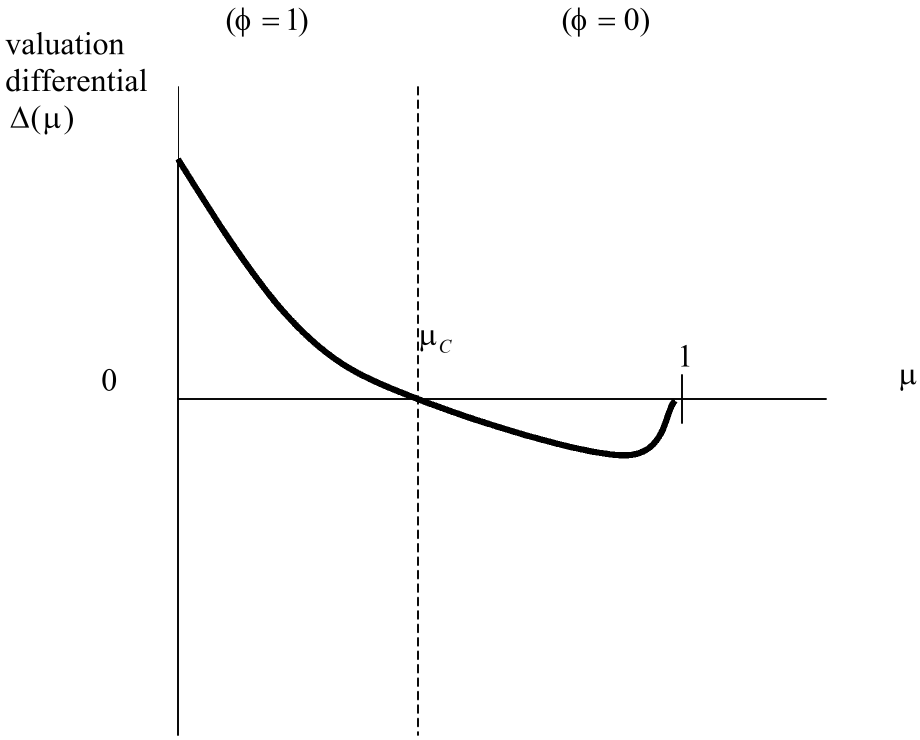

Figure 2. Agent's valuation differential between leakage and no leakage.

