# Outsourcing of Innovation

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February 2005

Abstract: 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 carry out the research in-house. We use a principal-agent framework and consider fixed and revenue-sharing contracts. We solve for the optimal contract under these constraints. We find that allowing for revenue-sharing contracts increases the chance of outsourcing and improves economic efficiency. However, the principal may still find it optimal to choose a contract that allows 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 nor improve welfare. (JEL Classification Numbers: D21, O31, L14)

Keywords: R&D Outsourcing, Principal-Agent Problem, Fixed versus Revenue-Sharing Contract.

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

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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, "it 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. Why is R&D not outsourced as much as some manufacturing products (such as automobiles) or services (such as legal or advertising services)? We believe this is due largely to its major disadvantage – the possibility that outsourcing R&D will lead to the leakage of trade secrets in the absence of perfect contracting.[2] To our knowledge, there has not been any work that formally models 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, Jones, 2000, Grossman and Helpman, 2002 and 2004, and papers cited therein). This literature focuses primarily on the degree of production outsourcing based on the "theory of the firm". One reason there has been less attention paid to R&D outsourcing is, as Milgrom and Roberts (1992, Chapter 16) point out, R&D outsourcing is difficult to do because of the difficulty of writing a contract and monitoring the subcontractor. In this paper, we tackle this issue 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).

We begin by supposing that there is a fixed number of firms producing differentiated products in the goods market, which we assume to be monopolistically competitive. As in product cycle theory, after the technology is standardized, the firms seek to lower the cost of production. One way is to engage in cost-reduction R&D. We use a principal-agent framework to analyze whether or not a production firm under monopolistic competition 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

[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.

workers are able to work cooperatively with other research workers; non-cooperative workers are not. The 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 that non-cooperative workers do not have the ability to work in a research firm. We also assume that, because of agglomeration and knowledge spillover effects, these research firms have a comparative advantage in R&D activities. 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] On the negative side, in the research process, information sharing takes place within the research firm between partners. This setup facilitates information leakage.

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 and leave the extension to product innovation for future research.[4] So, in our model production firms either do in-house cost reduction research or outsource this job 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 "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 research subcontractor, could be sold to the production firm's competitors which would lead to erosion of the market share of the production firm.[5] 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 revenue-sharing. In the first case, a revenue-sharing contract is the equilibrium outcome, and there is no information leakage. In the second case, the equilibrium features a lump-sum contract, and there will be information leakage. This is the second best outcome when information leakage cannot be monitored or verified. 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 therefore improves economic efficiency.

[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.

[4] Nonetheless, we can think of the innovation explored in this paper as increasing the value of the product (without changing the nature of the product).

[5] Another possibility is that the research firm could enter the industry as a competitor.

Whether or not the optimal contract is revenue-sharing is endogenous. We find that a revenue-sharing contract is more likely to be optimal when the agent's gain from information leakage is a smaller fraction of the principal's loss. This will occur, for example, when there is a larger number of firms in the output market. Even under this circumstance, revenue-sharing is optimal only when the principal's loss from leakage is not too small or too large.

Since leakage reduces the chance of outsourcing R&D, any government measure that reduces losses to the principal or the gains of the agent from appropriating the principal's proprietary information may improve economic efficiency. For example, increased protection of trade secrets should be one such measure that mitigates the information leakage problem. However, we find that strengthening intellectual property (IP) protection systems need not induce more R&D outsourcing and thus, need not improve economic efficiency, because it may affect other aspects of the market that favor in-house R&D, such as the length of the product cycle.

## Related Literature

It is important to contrast our study with those modeling outsourcing of production by firms, particularly the more recent work regarding the make-or-buy outcome as an equilibrium phenomenon. Two seminal contributions by Grossman and Helpman (2002, 2004) focus on the incomplete contract (cf. Grossman and Hart, 1986, and Hart and Moore, 1990) aspect of production outsourcing in two vertically linked economies. They highlight the trade-off between operating a larger organization with less specialization (in-house) and conducting costly search with contracting incompleteness (outsourcing). Another recent work by Antras (2004) explains that firms trade off the benefit of subcontracting (through incomplete contracting) against the cost arising from the hold-up problem. Internalization (in-house production) is optimal when the potential hold-up problem faced by the principal is serious, but then subcontracting occurs when this problem eases in the later stage of the product's cycle. Our paper tackles the fundamental agency problem associated with outsourcing R&D by emphasizing the trade-off between the cost arising from information leakage and the benefit from innovation specialization.

