Outsourcing of Innovation

Edwin L.-C. Lai
City University of Hong Kong

Raymond Riezman
University of Iowa

Ping Wang
Vanderbilt University and NBER

September 2004

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 the outsourcing of research and development (R&D) activities. We consider cost reducing R&D and allow manufacturing firms to decide whether to outsource the project to research subcontractors 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. We find that the use of performance-based contracts increases the chance of outsourcing and improves social efficiency. However, the principal may still find it optimal to design a contract in such a way as to allow the leakage to occur – a second-best outcome when leakage cannot be monitored or verified. Moreover, stronger protection of intellectual property need not induce more R&D outsourcing and thus need not enhance social efficiency. (JEL Classification Numbers: D21, O31, L14)

Keywords: R&D Outsourcing, Agency Problem, Optimal Contract.

Acknowledgment: We have benefitted from comments from Bob Becker, Rick Bond, Kenneth Chan, Kenji Fujiwara, Shingo Ishiguro, Seiichi Katayama, Jennifer Reinganum, Koji Shimomura, and seminar participants at Arizona State, Indiana, Kobe, Osaka, Purdue, the Midwest Economic Theory and International Trade Meetings at Indianapolis, the WTO and Globalization Conference at Hitotsubashi (Japan) and the CES-IFO Conference in Munich (Germany). We also thank Marketa Sonkova for research assistance.

Correspondence: Raymond Riezman, Department of Economics, University of Iowa, Iowa City, IA 52242; 319-335-0832 (Phone); 319-335-1956 (Fax); raymond-riezman@uiowa.edu (E-mail).

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."[1] There is other anecdotal evidence of outsourcing of R&D such as software development outsourced to India. Despite its growing trend and increasing importance, outsourced R&D is still a relatively small fraction of total R&D. We believe this is due , in part, to its major disadvantage– the possibility that outsourcing R&D will lead to the leakage of the trade secrets.[2] 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. Milgrom and Roberts (1992, Chapter 16) point out that R&D outsourcing is difficult to do because of the difficulty of writing and monitoring a contract. In this paper, we tackle these difficulties by considering a very simple R&D outsourcing problem using a principal-agent framework following the lead of Grossman and Hart (1983) and Myerson (1983). While Grossman and Helpman (2002) focus on the incomplete contract (cf. Grossman and Hart, 1986, and Hart and Moore, 1990) aspect of production outsourcing in two vertically linked economies, our paper tackles the fundamental agency problem associated with outsourcing R&D.

We begin by supposing that there is a fixed number of firms in the goods market, that we assume to be monopolistically competitive. We use a principal-agent framework to analyze whether or not this monopolistically competitive production firm should outsource R&D or do it in-house. The principal in our problem is the owner of the production firm that produces output for this monopolistically competitive market. The research firm is the agent. There is an unlimited supply of workers who can work as in-house researchers for the principal at a competitive wage.

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

[1] Howells (1999) reports that outsourcing of R&D in the UK doubled in real terms between 1985 and 1995 and that outsourced R&D as a percentage of total R&D increased from 5.5% to 10% over the same period.

[2] See, for example, *R&D Magazine*, January 2001.

cooperative workers have the ability to become entrepreneurs, operating research subcontracting firms and serving as the agents for goods production firms that outsource their R&D. We assume, because of agglomeration and knowledge spillover effects, that these research firms have a comparative advantage in R&D activities. In the research process, information sharing takes place within the research firm between partners. This setup facilitates information leakage. On the positive side, they innovate faster and more cheaply than the principal's in-house employees. In addition, there may be economies of scale in research for these contractors.[3] We assume that non-cooperative workers do not have the ability to work in a research firm.

In general, the principal could be involved in two types of R&D, cost reduction (or process innovation) research and new product innovation. We will analyze cost reduction R&D although the extension to new production innovation is straightforward. So, production firms either engage in in-house cost reduction research or outsource this research to a research firm.

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 that the information leakage problem will sometimes lead to research being done in-house even though it can be done more cheaply and effectively by an outside research firm. This is because useful information about the manufacturing firm, obtained by the subcontractor, could be sold to the production firm's competitors which would lead to erosion of the market share of the production firm. Another possibility is that the research firm could enter the industry as a competitor. Thus, because of the information leakage problem, R&D may not be outsourced even when it is efficient to do so.

Our major findings are therefore, related to the information leakage problem, which distinguishes R&D outsourcing from production outsourcing. We find that the optimal outsourcing contract may or may not be performance-based. In the first case, a 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. Such a contractual arrangement thereby improves social efficiency.

We also will show that it is possible that the principal may find it optimal to design a contract that leads to information leakage. This is the second best outcome when the principal cannot monitor or verify information leakage. Finally, since leakage reduces the chance of outsourcing

[3] From the business management point of view, Quinn (2000) emphasizes the advantages of outsourcing R&D in scale economies, labor specialization, and innovation speed.

R&D, one would presume that any measure that reduces losses to the principal or the gains of the agent from appropriating the principal's proprietary information improves social efficiency. For example, increased protection of intellectual property, such as trade secrets protection should be one such measure to mitigate the information leakage problem. Yet, we find that such measures need not induce more R&D outsourcing and thus, need not improve social efficiency.

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 with a fixed number of firms, each firm is faced with a downward sloping inverse demand curve $p(x)$. Thus, the value of sales is $xp(x)$.[4] There is no entry or exit as long as all firms make positive operating profits at all dates, which we assume to be the case. 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: $xp(x)T$.[5]

We consider two possible ways in which R&D activities can be done, one by hiring *in-house researchers* and another via *outsourcing to a subcontractor*.[6] There is an unlimited supply of workers who can work as in-house researchers for the principal and receive a wage W^{IH} over the entire product cycle (with superscript IH denoting in-house) that is equal to the outside competitive wage W in equilibrium.[7] Research subcontracting firms are operated by cooperative workers who are able to cooperate with other research workers and thereby enjoy positive knowledge spillovers. These research subcontractors are the *agents*, serving the owners of goods production firms, or the *principals*.

Given this setup we can identify three important, easily identified features of R&D activities.

1. (*Adaptability of the outsourced R&D to the production firm's environment*) In-house R&D has

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

[5] 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.

[6] 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).

[7] One could include a constant "loyalty premium" $\rho \geq 0$ over the competitive wage W such that $W^{IH} = (1+\rho)W$. We assume that the loyalty premium is set high enough so that in-house researchers have no incentive to leak information.

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.[8] 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. In addition, outsourced innovation can produce more cost reduction benefits for the production firm than in-house R&D since specialization allows the subcontractor to produce higher quality research output than in-house researchers. The implications are that outsourcing shortens the innovation time for a given cost or effort and it produces more cost reduction benefit.

3. (*Information leakage*) Useful information about the operations of the production firm is obtained by the subcontractor.[9] Because of internal controls, in-house researchers are less likely to leak information. For analytic convenience, such possibilities are assumed away.[10] However, the subcontracting research firms can leak the information and might have an incentive to appropriate 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 obtained.[11] 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.[12]

[8] 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).

[9] This could include, for example, information about design for manufacturing (DFM). For a discussion of DFM the reader is referred to Allen (2002).

[10] As mentioned above, in-house researchers may also a receive a loyalty premium that reduces or eliminates their incentive to leak information.

[11] A research activity can range from having very specific goals to having very uncertain ex post outcomes. This paper focuses on the former type. Because of the high specificity of the research outcome, the contract can specify clearly what outcome needs to be achieved, and so it is very difficult for the researcher to shirk by exerting less effort. Thus, the problem of shirking by the agent is assumed away and the agency problem we are dealing with here concerns only the leakage of information.

[12] In this aspect, the informational friction in our R&D outsourcing model is very different from that in the product outsourcing model constructed by Grossman and Helpman (2002).

In points 1 and 2 above there are two effects that work in opposition. Adaptability means slower innovation from outsourced R&D while specialization leads to faster innovation. We assume that the benefit of outsourcing R&D (specialization) is more important than the adaptability delay so that the overall arrival time is shorter 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. We impose:

Assumption 1: $L > 0$.

Thus, the advantage of specialization under outsourcing outweighs the disadvantage of adaptability. 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 outlines the main incentive problem. The agent might have an incentive to leak information and that runs against the interests of the principal. We model this as a standard principal-agent problem as in Grossman and Hart (1983) and Myerson (1983). Accordingly, we assume that:

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

Although we do not model uncertainty explicitly, we implicitly are assuming that there is intrinsic uncertainty of the sunspot type. As a consequence, it is impossible for the principal to identify the underlying source of a bad sales outcome. Because of this, it is not meaningful to write a contract to require the agent not to leak information, since it would not be enforceable. Therefore the principal's problem is to design a contract that reduces the severity of the leakage problem. It is also possible that the information leakage problem could be mitigated by intellectual property (IP) protection since stronger IP protection could make leaked information less valuable.

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. As discussed in Point 3 above, 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*

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

In other words, the market share declines with information leakage at the rate $1-\delta$, which also captures the severity of information leakage.[13] Without outsourcing, $\phi = 0$.

The R&D we consider is cost-reduction R&D, though it can be interpreted as process innovation. We can easily extend the analysis to the case of quality enhancement. 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). This type of contract is commonly seen in research subcontracting in practice.[14] The outside option wage faced by the agent, W^{IH}, can be treated as the R&D cost for in-house research. Therefore, the gross profit (excluding the setup cost) over the entire product cycle to the production firm with in-house R&D is:

$$\Pi^{IH} = x[p(x) - c](T - L) - W^{IH}$$

With outsourcing it 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 therefore $p(x)$ 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

[13] An alternative interpretation is that the subcontractor may shirk, which yields lower product quality given the same production cost. In this case, $1-\delta$ can be referred to as the rate at which the product quality is depreciated as a result of shirking. One may also think of $1-\delta$ as the fraction of product that is substandard and cannot be sold in the market.