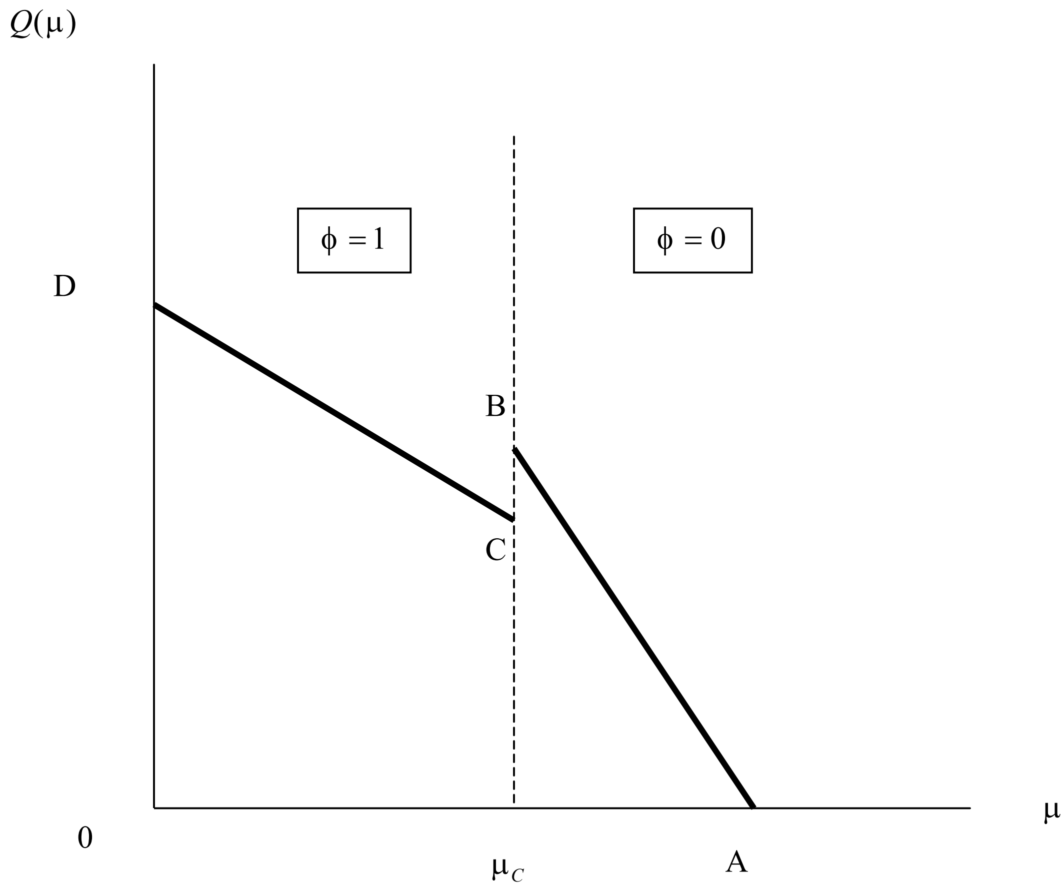

Figure 3

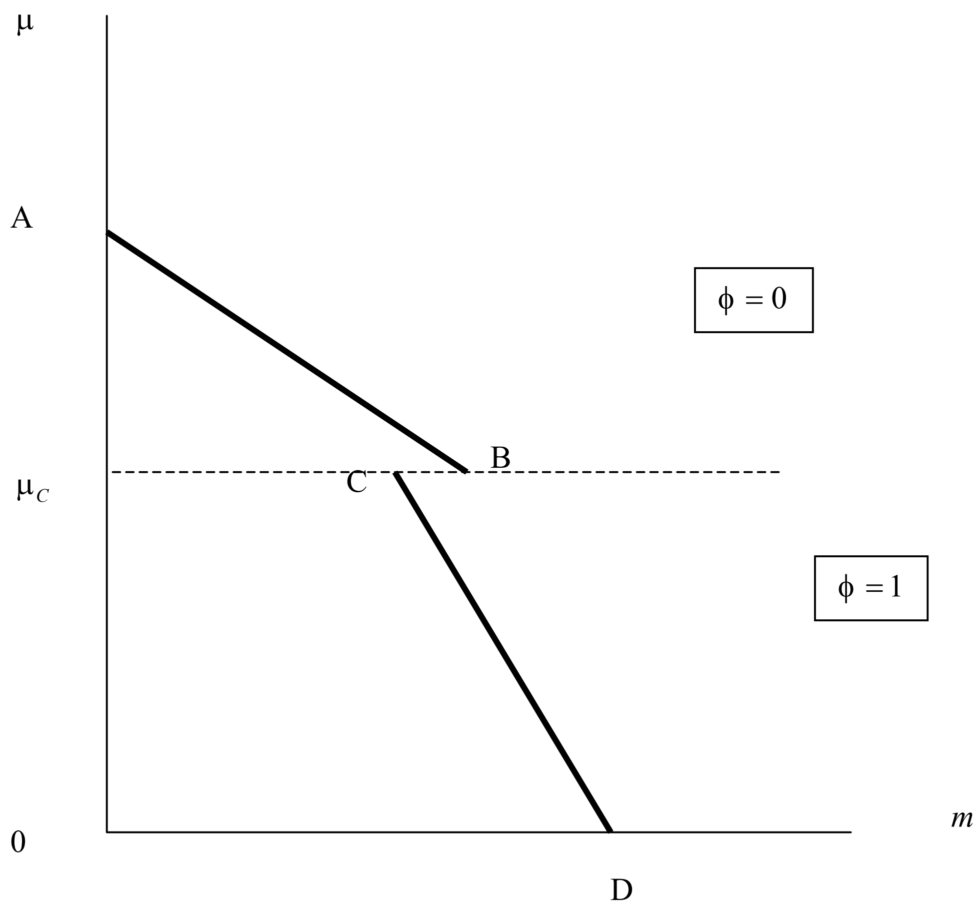

Figure 4.

Isoprofit line of the principal with profit equal to Π_0.