Our paper is also related to a pivotal paper by Ethier (1986). He argues that in-house production will occur when information exchanges between the principal and the agent are complex. Arm's length contracting (such as outsourcing) emerge when information exchanges are simple. Thus, one can interpret the information leakage problem as a cause of increasing complexity i.e., it makes exchange between the manufacturer and the subcontractor more difficult.

## 2 The Basic setup

Consider an environment in which each firm in the output market is an inventor of a differentiated product, the technology of which is already standardized. As in product cycle theory, the firms are seeking to reduce the cost of production through cost-reduction R&D. An output firm can carry out the cost-reduction innovations *in-house* by hiring a researcher, or it can *outsource* the R&D. 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 of a typical firm is $xp(x)$.[6] 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 product life starts at $t = 0$. The inception date of the research output is $t = I$ and the length of product cycle is $T$. That is, the product's life ends at $t = T$. Without discounting the future, the present-discounted value of sales over the entire product cycle is: $xp(x)\,(T - I)$.[7]

There are two possible ways to conduct R&D, one by hiring in-house researchers and the other via outsourcing to a subcontractor.[8] 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.[9] So, we shall use $W^{IH}$ and $W$ interchangeably in the rest of the paper. 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*.

We can now illustrate 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 no adaptability problem, since in-house researchers know the firm's operating environment. But outsourced R&D needs to be adapted to the host firm's operating environment, which

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

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

[8] 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).

[9] 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.

takes time.[10] 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.[11] Because of internal controls, in-house researchers are less likely to leak information. For analytic convenience, such possibilities are assumed away.[12] 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.[13] 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.[14]

In Points 1 and 2 above there are two effects that work in opposition. Adaptability means slower

[10] 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).

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

[12] We assume that the technology developed is largely codified, and so internal control over employee activities can limit to a large extent its leakage. Moreover, as mentioned above, in-house researchers may also receive a loyalty premium that reduces or eliminates their incentive to leak information.

[13] 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.

[14] 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, 2004).

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 under R&D outsourcing is shorter than that 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.

More specifically, information leakage cannot be monitored by the principal or verified by a third party such as a court of law. There are several ways one can justify this assumption. There are situations in which both parties to an agreement know whether the agreement was satisfied but there is no way for a third party to verify whether it was or not. It simply becomes one person's word against another person's word.[15] Moreover, one may argue that part of the information leaked can be of the general tacit knowledge type rather than purely related to the specific product manufactured by the principal. Spillovers of tacit knowledge can hardly be prohibited by the principal or the court.[16] Thus, given Assumption 2 it is not meaningful to write a contract that requires the agent not to leak information, since it would not be enforceable. Therefore, part of the principal's concern is to choose a contract that induces the agent to chose not to leak the information. It is also possible that the information leakage problem could be mitigated by

[15] An even simpler example is, suppose A robs B and there are no witnesses. A court cannot verify this even though both agents know the true state of the world.

[16] Alternatively, we could justify the lack of verifiability by assuming that there is intrinsic uncertainty of the sunspot type (though we do not model uncertainty explicitly). As a consequence, it is impossible for the court to identify the underlying source of a bad sales outcome.

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 $\phi$ 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 an inward shift of the demand curve faced by the production firm, or, more formally,

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

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

If $\phi = 0$ there is no leakage and demand is not affected. If information leakage occurs, the demand curve faced by the output firm shifts in by a fraction $1 - \delta$, which also captures the severity of information leakage. Notably, although the cost arising from information leakage is perfectly observable to the principal, the action of information leakage by subcontractors cannot be verified by third parties.