[14] The consideration of more complex forms of the royalty contract is beyond the scope of the present paper.

who designs the royalty contract (m, μ) which the agent (the research firm) may accept or reject. Once the contract is accepted, the agent must also decide, for a given royalty contract, whether to leak the information to the production firm's competitors. We focus on the case in which a match has been made between a firm (principal) and a research firm (agent). Given that a match exists this becomes a three stage game depicted schematically in Chart 1.

To ensure subgame perfection, we solve this problem backward. In the third and final stage, the agent decides whether to leak the information (chooses ϕ) given the contract offered by the principal, (m, μ). In the second stage, the principal, anticipating the decision on ϕ selects the optimal contract (m, μ). Finally, given the optimal contract and the existing outside wage, in the first stage the principal decides whether to do its R&D in-house or to outsource.

The solution to this game shows that the information leakage problem results in less outsourcing. Consequently, we are able to identify a distortion due to an informational asymmetry and as a result, resources are mis-allocated between in-house research and outsourced research. We begin by looking at the agent's decision.

3.1 Agent's Decision on Information Leakage

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 information sharing facilitates information leakage. The research firm only accepts contracts that yield a higher return than the market wage. There is no uncertainty and hence the agent does not have to evaluate risks.[15] So, for analysis of the third stage of the game, we assume that the agent does better as a subcontracting partner and accepts the principal's contract offer. We now 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.[16] Let B be the benefit of information leakage to the agent from selling information. Though it is inessential to the results to be established, it is

[15] In a more sophisticated model with risks and uncertainty, we need to take into account the degree of risk aversion. We will discuss the implication of such possibilities in Section 6 below.

[16] This is true if the output demand curve faced by the principal has a constant elasticity, as shown in the appendix.

reasonable to include an appropriation cost so that the value of the information leakage to the subcontractor is a fraction $\beta \in (0, 1-\delta)$ of the value of the principal's revenue loss from leakage. This assumption guarantees that the principal's revenue loss is always more than the agent's gains when the agent appropriates proprietary information. Specifically, we assume $\beta = \beta_0(1-\delta)$, with $\beta_0 \in (0, 1)$ being constant for any given market structure. Since β_0 measures the fraction of the principal's losses that translates into the agent's gains upon leakage, it is expected that β_0 will be smaller when the output market is more competitve. Then, the benefit of information leakage is given by:

$$B = \beta RT = \beta_0(1-\delta)RT \tag{1}$$

For most of the analysis below, we assume a constant-elasticity goods demand curve of the form $x = Ap^{-\epsilon}$ faced by the principal where $A > 0$ is a scaling factor which reflects the size of the market faced by the output firm, and $\epsilon > 0$ is the absolute value of the price elasticity of goods demand.

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 is reduced to $\delta\mu RT$. Therefore, when the agent leaks information about the principal, it loses revenue on account of the lowering of the principal's market share and hence its revenue. The agent's value is therefore given by:

$$V = \begin{cases} \mu RT + m & \text{when } \phi = 0 \\ \delta\mu RT + m + \beta_0(1-\delta)RT & \text{when } \phi = 1 \end{cases}$$

So, when the agent sells 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 possibly 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 as it is a function of the principal's revenue.[17]

We can write,

$$V|_{\phi=1} = V|_{\phi=0} + \Delta V \tag{2}$$

where $\Delta V = [\beta - (1-\delta)\mu]RT$ is the agent's valuation differential between leaking and not leaking. Define the critical value μ_C as the value of μ such that $\Delta V = 0$. One can easily compute: $\mu_C = \frac{\beta}{1-\delta} = \beta_0$. If the demand faced by the principal is constant elasticity it can be shown that $\Delta V > 0$ when $\mu < \mu_C$ and $\Delta V < 0$ when $\mu > \mu_C$. Moreover, ΔV decreases in μ at least until it reaches a value well beyond μ_C. This relationship is depicted in Figure 1. Thus, for any $\mu > \mu_C$,

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

$\Delta V < 0$, 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. We follow the literature by assuming that when an agent is indifferent (at $\mu = \mu_C$), he/she will not leak the information. Summarizing, we have, in equilibrium,

$$\phi(\mu) = \begin{cases} 0 & \text{if } \mu \geq \mu_C \\ 1 & \text{if } \mu < \mu_C \end{cases} \tag{3}$$

Thus, an agent's value can be rewritten as:

$$V(m,\mu) = \begin{cases} \mu R(\mu)T + m & \text{when } \mu \geq \mu_C \\ \delta\mu R(\mu)T + m + \beta_0(1-\delta)R(\mu)T & \text{when } \mu < \mu_C \end{cases} \tag{4}$$

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. For any particular response by the agent $\phi(\mu)$, the principal's gross profit over the entire product cycle under outsourcing with a royalty contract (μ, m) is:

$$\Pi(\mu,m) = \begin{cases} x(\mu)\left[p(x(\mu))(1-\mu) - (1-\lambda)c\right]T - m & \text{when } \mu > \mu_C \\ \delta x(\mu)\left[p(x(\mu))(1-\mu) - (1-\lambda)c\right]T - m & \text{when } \mu < \mu_C \end{cases} \tag{5}$$

which is decreasing in μ and discontinuous at $\mu = \mu_C$.

To determine the optimal contract consider the production firm's willingness to trade off between μ and m. For any given value of Π_0, we can define the iso-profit curve for each production firm as:

$$\Pi(\mu,m) = \Pi_0 \tag{6}$$

This relationship indicates the combinations of μ and m that leave the principal indifferent between outsourcing and conducting in-house R&D. We can then use (6) to find how μ and m vary along the iso-profit curve with gross profit equal to Π_0 (see Figure 2). Figure 2 shows the iso-profit curve which must be downward sloping for constant elastic demand since $\frac{d\Pi}{d\mu} = \frac{\partial\Pi}{\partial\mu} < 0$ by the Envelope Theorem. This is true whether $\mu > \mu_C$ or $\mu < \mu_C$.[18] An iso-profit curve closer to the origin is associated with a higher gross profit.

[18] For illustrative purposes, these iso-profit curves are drawn as linear functions.

The iso-profit curves are all discontinuous at $\mu = \mu_C$. This discontinuity occurs because as μ increases to μ_C from below, information leakage is eliminated and the market share is restored from $\delta < 1$ to $\delta = 1$. Thus, the total revenues jump up and the principal is willing to increase the lump-sum royalty payment (m) and still able to maintain the same profit. Furthermore, totally differentiating (5) 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 2) than if $\mu < \mu_C$ (segment CD in Figure 2) at least in the neighborhood of $\mu = \mu_C$. Again, the difference in the slopes is entirely due to the reduced market share from information leakage ($\delta < 1$). The iso-profit curve is steeper for $\phi = 1$ than for $\phi = 0$ because the marginal effect of μ on $\Pi(\mu, m)$ is smaller when $\phi = 1$, and so the principal is willing to give up more μ for each one-dollar reduction in lump sum payment.

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

$$\Pi^{IH} \equiv x^{IH}[p(x^{IH}) - c](T - L) - W^{IH} \tag{7}$$

where $x^{IH} = \arg\max_x \{x[p(x) - c]\}$ is the optimal output of the firm when it conducts in-house R&D (see the appendix for a derivation x^{IH}). Let $\underline{\Pi}$ denote the reservation profit of the principal. Throughout the paper, we assume that the participation constraint for in-house R&D is met, i.e., $\Pi^{IH} \geq \underline{\Pi}$. 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:

$$\Pi(\mu, m) \geq x^{IH}[p(x^{IH}) - c](T - L) - W^{IH}$$

In the next section, we show that any change in parameters $\{W, T, L, c\}$ affects the principal's decision on whether to outsource R&D in equilibrium.

4 Outsourcing Versus In-House R&D

To understand the decision to outsource innovation versus doing the cost reduction innovation in-house, we begin by characterizing the indifference curve of the agent in (m, μ) space. The indifference curve is the locus of pairs of (m, μ) for which $V(m, \mu) = V_0$ (a constant). Referring to Figure 2, note that, unlike the iso-profit locus of the principal, there is *no* discontinuity of the indifference curve where $\mu = \mu_C$ (when ϕ switches from 0 to 1). This follows directly from (2), which shows that $V|_{\phi=1} = V|_{\phi=0}$ when $\mu = \mu_C$. The variable V is continuous in μ because it is the maximum of two continuous functions in μ. Since V is continuous in μ, the indifference curve $V(m,\mu) = V_0$ is also continuous. Next, we compare the slopes of the indifference curve for $\mu > \mu_C$ and when $\mu < \mu_C$. Using (4), we totally differentiate $V(m,\mu) = V_0$ 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 $\mu = \mu_C$. When there is no leakage, the payoff of the agent is less tied to the revenue of the principal. For each dollar reduction in m, the agent requires a smaller increase in μ to compensate her for it. That means the indifference curve is kinked outward at $\mu = \mu_C$ (see curve EFG in Figure 2). Moreover, the indifference curve has higher utility in the northeast direction.[19] We next address the issue of bargaining power between the principal and the agent.