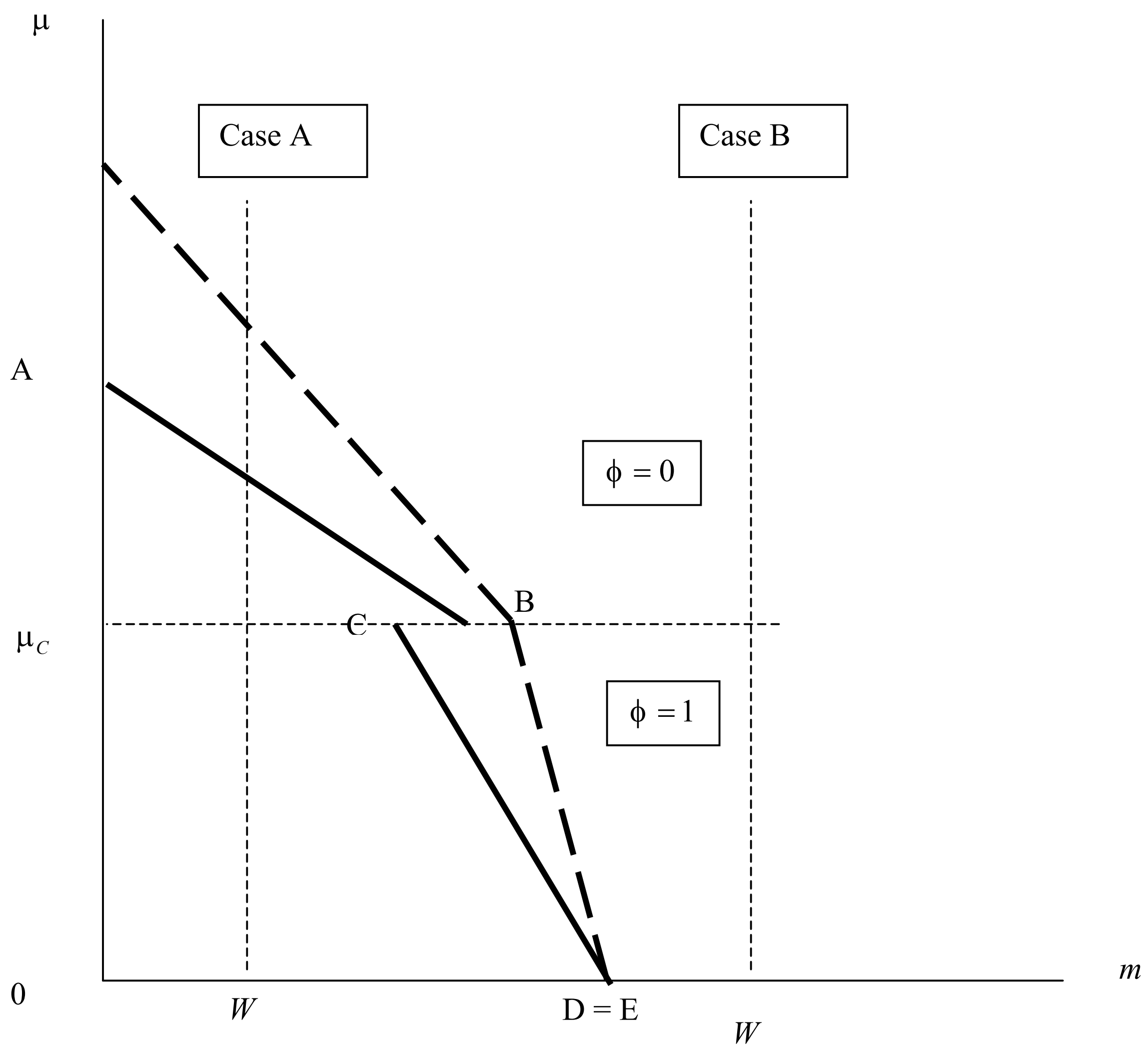

Figure 5. Case I:
A. Outsource with $\mu = 0$.
B. In-house R&D.