The R&D we consider is cost-reduction R&D, though it can be interpreted as process innovation — invention of a process that lowers the cost of producing the output.[17] We assume that the unit production cost resulting from in-house R&D is $c$ and that from outsourcing is $(1 - \lambda)c$ (where $\lambda$ 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 payment schedule for the outsourcing contract. The R&D contract $(m, \mu)$ specifies a fixed payment independent of the sales $(m)$ and a percentage fee based on the value of sales (a fraction $\mu$). This type of contract is commonly seen in research subcontracting in practice. It is also considered in Ghatak and Pandey (2000) concerning the agricultural sector and in Bajari and Tadelis (2001) concerning the construction industry. Assumption 2 effectively rules out the possibility of writing a more complicated contingent contract.[18]

[17] We can easily extend the analysis to the case of quality enhancement innovation.

[18] We can interpret a lump-sum contract as signifying an arm's length relationship between the principal and the agent, while a revenue-sharing contract as representing a more integrative, joint-venture type relationship. The consideration of more complex compensation contracts is beyond the scope of the present paper.

The outside option wage faced by the agent, $W$, 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 of the production firm with in-house R&D is:

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

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 who offers the R&D contract $(m, \mu)$ which the agent (the research firm) may accept or reject. Once the contract is accepted, the agent must also decide, for a given R&D 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 production 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 $\phi$) given the contract offered by the principal, $(m, \mu)$. In the second stage, the principal, anticipating the decision on $\phi$ selects the optimal contract $(m, \mu)$. 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. Clearly, the research firm only accepts contracts that yield a higher return than the market wage. Also, there is no uncertainty and hence, the agent does not have to evaluate risks.[19] For analysis of the third stage of the game, we assume that the agent does better as a subcontractor and accepts the principal's contract offer. We now turn to the question of whether the agent 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 $(m, \mu)$, the principal maximizes its profit by choosing $x$, given $\mu$ and $m$. Since the optimally chosen $x$ is a function of $\mu$, the variable $R$ will also be a function of $\mu$. Typically, $R$ is a decreasing function of $\mu$.[20] Let $B = \beta RT$ be the benefit of information leakage to the agent from selling information. It is reasonable to assume that $\beta \in (0, 1-\delta)$. 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 $\beta_0$ measures the fraction of the principal's losses that translates into the agent's gains upon leakage, it is expected that $\beta_0$ will be smaller when the output market is more competitive (i.e., when there are more firms in the output market).[21] 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 the principal is faced with a constant-elasticity demand curve for goods of the form $x = Ap^{-\epsilon}$, where $A > 0$ is a scaling factor which reflects the size of the

[19] 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.

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

[21] To justify $\beta_0 < 1$, or that the agent's gain from information leakage is less than the principal's revenue loss, suppose that the R&D results in the principal having a monopoly in the product market. Now, with information leakage another firm can compete and the market becomes duopolistic. It is well-known that the sum of profits of two duopolists is less than the profit of a monopolist. Therefore, the gain of the agent must be less than the loss of the principal's profit, which is less than the principal's revenue loss. Moreover, as the number of firms in the output market increases, the ratio of the agent's gain to the principal's loss decreases. Therefore, $\beta_0$ decreases when there are more firms in the output market.

market faced by the output firm, and $\epsilon > 0$ is the absolute value of the price elasticity of demand for goods.

When there is no leakage, the revenue-sharing allows the agent to gain $\mu RT$ (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 demand for the principal's product and hence its revenue. The agent's value (or payoff) 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 rival(s) who pay(s) for the information, and also possibly due to her ability to enter the output market as a competitor. Second, since information leakage erodes the demand for the principal's products, the agent's payment from the principal is reduced as it is a function of the principal's revenue.[22] 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 $\mu_C$ as the value of $\mu$ 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, $\Delta V$ decreases in $\mu$ until it reaches a value well beyond $\mu_C$. Thus, for any $\mu > \mu_C$, $\Delta V < 0$, which means the value of not leaking is higher than the value of leaking. In this case, the performance-dependent contract 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:

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

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

## 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 contract payment has two components, a fixed payment $m$ and a payment contingent on sales $\mu p(x)x$. So, the two parameters $(m, \mu)$ 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 contract $(\mu, m)$ is:

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

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

To determine the optimal contract consider the production firm's willingness to trade off between $\mu$ and $m$. For any given value of $\Pi_0$, 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 $\mu$ and $m$ that leave the principal indifferent between outsourcing and conducting in-house R&D. We can then use (6) to find how $\mu$ and $m$ vary along the iso-profit curve with gross profit equal to $\Pi_0$ (see Figure 1). Figure 1 shows the iso-profit curve, which must be downward sloping for constant elasticity 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 $\mu < \mu_C$.[23] An iso-profit curve closer to the origin is associated with a higher gross profit.

The iso-profit curves are all discontinuous at $\mu = \mu_C$. This discontinuity occurs because as $\mu$ increases to $\mu_C$ from below, information leakage is eliminated and the market share is restored from $\delta < 1$ to $\delta = 1$. Thus, the total revenues jump and the principal is able to increase the lump-sum contract payment ($m$) and still maintain the same profit. Furthermore, totally differentiating (5) with respect to $\mu$ 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 1) than if $\mu < \mu_C$ (segment $CD$ in Figure 1) 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 $\mu$ on $\Pi(\mu, m)$ is smaller when

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

$\phi = 1$, and so the principal is willing to give up more $\mu$ 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 $W$. The gross profit of the principal when doing R&D in-house is therefore given by

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

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:

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

In the next section, we show how changes in parameters $\{W, \beta_0, \lambda, L/T\}$ affect 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 carrying out the cost reduction innovation in-house, we begin by characterizing the indifference curve of the agent in $(m, \mu)$ space. The indifference curve is the locus of pairs of $(m, \mu)$ for which $V(m, \mu) = V_0$ (a constant). Referring to Figure 1, note that, unlike the iso-profit locus of the principal, there is *no* discontinuity of the indifference curve where $\mu = \mu_C$ (when $\phi$ switches from 0 to 1). This follows directly from (2), which shows that $V|_{\phi=1} = V|_{\phi=0}$ when $\mu = \mu_C$. Alternatively, equation (4) shows that $V$ is continuous in $\mu$ because it is the maximum of two continuous functions in $\mu$.[24] Since $V$ is continuous in $\mu$, 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 for $\mu < \mu_C$. Using (4), we totally differentiate $V(m, \mu) = V_0$ with respect to $m$ and $\mu$. 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 in the neighborhood of $\mu = \mu_C$. That means the indifference curve is kinked outward at $\mu = \mu_C$ (see curve $EFG$

[24] Precisely, we have $V = \max\{\mu R(\mu)T + m,\ \delta\mu R(\mu)T + m + \beta_0(1 - \delta)R(\mu)T\}$.

in Figure 1). The indifference curve is flatter when $\mu > \mu_C$ because when there is no leakage, the payoff of the agent is less tied to the revenue of the principal. The agent requires a smaller increase in $\mu$ to compensate her for each dollar reduction in $m$. Note that the indifference curve has higher utility in the northeast direction.[25] We next address the issue of bargaining power between the principal and the agent.

For illustrative convenience, we bestow all bargaining 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 assumed in our paper, 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 straightforward. It implies that: (i) when the payment to the subcontractor ($\mu$, $m$) satisfying $\Pi(\mu,\, m) = \Pi^{IH}$ yields $V(\mu,\, m) \geq W$, the principal outsources R&D; (ii) otherwise, the principal conducts R&D in house. Another interpretation of this assumption is that, given the various possible contracts offered by potential principals, the agent is the decisive player, selecting the contract she most prefers. If that contract yields her an income higher than her wage when employed in-house, she accepts the outsourcing contract. It is important to note that even if we relax Assumption 4 and allow the principal to have some or even all the bargaining power, the same qualitative results will be obtained.[26] Therefore, we focus on the benchmark case in which

[25] 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 $(m, \mu)$ space, meaning that an increase in $\mu$ 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.