For analytic convenience, we bestow all power with the agent:

Assumption 4: *The principal has no bargaining power in the sense that all the surplus accrues to the agent.*

This is justified if, for example, there is a large number of production firms but limited supply of potential agents (as there are few researchers who are able to cooperate with other researchers to form a subcontracting firm). This assumption makes the solution to our problem simpler and implies that: (i) when the payment to the subcontractor (μ, m) satisfying $\Pi(\mu, m) = \Pi^{IH}$ yields $V(\mu, m) \geq W^{IH}$, the principal outsources R&D; (ii) otherwise, the principal conducts R&D in house. Another interpretation of this assumption is, given the various possible contracts offered by the potential principals, the agent is the decisive player, selecting the one she most prefers. If that contract yields her an income higher than her wage when employed in-house, she accepts the

[19] Note that we have depicted the indifference curve as downward sloping, which is not the case in general. In Appendix A, we show that the indifference curve may be upward sloping in (m, μ) space, meaning that an increase in μ leads to such a large decrease in R that the agent has to be compensated by being paid a higher lump-sum m to make her indifferent compared with before.

outsourcing contract.[20] Therefore, the agent solves:[21]

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

That is, the agent chooses the contract that maximizes her utility subject to the principal getting Π^{IH}. This contract is acceptable if it is more attractive than the researcher's best outside option – the in-house wage: $V(\mu,\ m) \geq W^{IH}$.

It is shown in the appendix that

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

That is, the indifference curve is always steeper than the iso-profit curves for any given μ, as in Figure 2. That is, for each dollar reduction in m, the agent requires a greater increase in μ than the principal is willing to yield. Finally, we can also conclude that the iso-profit curves and the indifference curves are convex in each of the zones $\mu < \mu_C$ and $\mu > \mu_C$.[22]

4.1 Two Types of Outsourcing Contracts

We can immediately identify two cases, Case I and Case II, distinguished by the type of outsourcing contract in equilibrium when R&D outsourcing does occur.[23] Refer to Figures 2 and 3. Since the iso-profit line $ABCD$ is not convex, it proves convenient to construct a "convexified" iso-profit curve ABD, where BD is a straight line. We can use this convexification because the parts of the iso-profit curve inside the convexified curve are irrelevant to the analysis, since they are not

[20] 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). For example, when the two parties have symmetric bargaining power, the optimization problem becomes: $\max_{\mu,m} [V(\mu,m) - W]^{1/2} \left[\Pi(\mu,m) - \Pi^{IH}\right]^{1/2}$. The first-order conditions with respect to μ and m, respectively, are: $dV(\mu,m)/d\mu = -d\Pi(\mu,m)/d\mu$ and $V(\mu,m) - W = \Pi(\mu,\ m) - \Pi^{IH}$. The main findings concerning the different roles of μ and m in alleviating the agency problem remain unchanged.

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

[22] Note that even if the indifference curve is upward sloping or partially upward sloping (when the indifference curve is upward sloping, $\frac{d\mu}{dm}\big|_{V_0} > 0 > \frac{d\mu}{dm}\big|_{\Pi_0}$), the indifference curve EF must always be to the right of the iso-profit line DC in Figure 2, as long as D and E start from the same point. This ensures that the equilibrium contract will either be at point B or point D. These are the Cases I and II we discuss below. There is no possibility of an equilibrium at any point between B and D.

[23] Obviously there is a third, knife-edge case in which the two types of outsourcing contract can co-exist. We do not consider this case of multiple equilibria because it is very unlikely to occur.

candidates for tangent points with agent's indifference curves. Consequently, which outsourcing contract occurs depends on whether the line EF is steeper than the "convexified" iso-profit line DB. If the indifference curve is steeper than the convexified iso-profit line then we have Case I shown in Figure 2. Otherwise, we have Case II shown in Figure 3. It can be shown that an increase in δ or β_0 would reduce the gap CB, the principal's profit gap between leaking and no leaking. This in turn reduces the slope of DB. Moreover, it also increases the slope of the line EF. Hence, an increase in δ or β_0 would make Case I more likely to occur and Case II less likely to occur.

Refer to Figure 2. In Case I, δ or β_0 is sufficiently large so that EF is steeper than DB. When the agent's indifference curve EF is steep, it means that the agent must be given a larger increment in revenue-sharing to compensate for each dollar reduction in lump-sum payment. We call this trade-off the "rate of substitution" of m for μ by the agent. On the other hand, along the convexified iso-profit line DB, for each dollar reduction in lump-sum payment, the principal is willing to give up more revenue-share. This rate of trade-off is the "price" faced by the agent if she were to switch from not leaking to leaking. In Case I, the rate of substitution is greater than the price of leaking (i.e. EF is steeper than DB), and so the agent is willing to substitute m for μ, through leaking. Thus, if outsourcing does occur in equilibrium in Case I, we have a corner solution under outsourcing as shown in Case IA of Figure 2, and the agent would rather take a pure lump-sum contract from the principal. Now refer to Figure 3 for Case II. In this regime, δ or β_0 is sufficiently small, so that DB is steeper than EF. Therefore, the rate of substitution of the agent is lower than the price when switching from no leaking to leaking. So, the agent is not willing to substitute m for μ through leaking. Thus, we have an interior solution when outsourcing does occur, as shown in Case IIA of Figure 3. We have a mixed contract with a positive lump sum payment and a positive revenue-share.[24]

We next derive the boundary between Cases I and II explicitly and show it in Figure 4. Essentially, the calculation is based on the observation that we have Case I iff $\overline{OD} > \overline{OE}$ and Case II iff $\overline{OD} < \overline{OE}$ (see Figure 3). It is shown in the appendix that this boundary is given by,

$$D(\beta_0, \delta) \equiv (1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha\,(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)\delta = 0 \tag{8}$$

Case I arises in equilibrium if $D(\beta_0, \delta) < 0$; otherwise, we have Case II. The reader is referred to Figure 4 for the boundary between Cases I and II in (β_0, δ) space according to equation (8). As

[24]Note that, as mentioned before, the non-convexified part of the iso-profit curve and the indifference curves in these diagrams are not really straight lines, but are shown that way for illustrative convenience.

discussed above, we have Case I when δ or β_0 is large, and Case II when δ or β_0 is small. Note that when $\beta_0 > 1 - \alpha$, Case II cannot arise. In other words, outsourcing with a mixed contract is less likely when the output market is less competitive.

It is evident that each of Cases I and II has two subcases, which depend on the agent's wage relative to the lump-sum equivalent that the agent can extract from the principal under R&D outsourcing. In subcase A, there is R&D outsourcing in equilibrium, while in subcase B there is in-house R&D.

(i) Case I: The agent's price of leaking is relatively low (Figure 2). This case occurs if δ or β_0 is large, as shown in Figure 4. Within this case, the boundary between in-house (IH) and outsourced R&D (OS) is shown in Figure 5. A derivation of this boundary is given in the appendix.

(IA) Referring to Figure 2, when $W^{IH} < \overline{OE}$, i.e. the wage is less than the lump-sum equivalent of the researcher's payoff under outsourcing, we have Case IA. *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. Within Case I, this regime would take place when δ is relatively large.

(IB) Referring to Figure 2 again, when $W^{IH} > \overline{OE}$, we have Case IB, as shown in Figure 2. 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. Within Case I, this regime would prevail when δ is relatively small.

(ii) Case II: The agent's price of leaking is relatively high (Figure 3). This will be the case if δ or β_0 is small, as shown in Figure 4.[25]

[25] See Figure 5 for the boundary between in-house (IH) and outsourced (OS) R&D.

(IIA) Referring to Figure 3, when $W^{IH} < \overline{OE}$, *there is outsourcing with a mixed contract* (m, μ) such that μ is set at μ_C and m is set positive. *There will be no information leakage.* Under this contract, the agent strictly prefers not leaking information (albeit with only a slight preference), and the principal also strictly prefers no leakage (with a strong preference) since the loss from leakage is positive and non-trivial. Within Case II, this regime would take place when δ is relatively large or β_0 is relatively small.

(IIB) Referring to Figure again, when $W^{IH} > \overline{OE}$, there is in-house R&D. Within Case II, this regime would take place when δ is relatively small and β_0 is relatively large.

In the next two subsections, we describe in detail for Case I and Case II the transition between in-house R&D and outsourcing.

4.2 Case I

To better understand how the parameters in the model determine how research is done, we derive the boundary condition between outsourcing and in-house research. First, consider Case I. We know that there will be outsourcing iff $\overline{OE}(= \overline{OD}) > W$ (see Figure 2). We next show that this condition implies that as δ, $\frac{L}{T}$ or λ gets larger, outsourcing is more likely. However, β_0 and W have no effect on who carries out R&D. See Figure 5 for a diagram depicting the boundary between outsourcing and in-house research in (δ, β_0) space.

To show this we first solve for the relationship between the distance $\overline{OD}$ in Figures 2 and 3 and Π^{IH}. $(\overline{OD}, 0)$ lies on the iso-profit line corresponding to $\Pi(m, \mu) = \Pi^{IH}$. Hence, 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 sharing for the agent, so as to keep the principal's profit equal to Π^{IH}. At $\mu = 0$, we know that $\phi = 1$ from (3). 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 $\Pi(\mu, m) = \Pi^{IH}$ in (5), we obtain

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

which implies that

$$\overline{OD} = \delta x_0 \left[p(x_0) - (1 - \lambda)c \right] T - \Pi^{IH} \tag{9}$$

Equation (9) 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.

On the other hand, (7) implies that

$$W^{IH} = x^{IH}[p(x^{IH}) - c](T - L) - \Pi^{IH} \tag{10}$$

That is, a higher W^{IH} is reflected in a higher gap between the operating profit and the net profit under outsourcing.