indifference curve of the agent

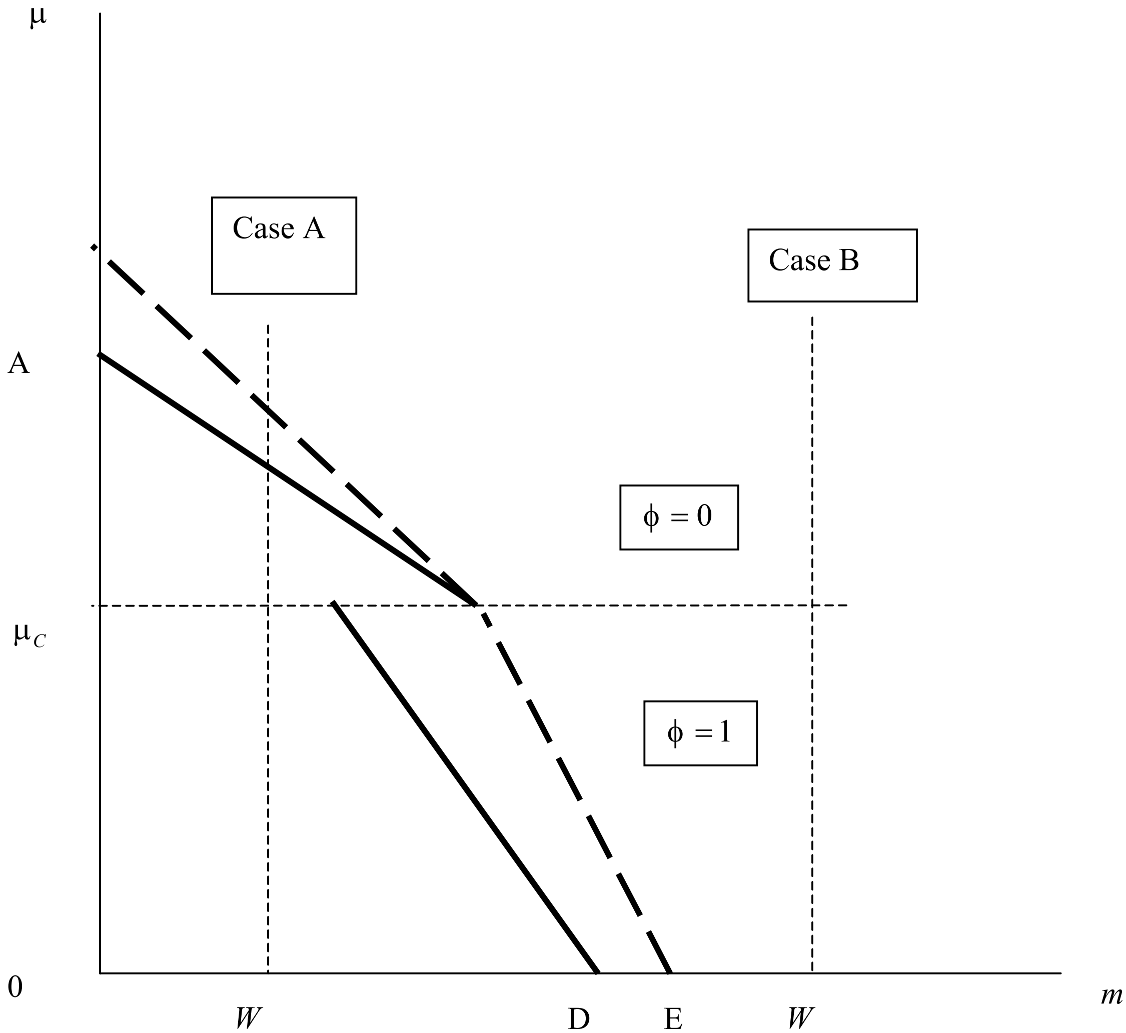

Figure 6. Case II:
A. Outsource with positive μ and m.
B. In-house R&D.