[26] 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): $\max_{\mu,m} \left[V(\mu,m) - W\right]^b \left[\Pi(\mu,m) - \Pi^{IH}\right]^{1-b}$, where $b \in [0,1]$ measures the relative bargaining power of the agent. For example, $b = 1$ under Assumption 4 and $b = 1/2$ when the two parties have symmetric bargaining power. The first-order conditions with respect to $\mu$ and $m$, respectively, are:

$$\begin{aligned}(\mu - \mu_C)\left[dV(\mu,m)/d\mu + d\Pi(\mu,m)/d\mu\right] &= 0 \quad \text{for } \mu \geq \mu_C \\ \mu\left[dV(\mu,m)/d\mu + d\Pi(\mu,m)/d\mu\right] &= 0 \quad \text{for } \mu < \mu_C\end{aligned}$$

and

$$m\left[b\left(\Pi(\mu,m) - \Pi^{IH}\right) - (1-b)\left(V(\mu,m) - W\right)\right] = 0$$

the agent solves:[27]

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

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

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 $\mu$, as in Figure 1. That is, for each dollar reduction in $m$, the agent requires a greater increase in $\mu$ 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 $\mu > \mu_C$.[28]

### 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.[29] Refer to Figures 1 and 2. Since the area below the iso-profit curve $ABCD$ 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 candidates for tangent points with the agent's indifference curves. Consequently, which outsourcing contract occurs depends on whether the curve $EF$ is steeper than the convexified portion of the iso-profit curve $BD$. If the indifference curve is steeper than the convexified iso-profit curve then we have Case I shown in Figure 1. Otherwise, we have Case II shown in Figure 2. It can

where each of the expressions in square brackets is non-positive. We will elaborate in Section 4.1 that such a generalization would not alter our main findings.

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

[28] 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 curve DC in Figure 2, as long as D and E are the same point. This ensures that the equilibrium contract will either be at point B or point D (i.e.$\mu = 0$ or $\mu_C$). These are the Cases I and II we discuss below. There is no possibility of an equilibrium at any point between $\mu = 0$ and $\mu = \mu_C$ .

[29] 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.

be shown that an increase in $\delta$ or $\beta_0$ would reduce the gap $CB$, the principal's profit gap between leaking and no leaking. This in turn reduces the slope of $BD$. Moreover, it also increases the slope of the curve $EF$. Hence, an increase in $\delta$ or $\beta_0$ would make Case I more likely to occur and Case II less likely to occur.

Refer to Figure 1. In Case I, $\delta$ or $\beta_0$ is sufficiently large so that $EF$ is steeper than $BD$. 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 $\mu$ by the agent. On the other hand, along the convexified iso-profit curve $BD$, 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 $BD$), and so the agent is willing to substitute $m$ for $\mu$, 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 1, and the agent would rather take a pure lump-sum contract from the principal. Now refer to Figure 2 for Case II. In this regime, $\delta$ or $\beta_0$ is sufficiently small, so that $BD$ 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 $\mu$ through leaking. Thus, we have an interior solution when outsourcing does occur, as shown in Case IIA of Figure 2. We have a mixed contract with a positive lump sum payment and a positive revenue-share, and there is no leakage.[30]

We next derive the boundary between Cases I and II explicitly and show it in Figure 3. Essentially, the calculation is based on the observation that, in Figure 2, we have Case I iff $\overline{OD} > \overline{OE}$ and Case II iff $\overline{OD} < \overline{OE}$ given that $B$ and $F$ overlap. 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 AEC in Figure 3 for the boundary between Cases I and II in $(\beta_0, \delta)$ space according to equation (8). Case I lies to the northeast of AEC and Case II lies to the southwest of it. As discussed above, we have Case I when $\delta$ or $\beta_0$ is large, and Case II when $\delta$ and $\beta_0$ are small. Note that when

[30] 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.