From equations (9) and (10), we obtain

$$\Delta \equiv \overline{OD} - W^{IH} = \left\{\delta x_0 \left[p(x_0) - (1-\lambda)c\right] T - x^{IH}[p(x^{IH}) - c](T - L)\right\} \tag{11}$$

When the demand faced by each firm is constant-elasticity of the form $x = Ap^{-\epsilon}$, it follows that (see the appendix),

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

Substituting into (11) we get

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

To better understand how the various parameters affect the outsourcing decision we next turn to solving explicitly for the critical values of the key parameters under the assumption that 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 (11) that

$$\overline{OD} - W^{IH} = \left(\frac{\alpha}{c}\right)^{\frac{\alpha}{1-\alpha}} A(1-\alpha)\left\{\delta(1-\lambda)^{\frac{-\alpha}{1-\alpha}} T - (T - L)\right\} \tag{12}$$

From (12), the threshold values (δ, L/T) that drive $\overline{OD} - W^{IH}$ to zero for given λ and α satisfy:

$$\delta = (1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \frac{L}{T}\right) \tag{13}$$

Since this boundary is independent of β_0, it is horizontal in (β_0, δ) space (Figure 5). We can conclude:

Proposition 1: *Under Assumptions 1-4, Case I and constant elastic demand, R&D is outsourced in equilibrium if* $\delta > (1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \frac{L}{T}\right)$; *otherwise, it is conducted in-house. Changes in* W *or* β_0 *have no effect on who carries out R&D in equilibrium under Case I.*

Next, consider the boundary between outsourcing and in-house research in $(\delta, L/T)$ space (see (Figure 6)). The threshold values of δ and L/T must be between 0 and 1. Thus, if $\delta > (1-\lambda)^{\frac{\alpha}{1-\alpha}}$, outsourcing is always the equilibrium outcome, since no value of L/T would ever make the sign of $\overline{OD} - W^{IH}$ 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.[26] In general, when L/T is large, the threshold value of δ is small. In other words, when the disadvantage of in-house R&D due to delayed arrival (measured by L/T) is larger, the loss of profit from leakage $(1 - \delta)$ by outsourcing can be higher and the principal will still choose to outsource R&D. Thus, the threshold locus in $(\delta\ ,\ L/T)$ space is downward sloping , where the horizontal intercept is at $L/T = 1$.

In Figure 6 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. If δ is sufficiently large or L sufficiently close to T, R&D is always outsourced in equilibrium. 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.

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. In this case, the vertical intercept becomes one and the boundary between the two regimes rotates 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 approaches one, innovation reduces production cost to zero, and so the cost advantage of outsourcing reaches the maximum. In this case, the boundary between the two regimes overlaps with the horizontal axis and all values of parameters support R&D outsourcing as the equilibrium.

Note that an increase in W causes Π^{IH} to decrease, which in turn causes $\overline{OD}$ to increase by the same amount. In the end, W has no effect on $\overline{OD} - W^{IH}$, and therefore it has no effect on the mode of R&D. 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

[26] 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 Δ that matters now.

ignores the fact that an increase in W raises the principal's willingness to pay for outsourcing R&D as Π^{IH} decreases. Thus, both $\overline{OD}$ and W^{IH} increase by the same amount. 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. Thus, it would not change the value of $\overline{OD} - W^{IH}$, and so it would not change who carries out R&D in equilibrium.

4.3 Case II

We next compute the boundary condition between outsourcing and in-house research for case II. Here there will be outsourcing iff $\overline{OE} > W$ in Figure 3. This is given by,

$$\Gamma(\beta_0, \delta, \frac{L}{T}) \equiv (1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha\,(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)\,(1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \frac{L}{T}\right) = 0 \quad (14)$$

where $\Gamma(\beta_0, \delta, \frac{L}{T})$ measures the net benefit of outsourcing R&D. That is, R&D would be outsourced iff $\Gamma(\beta_0, \delta, \frac{L}{T}) > 0$; otherwise, it would be conducted in-house. This boundary specified in (14) is upward sloping in (δ, β_0) space and downward sloping in $(\delta, L/T)$ space. A diagrammatic presentation of this boundary in (δ, β_0) $((\delta, L/T))$ space is given in Figure 5(6). Note that outsourcing is more likely to occur as δ or $\frac{L}{T}$ gets larger, or as β_0 gets smaller.

In Case II, $\overline{OD} < \overline{OE}$, that is, the maximum lump-sum-equivalent that the principal is willing to give up so as to maintain its gross profit of Π^{IH} 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 $\overline{OE} - W^{IH} > 0$, a sufficient *but not necessary* condition for outsourcing is that $\overline{OD} - W^{IH} > 0$. In other words, we have weaker conditions than Propositions 1 and 2 for outsourcing to be the equilibrium outcome:

Proposition 2: *Under Assumptions 1-4, the condition that supports outsourcing in Case I also supports outsourcing in Case II. However, even with the condition that supports 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* when β_0 is sufficiently small.

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 do R&D for 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 likelihood of outsourcing. This is possible when β_0 is sufficiently small, i.e., when the output market is sufficiently competitive. The possibility of writing a mixed contract explains why the OS region in Case II shown in Figure 5 extends beyond the region $\delta > (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)$ (which is the condition defining the OS region in Case I). In fact, as Figure 5 shows, as β_0 gets smaller, the range of δ that supports the OS equilibrium gets larger.

4.4 The boundary between the IH and OS regimes

Combining Cases I and II, we can depict the boundary between the IH and OS regimes in (δ, β_0) space (see Figure 5). It shows that we have the IH regime only when β_0 is large and δ is small. This is intuitive because it means when the principal's loss and the agent's gain from leakage are both high outsourcing is unlikely.

From (13), we see that β_0 has no effect on who carries out R&D under Case I. However, it does have an effect in Case II. Starting from Case I, the regime will eventually switch to Case II as β_0 decreases. Recall that $\mu_C = \beta_0$. Since a reduction in β_0 reduces μ_C, it extends line AB in Figure 2 further down and to the right. Moreover, line EF in Figure 3 is also flatter, according to the derivation in the appendix. Therefore, $\overline{OE}$ is longer, which makes $\overline{OE} - W^{IH} > 0$ more likely. Thus a decrease in β_0 makes R&D outsourcing more likely. In the extreme case when $\beta_0 \to 0$ (so that $\mu_C \to 0$), line AB in Figure 3 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 $W^{IH} = x^{IH}[p(x^{IH}) - c](T-L) - \Pi^{IH}$, and the former expression is greater than the latter, we can conclude that there must be R&D outsourcing when $\beta_0 \to 0$, 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. This explains why in Figure 5, for any given δ, we would eventually reach the OS region as β_0 decreases. We summarize these remarks in Proposition 4.

Proposition 3: *Under Assumptions 1-4, R&D is outsourced when the degree of market erosion due to information leakage is low (δ large) or the subcontractor's benefit from leaking is not too high (β_0 small); otherwise, R&D is conducted in-house.*

5 Welfare Implications

We now turn to the question of whether R&D outsourcing or in-house research results in higher economic welfare. Suppose there is no information leakage. The research firm can do R&D faster and better which implies that R&D outsourcing is *more efficient* than in-house research and thus is associated with higher welfare. Information leakage therefore 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? We suppose that policy makers have no direct control over the actions of research firms. Now consider a policy of tighter protection of trade secrets or stronger patent protection. Such a policy would reduce the principal's loss associated with information leakage (i.e., higher δ).[27] Proposition 4 implies that this effect increases the chance of R&D outsourcing. Therefore, it would seem that stronger protection of trade secrets improves welfare.

However, this analysis ignores the possibility that stronger IP protection may lengthen the product cycle (i.e., increase T), which makes the relative disadvantage from delayed arrival of in-house R&D less severe (as L/T is lower). This is because stronger IP protection in the form of wider scope of IP protection such as broader patents makes it more costly for other firms to conduct future cost reduction innovation based on the existing patents. See, for example, Green and Scotchmer (1995) and O'Donaghue, Scotchmer and Thisse (1998), where they argue that wider patent breadth stifles future quality-improvement innovations by making them more costly to conduct.

To be more specific, consider Case I. Figure 6 illustrates the tension between the information leakage effect via δ and the product cycle effect via L/T. Suppose we begin from point E in Figure 6 at which the production firm is indifferent between outsourcing and in-house R&D. Imagine now that the government implements a tighter IP protection policy. When the product cycle effect is dominant, one moves from point E to point A and hence the production firm chooses to do R&D in-house. This is because in the presence of information leakage, a longer duration of monopoly power gives more incentive for the production firm to conduct in-house R&D so as to prevent erosion of profits from information leakage. On the contrary, when the product cycle effect is weak, one moves from point E to point B. In this case, the production firm outsources R&D in equilibrium.

[27] Let $\beta(\tau) = \beta_0 [1 - \delta(\tau)]$ where τ represents strength of IP protection and δ is increasing in τ. That is, an strengthening of IP protection increases the fraction of the market share retained by the principal even in the face of leakage.

A specific example is given in the appendix. Summarizing these results:

Proposition 4: *Under Assumptions 1-4, stronger IP protection that reduces the principal's losses and the agent's gains from information leakage can encourage R&D outsourcing and improve social efficiency if the product cycle effect is small. Otherwise, stronger IP protection may reduce the incentive to outsource R&D and lower social efficiency.*

In the literature, stronger IP protection may improve social efficiency by promoting the inventors' incentive to invest, i.e., by inducing a greater amount of R&D investment. In contrast, the efficiency gain of IP protection in our model is not based on the amount of R&D investment itself, but the "institutional arrangement" of R&D. That is, with a weaker product cycle effect, stronger IP protection can enhance social efficiency by encouraging in-house R&D projects to be outsourced to more efficient subcontractors.

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 the leakage of trade secrets and the subsequent erosion of the competitive advantage of the principal. These leakage problems might prevent R&D from being outsourced. Here, a very simple model reveals a rich array of principles. By solving for and characterizing the optimal contract which best mitigates these leakage problems, we find that the optimal outsourcing contract may or may not be performance-based. If it is performance-based, there would not be leakage of information. Interestingly, manufacturing firms may still outsource R&D by writing a lump-sum contract, despite knowing that leakage will occur. Stronger IP protection need not enhance social efficiency unless it can improve the institutional arrangement of R&D by encouraging in-house R&D projects to be outsourced to more specialized subcontractors.

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 outside 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 further reduce R&D outsourcing.

Appendix A

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 $R = x^{\alpha}A^{1-\alpha}$.