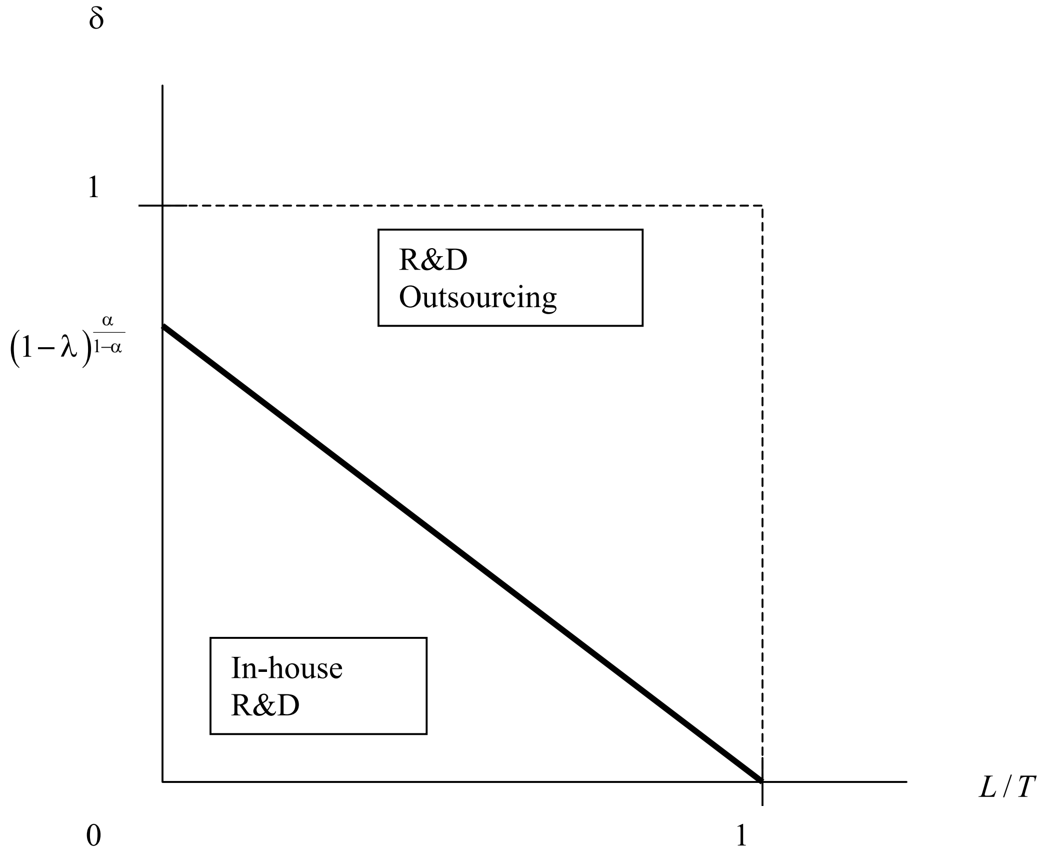

Figure 7a: Case I: Sets of Parameters
Supporting In-house and Outsourcing R&D
with $0 < \lambda < 1$