$\beta_0 > 1 - \alpha$, Case II cannot arise. In other words, outsourcing with a mixed contract is less likely when the output market is less competitive ($\beta_0$ higher), so that the ratio between the agent's gain and the principal's loss in case of leakage is relatively high (closer to one).

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 1).** This case occurs if $\delta$ or $\beta_0$ is large, as shown in Figure 3. Within this case, the boundary between in-house (IH) and outsourced R&D (OS) is shown in Figure 3 as $EB$ (see the Appendix).

**(IA)** Referring to Figure 1, 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. *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 $\beta RT$. 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 $\delta$ is relatively large.

**(IB)** Referring to Figure 1 again, when $W > \overline{OE}$, we have Case IB. 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 $\delta$ is relatively small.

**(ii) Case II: The agent's price of leaking is relatively high (Figure 2).** This will be the case if $\delta$ or $\beta_0$ is small, as shown in Figure 3.[31] The boundary between the OS and IH regimes for case II is shown in Figure 3 as $ED$ (see the Appendix).

**(IIA)** Referring to Figure 2, when $W < \overline{OE}$, *there is outsourcing with a mixed contract* $(m, \mu)$ such that $\mu$ is set at $\mu_C$ and $m$ is set positive. *There will be no information*

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

*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 $\delta$ is relatively large or $\beta_0$ is relatively small.

**(IIB)** Referring to Figure 2 again, when $W > \overline{OE}$, there is in-house R&D. Within Case II, this regime would take place when $\delta$ is relatively small and $\beta_0$ 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. Before deriving the results formally, however, we would like to provide further insight into the determination of the equilibrium outcomes by way of comparing the "threat points" facing the principal and the agent. In doing so, we can see more clearly that our main findings do not rely on the assumption we make about the relative bargaining powers of the two parties (viz. Assumption 4). Specifically, the threat points facing the principal and the agent are, respectively, represented by a particular iso-profit curve, $\Pi(m,\mu) = \Pi^{IH}$, and a particular indifferent curve, $V(m,\mu) = W^{IH}$, because $\Pi^{IH}$ and $W^{IH}$ are the corresponding best outside options (from in-house production). Refer now to Figure 4. Active participation in outsourcing activity requires that a contract $(m,\mu)$ be in the area on or below $\Pi(m,\mu) = \Pi^{IH}$ and on or above $V(m,\mu) = W^{IH}$ (that is, both the principal and the agent are at least as well off as when R&D is conducted in-house). Depending on the relative positions of the two threat-point curves, there are four scenarios:

**(a)** $\Pi(m,\mu) = \Pi^{IH}$ is entirely below $V(m,\mu) = W^{IH}$;

**(b)** $\Pi(m,\mu) = \Pi^{IH}$ is entirely below $V(m,\mu) = W^{IH}$ for $\mu \geq \mu_C$ but at least part of $\Pi(m,\mu) = \Pi^{IH}$ is above $V(m,\mu) = W^{IH}$ for $\mu < \mu_C$;

**(c)** $\Pi(m,\mu) = \Pi^{IH}$ is entirely below $V(m,\mu) = W^{IH}$ for $\mu < \mu_C$ but at least part of $\Pi(m,\mu) = \Pi^{IH}$ is above $V(m,\mu) = W^{IH}$ for $\mu \geq \mu_C$;

**(d)** at least part of $\Pi(m,\mu) = \Pi^{IH}$ is above $V(m,\mu) = W^{IH}$ for both $\mu < \mu_C$ and $\mu \geq \mu_C$ (including the case where $\Pi(m,\mu) = \Pi^{IH}$ is entirely above $V(m,\mu) = W^{IH}$).