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

$$\begin{aligned} x^{IH} &= \left(\frac{\alpha}{c}\right)^{\epsilon} A \\ p^{IH} &\equiv p(x^{IH}) = \frac{c}{\alpha} \\ R^{IH} &\equiv x^{IH}p^{IH} = \left(\frac{\alpha}{c}\right)^{\epsilon-1} A. \end{aligned} \tag{A1}$$

Under R&D outsourcing, (5) implies 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

$$\begin{aligned} x &= \left[\frac{(1-\mu)\alpha}{(1-\lambda)c}\right]^{\epsilon} A \\ p &= \frac{(1-\lambda)c}{(1-\mu)\alpha} \\ R &= \left[\frac{(1-\mu)\alpha}{(1-\lambda)c}\right]^{\epsilon-1} A \end{aligned} \tag{A2}$$

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

Now, from (4) we obtain, for $\phi = 0$,

$$\left|\frac{d\mu}{dm}\right|_{V_0} = \left|\frac{dV(0)/dm}{dV(0)/d\mu}\right| = \frac{1}{RT + \mu T\frac{dR}{d\mu}} = \frac{1}{RT - \mu T\left|\frac{dR}{d\mu}\right|} \tag{A3}$$

Note that $RT - \mu T \left|\frac{dR}{d\mu}\right|$ needs not be positive. In other words, the indifference curve may be upward sloping in (m, μ) space, meaning that an increase in μ leads to such a decrease in R that the agent has to be compensated by being paid a higher lump-sum m to make her indifferent compared with before.

Refer again to (5), which is stated above. 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 $\phi = 0$,

$$\left|\frac{d\mu}{dm}\right|_{\Pi_0} = \left|\frac{d\Pi/dm}{d\Pi/d\mu}\right|_{\phi=0} = \frac{1}{RT} \tag{A4}$$

Comparing (A3) and (A4), 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 $\phi = 0$.

Similarly, we can prove from (4) and (5) 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 $\phi = 1$.

Appendix B

(I) Boundary between Case I and Case II

All iso-profit lines have the same slope for any given μ. Similarly, all indifference curves have the same slope for any given μ. Let point B in Figures 2 and 3 be represented by $(m, \mu) = (m_0, \mu_C)$, point D in Figures 2 and 3 by $(m, \mu) = (m_1, 0)$, and point E in Figure 3 by $(m, \mu) = (m_2, 0)$.

Since a typical iso-profit curve $\Pi(\mu, m) = \Pi_0$ passes through both (m_0, μ_C) and $(m_1, 0)$, we can apply (5), (15) and $\mu_C = \beta_0$ to obtain:

$$\begin{aligned}\Pi_0 &= x(\mu_C)\left[p(x(\mu_C))(1-\mu_C) - (1-\lambda)c\right]T - m_0 \\ &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)(1-\beta_0)^{\frac{1}{1-\alpha}} - m_0\end{aligned}$$

$$\begin{aligned}\Pi_0 &= \delta x(0)\left[p(x(0)) - (1-\lambda)c\right]T - m_1 \\ &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\delta - m_1\end{aligned}$$

Eliminating Π_0 yields,

$$m_1 - m_0 = AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\left[\delta - (1-\beta_0)^{\frac{1}{1-\alpha}}\right] \tag{B1}$$

Similarly, consider an indifference curve that passes through (m_0, μ_C) and $(m_2, 0)$ and let $V(m_0, \mu_C) = V(m_2, 0) = V_0$. Therefore, from (4), we have:

$$\begin{aligned}V_0 &= \mu_C R(\mu_C)T + m_0 \\ &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\beta_0(1-\beta_0)^{\frac{\alpha}{1-\alpha}} + m_0\end{aligned}$$

$$\begin{aligned}V_0 &= \beta_0(1-\delta)R(0)T + m_2 \\ &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\beta_0(1-\delta) + m_2\end{aligned}$$

Eliminating V_0 leads to,

$$m_2 - m_0 = AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\beta_0\left[(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - (1-\delta)\right] \tag{B2}$$

Note that there is no need for $m_2 - m_0$ to be positive since the indifference curve can be upward sloping or partially upward sloping, and the results of the paper would not be affected.

Combining (B1) and (B2), we obtain:

$$\begin{aligned}m_2 - m_1 &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\left\{\beta_0\left[(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - (1-\delta)\right] - (1-\alpha)\left[\delta - (1-\beta_0)^{\frac{1}{1-\alpha}}\right]\right\} \\ &= AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\left[(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)\delta\right]\end{aligned}$$

Therefore, Case I (II) arises iff $m_1 > (<) m_2$ or, iff

$$D(\beta_0, \delta) \equiv (1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)\delta < (>) 0 \tag{B3}$$

and the boundary between these two cases is given by (8).

When there is perfect IP protection, $\delta \to 1$ and $D(\beta_0, 1) = (1-\beta_0)^{\frac{\alpha}{1-\alpha}}\left[1 - \alpha(1-\beta_0)\right] - (1-\alpha) \leq 0$ (the equality holds as $\beta_0 = 0$). So, we have Case I when there is perfect IP protection.

We can easily show: $\frac{\partial D}{\partial \beta_0} = -\frac{\alpha}{1-\alpha}\beta_0(1-\beta_0)^{\frac{\alpha}{1-\alpha}-1} - (1-\delta) < 0$. Therefore, Case II becomes more likely as β_0 gets smaller. For example, we have $D(0, \delta) = (1-\alpha)(1-\delta) > 0$, under which Case

II arises. Moreover, $\frac{\partial D}{\partial \delta} = \beta_0 - (1-\alpha) < 0$ if $\beta_0 < 1-\alpha$. Since $D(1-\alpha, \delta) = \alpha^{\frac{\alpha}{1-\alpha}}(1+\alpha) - 1 < 0$, $D(1, \delta) = -(1-\alpha\delta) < 0$ and $\frac{\partial D}{\partial \delta} > 0$ for $\beta_0 \in (1-\alpha, 1]$, Case II cannot arise if $\beta_0 > 1-\alpha$. When β_0 is sufficiently small (less than β_0^* where β_0^* satisfies $D(\beta_0^*, 0) = 0$), Case II becomes more likely to emerge as δ gets smaller. In summary, the boundary between the two regimes in (β_0, δ) space is downward sloping with horizontal intercept at $\beta_0^* < 1-\alpha$ and vertical intercept at 1, as depicted in Figure 4.

(II) Boundary between in-house and outsourcing under Case I

In this case, $\Pi(\mu, m) = \Pi^{IH}$ implies:

$$\Pi^{IH} = \Pi_0 = AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\delta - m_1 \tag{B4}$$

By substituting (B4) into (10), we have:

$$\begin{aligned} W &= W^{IH} = x^{IH}[p(x^{IH}) - c](T-L) - \Pi^{IH} \\ &= A\left(\frac{\alpha}{c}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)(T-L) - AT\left[\frac{\alpha}{c(1-\lambda)}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\delta + m_1 \end{aligned}$$

which implies,

$$m_1 - W = AT\left[\frac{\alpha}{c(1-\lambda)}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\left[\delta - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1 - \frac{L}{T}\right)\right] \tag{B5}$$

Thus, given that we are in Case I, R&D is outsourced (conducted in-house) iff $m_1 > (<) W$, or, iff

$$\delta - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1 - \frac{L}{T}\right) > (<) 0$$

The boundary is given by (13) and depicted in (β_0, δ) space in Figure 5 and in $(\delta, \frac{L}{T})$ space in Figure 6.

(III) Boundary between in-house and outsourcing under Case II

In this case, $\Pi(\mu, m) = \Pi^{IH}$ implies:

$$\Pi^{IH} = \Pi_0 = AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)(1-\beta_0)^{\frac{1}{1-\alpha}} - m_0 \tag{B6}$$

By substituting (B6) into (10), we have:

$$\begin{aligned} W &= W^{IH} = x^{IH}[p(x^{IH}) - c](T-L) - \Pi^{IH} \\ &= A\left(\frac{\alpha}{c}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)(T-L) - AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)(1-\beta_0)^{\frac{1}{1-\alpha}} + m_0 \end{aligned}$$

which implies,

$$m_0 - W = AT\left[\frac{\alpha}{c(1-\lambda)}\right]^{\frac{\alpha}{1-\alpha}}(1-\alpha)\left[(1-\beta_0)^{\frac{1}{1-\alpha}} - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)\right] \tag{B7}$$

Utilizing (B2) and (B7), we obtain:

$$\begin{aligned}
& m_2 - W \\
= \ & (m_2 - m_0) + (m_0 - W) \\
= \ & AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\left\{\beta_0\left[(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - (1-\delta)\right] + (1-\alpha)\left[(1-\beta_0)^{\frac{1}{1-\alpha}} - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)\right]\right\} \\
= \ & AT\left[\frac{\alpha}{(1-\lambda)c}\right]^{\frac{\alpha}{1-\alpha}}\left[(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)(1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)\right]
\end{aligned}$$

Thus, given that we are in Case II, R&D is outsourced (conducted in-house) iff $m_2 > (<)W$, or, iff

$$\Gamma(\beta_0, \delta, \frac{L}{T}) \equiv (1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)(1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right) > (<)0$$

The boundary is given by (14).

Since from (B3) Case II arises when $(1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) > (1-\alpha)\delta$, we have:

$$\Gamma(\beta_0, \delta, \frac{L}{T}) > (1-\alpha)\left[\delta - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)\right]$$

Thus, if R&D is outsourced under Case I (the RHS of the above inequality is positive), it must be so arranged under Case II. It is straightforward to show that $\frac{\partial\Gamma}{\partial\beta_0} = \frac{\partial D}{\partial\beta_0} < 0$, $\frac{\partial\Gamma}{\partial\delta} > 0$ and $\frac{\partial\Gamma}{\partial L/T} > 0$. So the boundary (14) is upward sloping in (β_0, δ) space and downward sloping in $(\frac{L}{T}, \delta)$ space. In (β_0, δ) space, $\Gamma(\beta_0^*, \delta, \frac{L}{T}) = \delta - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)$ and $\Gamma(0, \delta, \frac{L}{T}) \equiv (1-\alpha)\left[1 - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right)\right] > 0$ (implying the boundary must have a horizontal intercept). Combining (13) and (14), we have the kinked boundary between outsourcing and in-house as depicted in Figure 5.