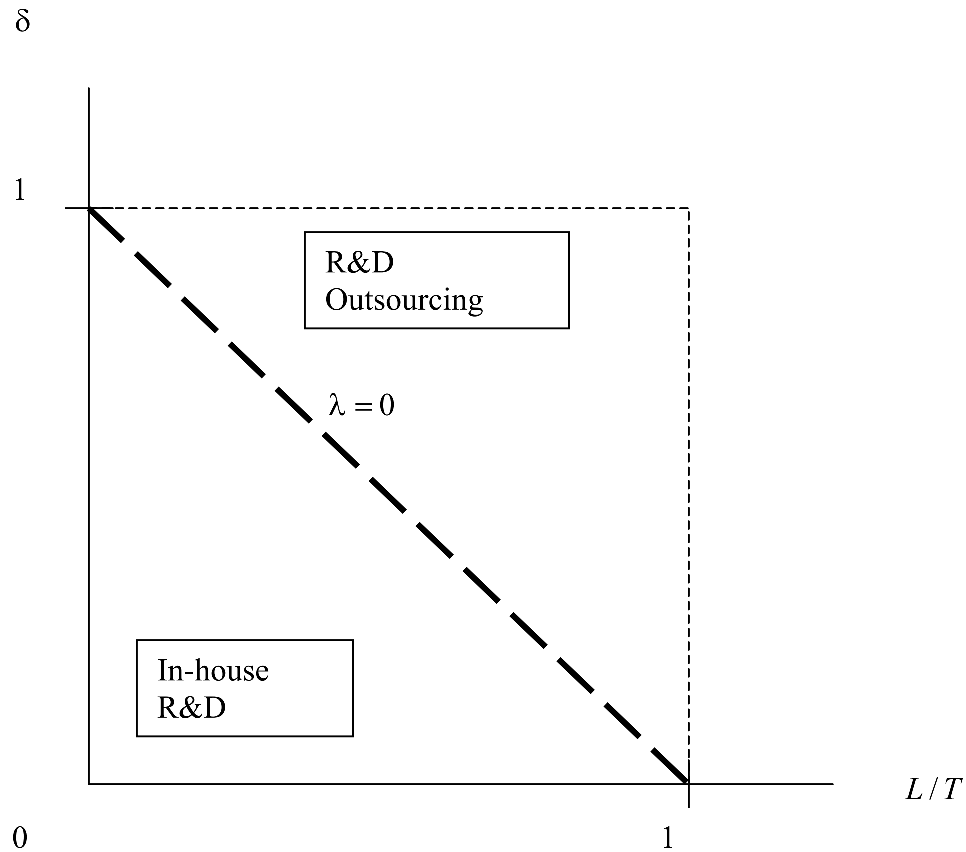

Figure 7b: Case I: Sets of Parameters Supporting In-house and Outsourcing R&D with $\lambda = 0$

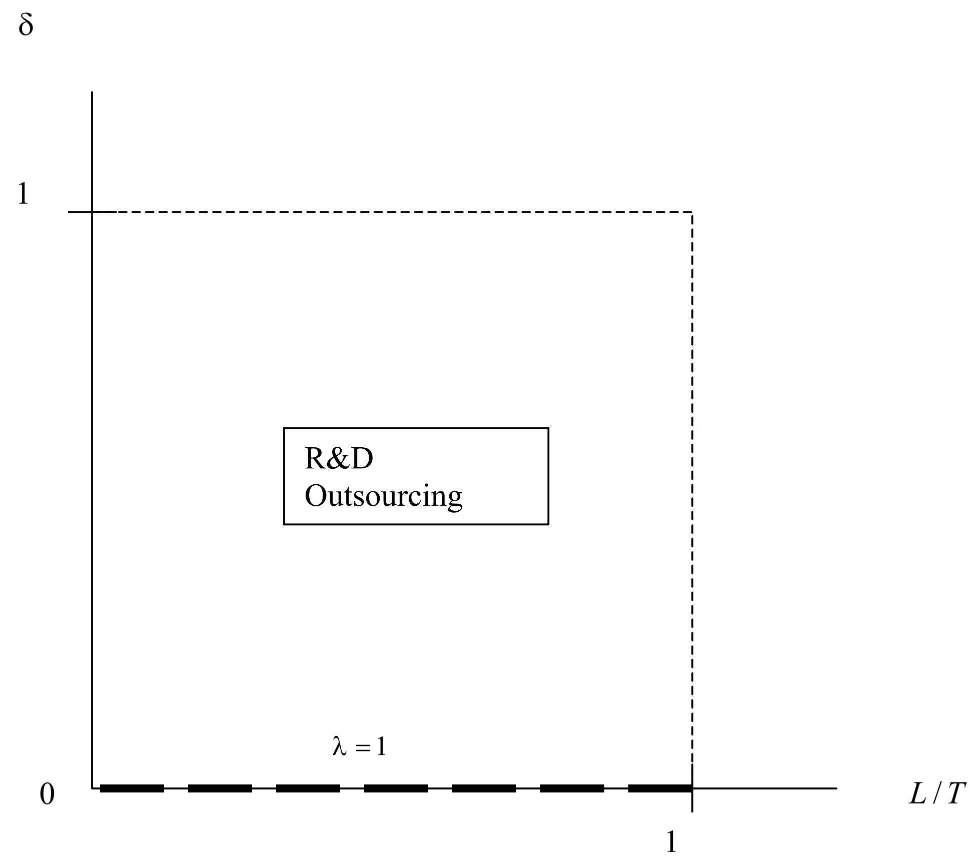

Figure 7c: Case I: All Values of Parameters will Support Outsourcing R&D when λ = 1