Appendix C (Not Intended for Publication)

Let us measure the level of IP protection by τ and normalize the benchmark economy with $\tau = 0$ (i.e., a strengthened protection is associated with $\tau > 0$ and a weakened protection with $\tau < 0$). Thus, both δ and T are increasing functions of τ. It is convenient to consider the following forms:

$$\delta(\tau) = \begin{cases} \underline{\delta} & \text{if } \tau \leq -\frac{\delta_0 - \underline{\delta}}{\delta_1} \\ \delta_0 + \delta_1\tau & \text{if } -\frac{\delta_0 - \underline{\delta}}{\delta_1} < \tau \leq \frac{\overline{\delta} - \delta_0}{\delta_1} \\ \overline{\delta} & \text{if } \tau > \frac{\overline{\delta} - \delta_0}{\delta_1} \end{cases}$$

$$T(\tau) = \begin{cases} \frac{L}{\widetilde{\ell}} & \text{if } \tau \leq -\frac{\widetilde{\ell}-\overline{\ell}}{\ell_1} \\ \frac{L}{\overline{\ell}-\ell_1\tau} & \text{if } -\frac{\widetilde{\ell}-\overline{\ell}}{\ell_1} < \tau \leq \frac{\overline{\ell}-\ell_0}{\ell_1} \\ \frac{L}{\ell_0} & \text{if } \tau > \frac{\overline{\ell}-\ell_0}{\ell_1} \end{cases}$$

where $0 < \underline{\delta} < \delta_0 < \overline{\delta} < 1$, $0 < \ell_0 < \overline{\ell} < \widetilde{\ell} < 1$. These ensure well-defined values for δ and T for any value of τ.

Now, suppose initially $\delta_0 < (1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \overline{\ell}\right)$ and hence R&D is undertaken in house. Consider the case with $\tau \in \left(-\frac{\delta_0-\underline{\delta}}{\delta_1}, \frac{\overline{\delta}-\delta_0}{\delta_1}\right) \cap \left(-\frac{\widetilde{\ell}-\overline{\ell}}{\ell_1}, \frac{\overline{\ell}-\ell_0}{\ell_1}\right)$, under which (**??**) can be rewritten as:

$$\delta_0 + \delta_1\tau = (1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \overline{\ell} + \ell_1\tau\right)$$

This yields the minimum adjustment in IPR protection to ensure R&D outsourcing as the equilibrium outcome:

$$\tau^* = \frac{(1-\lambda)^{\frac{\alpha}{1-\alpha}} \left(1 - \overline{\ell}\right) - \delta_0}{\delta_1 - (1-\lambda)^{\frac{\alpha}{1-\alpha}}\ell_1}$$

While the numerator is always positive by construction (in-house R&D initially), the denominator could be positive or negative. When $\delta_1 > (1-\lambda)^{\frac{\alpha}{1-\alpha}}\ell_1$, the information leakage effect dominates and a stronger protection is needed ($\tau^* > 0$). Yet, such a policy is effective only if $\tau^* < \min\left\{\frac{\overline{\delta}-\delta_0}{\delta_1}, \frac{\overline{\ell}-\ell_0}{\ell_1}\right\}$. Conversely, in the case with $\delta_1 < (1-\lambda)^{\frac{\alpha}{1-\alpha}}\ell_1$, the product cycle effect dominates. So a weaker protection should be implemented ($\tau^* < 0$) and such a policy is effective only if $\tau^* > \max\left\{-\frac{\delta_0-\underline{\delta}}{\delta_1}, -\frac{\widetilde{\ell}-\overline{\ell}}{\ell_1}\right\}$.

References

[1] Aghion, Philippe and Peter Howitt (1992), "A Model of Growth Through Creative Destruction," *Econometrica,* 60, 323-351.

[2] Allen, Beth (2002),"Design for Manufacturing," Unpublished Manuscript, University of Minnesota, Minneapolis, MN.

[3] Burdett, Kenneth and Dale T. Mortensen (1981), "Search, Layoffs, and Labor Market Equilibrium," *Journal of Political Economy*, 88, 652-672.

[4] Chen, Been-Lon and Koji Shimomura, 1998, Self-Fulfilling Expectations and Economic Growth: A Model of Technology Adoption and Industrialization, *International Economic Review*, 39, 151-170.

[5] Chen, Been-Lon, Jie-Ping Mo and Ping Wang (2002), "Technology Adoption, Growth and Matching," *Journal of Economic Dynamics and Control*, 26, 1927-1954.

[6] Green, Jerry and Suzanne Scotchmer (1995) "On the Division of Profit between Sequential Innovators," The Rand Journal of Economics, 26, 20-33.

[7] O'Donaghue, Ted, Suzanne Scotchmer and and Jacques Thisse (1998) "Patent Breadth, Patent Life, and the Pace of Technological Improvement," Journal of Economics and Management Strategy, 7, 1-32.

[8] Grossman, Gene and Elhanan Helpman (1992), *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press, Chapter 4.

[9] Grossman, Gene and Elhanan Helpman (2002), "Integration Versus Outsourcing in Industry Equilibrium," *Quarterly Journal of Economics*, 117, 85-120.

[10] Grossman, Sanford J. and Oliver D. Hart (1983), "An Analysis of the Principal-Agent Problem," *Econometrica*, 51, 7-45.

[11] Grossman, Sanford J. and Oliver D. Hart (1986), "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, 94, 691-719.

[12] Harris, M. and A. Raviv (1979), Optimal Incentive Contracts with Imperfect Information," *Journal of Economic Theory*, 20, 231-259.

[13] Hart, Oliver D. and John Moore (1990), "Property Rights and the Nature of the Firm," *Journal of Political Economy*, 1119-1158.

[14] Horowitz, Andrew W. and Edwin L.-C. Lai (1996), "Patent Length and Rate of Innovation," *International Economic Review*, 37, 785-801.

[15] Laing, Derek, Theodore Palivos and Ping Wang (1995), "Learning, Matching, and Growth, " *Review of Economic Studies*, 62, 115-129.

[16] Milgrom, Paul (1988), "Employment Contract, Influence Activities and Efficient Organization Design," *Journal of Political Economy*, 96, 42-60.

[17] Milgrom, Paul and John Roberts (1992), *Economics, Organization and Management*, Englewood Cliffs, NJ: Prentice-Hall, chapter 6.

[18] Myerson, Roger B. (1983), "Mechanism Design by an Informed Principal," *Econometrica*, 51, 1767-1797.

[19] *R&D Magazine*, January 2001.

[20] Reinganum, Jennifer F. (1981), "Dynamic Games of Innovation," *Journal of Economic Theory*, *25*, 21-41.

[21] Shell, Karl (1973), "Inventive Activity, Industrial Organisation and Econmic Growth," in James A. Mirrlees and Nicolas Stern (edited), *Models of Economic Growth*, London, UK: Macmillan, 77-100.

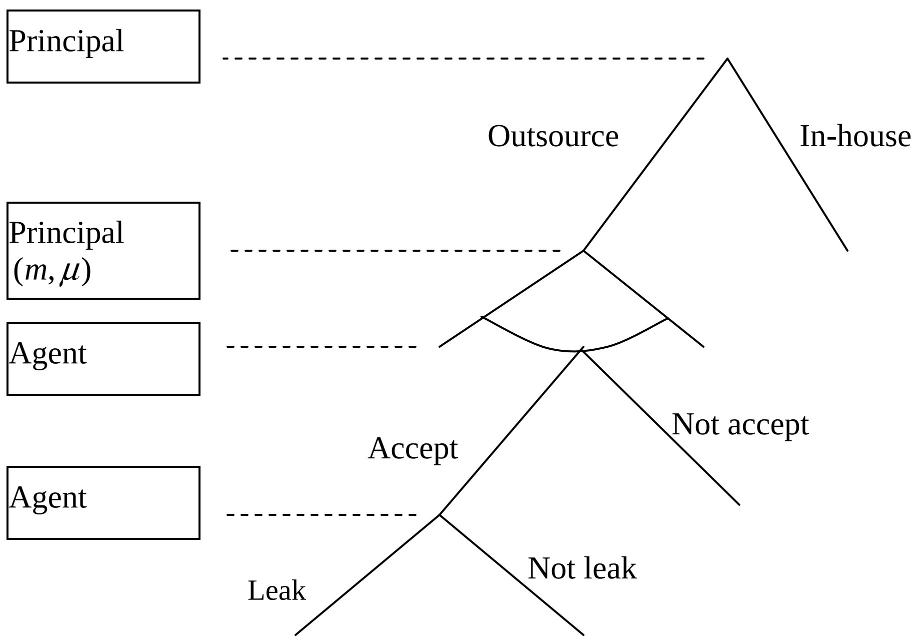

Chart 1. The Game Tree.

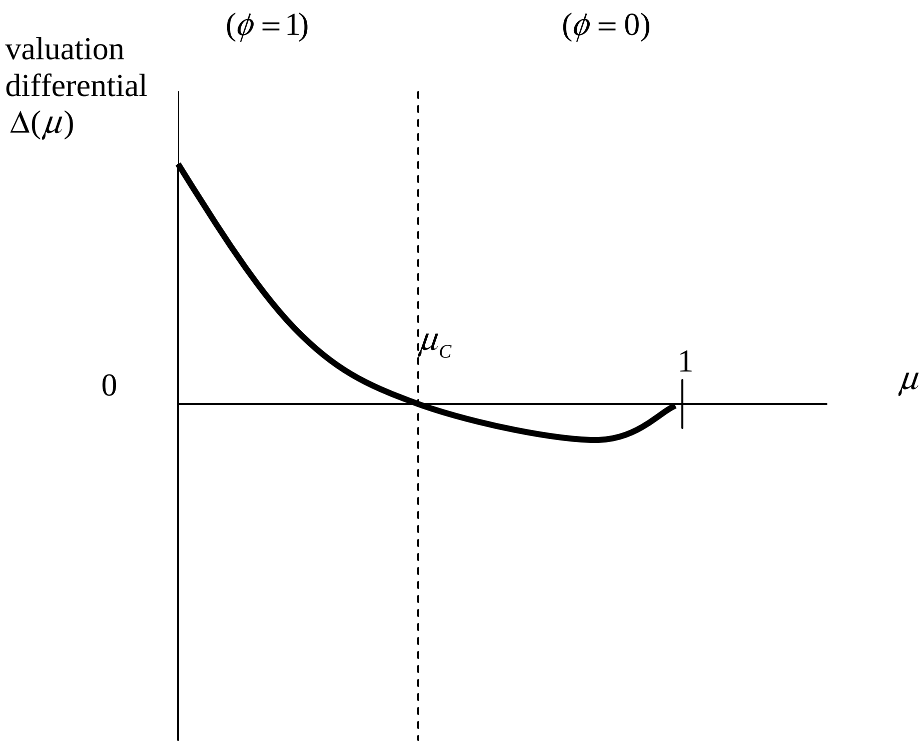

Figure 1. Agent's valuation differential between leakage and no leakage.

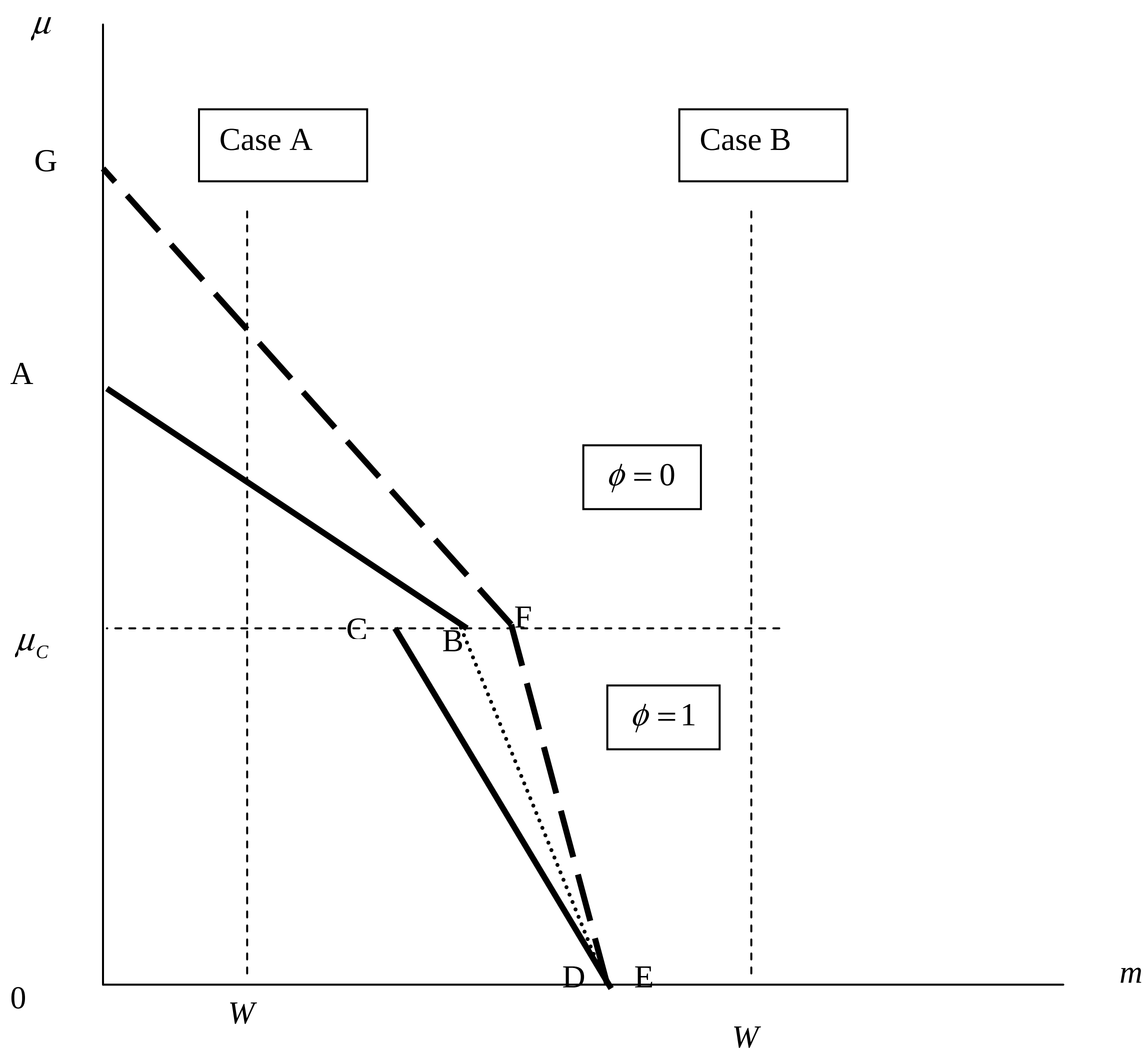

Figure 2. Case I:
A. Outsource with $\mu = 0$.
B. In-house R&D.

Indifference curve of the agent with payoff equal to V_0

Isoprofit line of the principal with profit equal to Π_0.

Convexified part of the iso-profit line of the principal

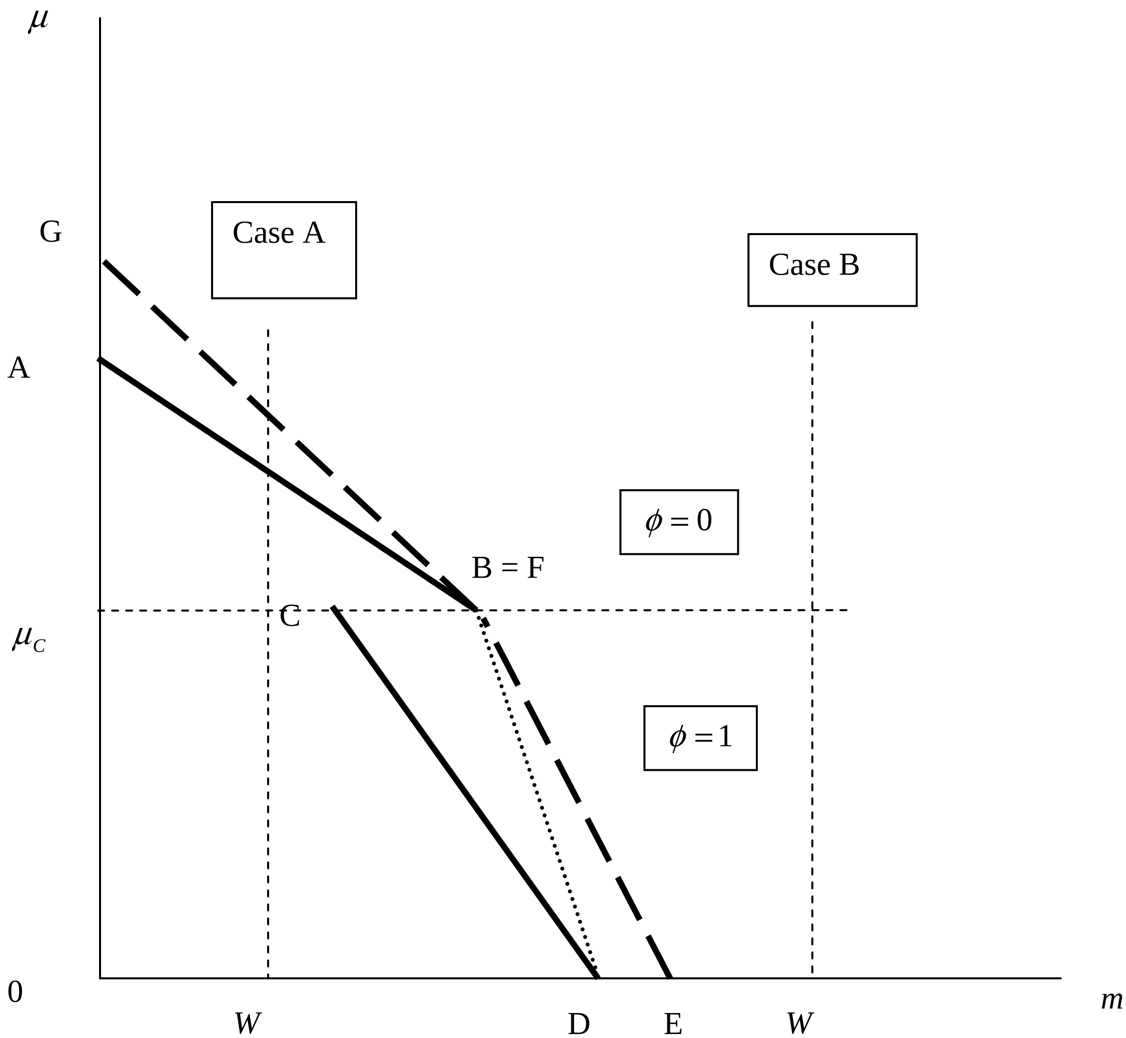

Figure 3. Case II:
A. Outsource with $\mu > 0$.
B. In-house R&D.

Indifference curve of the agent with payoff equal to V_0

Isoprofit line of the principal with profit equal to Π_0.

Convexified part of the iso-profit line of the principal

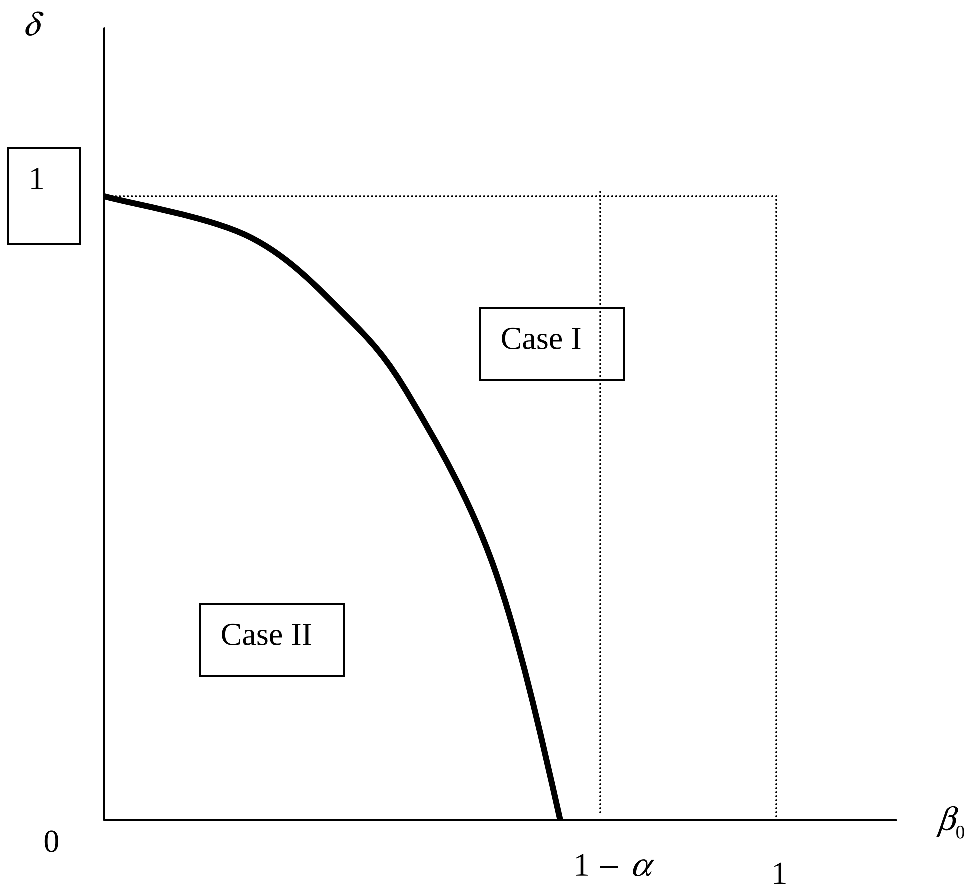

Figure 4. The boundary between Case I and Case II.

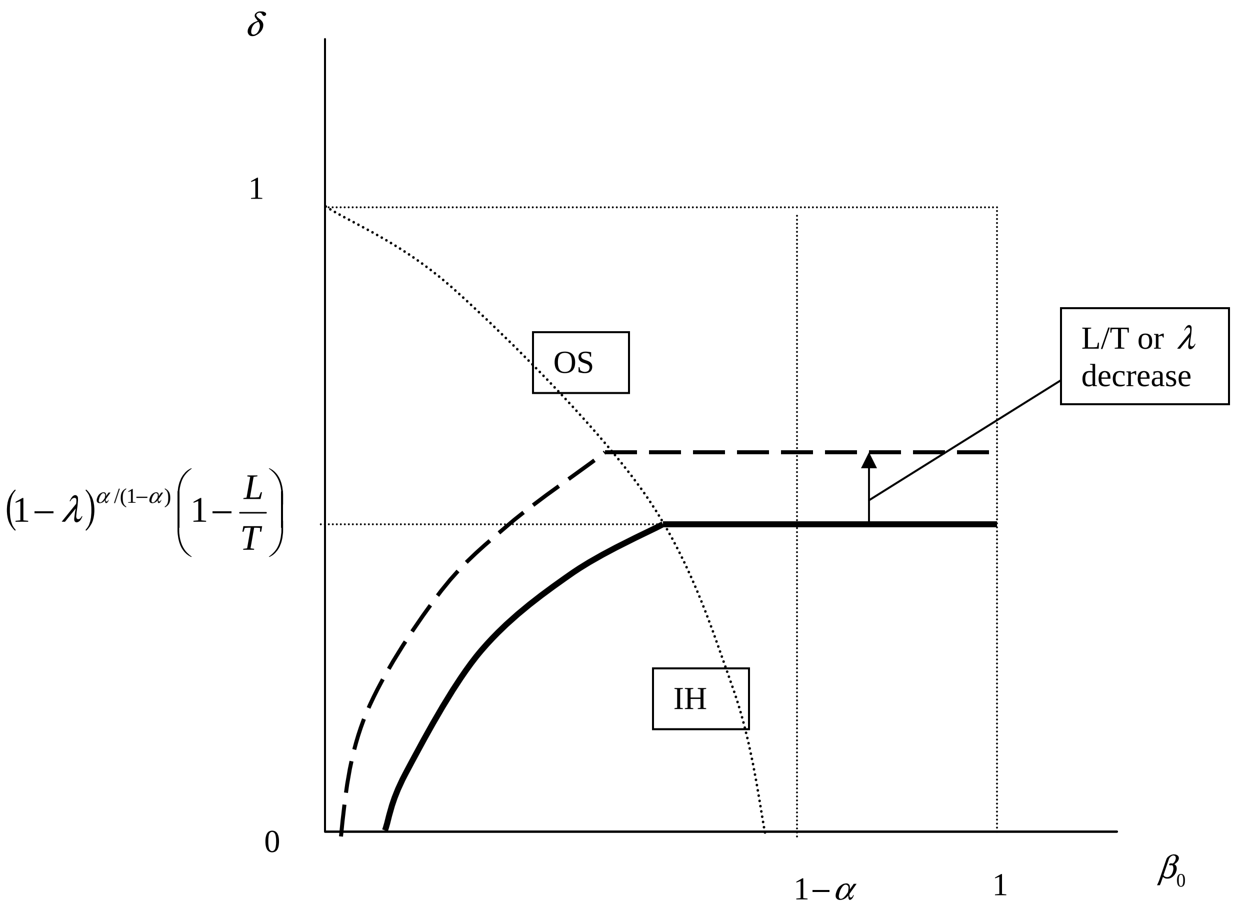

Figure 5. The boundary between in-house R&D (IH) and outsourcing R&D (OS).

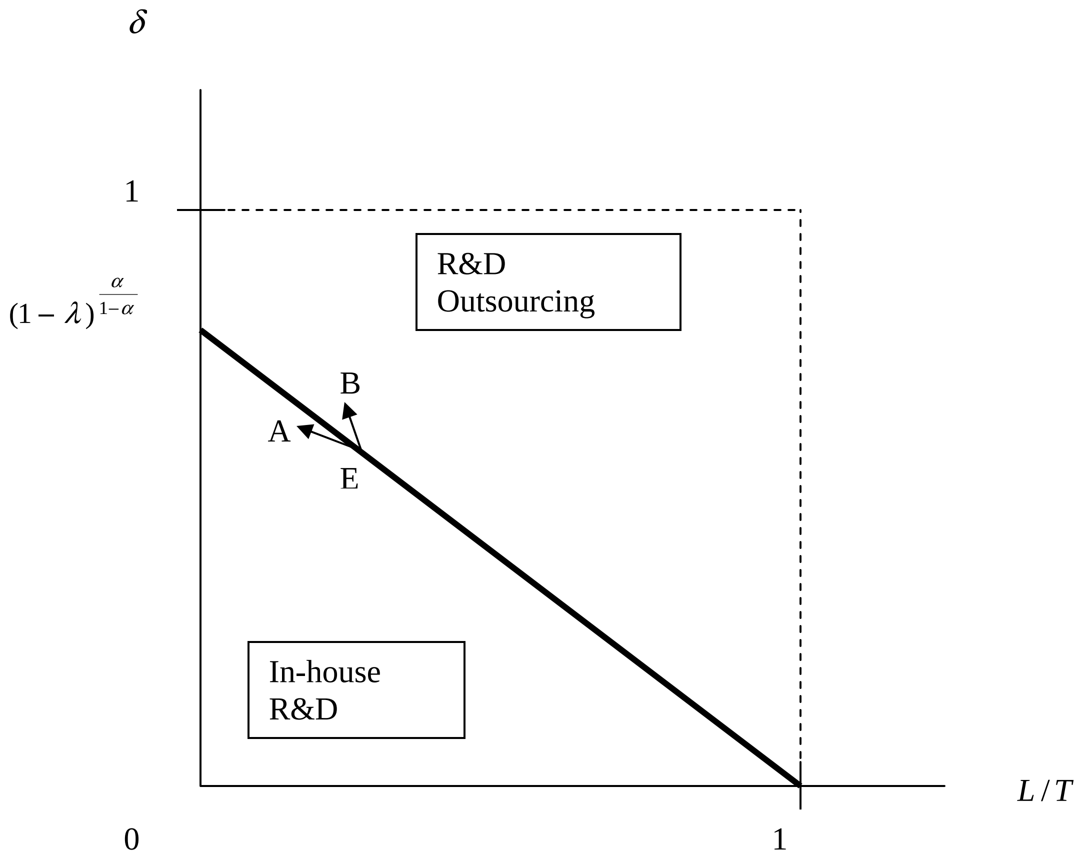

Figure 6. Outsourcing vs. In-house in Case I
and Responses to Stronger IPR Protection.