In scenario (a), outsourcing is inferior to both the principal and the agent regardless of the assumption of the relative bargaining powers. Thus, the equilibrium outcome must be in-house R&D. For the other three scenarios, there are joint surpluses accrued as a result of outsourcing R&D and hence, in equilibrium, R&D must be subcontracted. While R&D is outsourced with a lump-sum contract ($\mu = 0$) in scenario (b), equilibrium features a mixed outsourcing contract with $\mu = \mu_C$ in scenario (c). In scenario (d), whether the outsourcing contract is revenue-sharing depends on the relative magnitude of $\overline{BF}$ versus $\overline{OD} - W^{IH}$ (see panel (d) of Figure 4). It is clear that the resulting forms of the contract (either $\mu = 0$ or $\mu = \mu_C$) as well as the main findings concerning the different roles of $\mu$ and $m$ in alleviating the agency problem remain unchanged for different assumptions about the relative bargaining power.[32]

## 4.2 Boundary between OS and IH: Case I

To better understand how the parameters in the model determine whether research is outsourced, 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 1). We next show that this condition implies that as $\delta$, $L/T$ or $\lambda$ gets larger, outsourcing is more likely. However, $\beta_0$ and $W$ have no effect on who carries out R&D. The boundary between the outsourcing and in-house research regimes in $(\beta_0, \delta)$ space is shown in Figure 3 as $EB$.

To show this we first solve for the relationship between the distance $\overline{OD}$ in Figures 1 and 2 and $\Pi^{IH}$. $(\overline{OD}, 0)$ lies on the iso-profit curve 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 (with zero revenue sharing) to keep the principal's profit equal to $\Pi^{IH}$. 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.

[32] Specifically, while $\mu$ always takes on the value 0 or $\mu_C$, the relative bargaining power only affects the equilibrium value of $m$ (and hence only the boundary between Case I and Case II). Regardless of the relative bargaining power, leakage still occurs in the case where $\mu = 0$ (Case I), whereas under $\mu = \mu_C$ (Case II) the agency problem is completely alleviated.

On the other hand, (7) implies that

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

That is, a higher $W$ is reflected in a higher gap between the operating profit and the net profit under outsourcing.

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

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

When the demand faced by each firm is constant-elasticity of the form $x = Ap^{-\epsilon}$, where $\epsilon = 1/1-\alpha$, 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

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

Since $p(x^{IH}) - c > 0$, $\Delta$ has the same sign as $\delta(1-\lambda)^{1-\epsilon}T - (T - L)$. Therefore, the threshold values ($\delta$, $L/T$) that drive $\Delta \equiv \overline{OD} - W$ to zero (given $\lambda$ and $\alpha$) satisfy:

$$\delta = (1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1 - \frac{L}{T}\right) \tag{12}$$

Since this boundary is independent of $\beta_0$, it is horizontal in $(\beta_0, \delta)$ space (Figure 3). We can conclude:

**Proposition 1:** *Under Assumptions 1-4, Case I and constant elastic output demand, R&D is outsourced in equilibrium if* $\delta > (1-\lambda)^{\frac{\alpha}{1-\alpha}}(1 - L/T)$; *otherwise, it is conducted in-house. Changes in* $W$ *or* $\beta_0$ *have no effect on who carries out R&D in equilibrium under Case I.*

The first part of the Proposition is very intuitive. Basically, it says that if the advantage of R&D outsourcing (values of $\delta$ and $\lambda$) and/or the disadvantage of in-house R&D (value of $L/T$) are/is larger, R&D outsourcing will be the equilibrium outcome. The boundary between outsourcing and in-house research in $(\delta, L/T)$ space is indeed linear, as shown in Figure 5.

The interesting effects are those of $W$ and $\beta_0$. An increase in $W$ causes $\Pi^{IH}$ to decrease, which in turn causes $\overline{OD}$ to increase by the same amount. In the end, $W$ has no effect on $\Delta \equiv \overline{OD} - W$, 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 incorrect because it ignores the fact that an increase in $W$ raises the principal's willingness to pay for outsourcing R&D as $\Pi^{IH}$ decreases. Thus, both $\overline{OD}$ and $W$ increase by the same amount. In other words, though the subcontractor gets a higher wage while working as the principal's employee, she also receives more fees from the principal through outsourcing. Thus, it would not change the value of $\overline{OD} - W$, and so it would not change who carries out R&D in equilibrium. The effects of $\beta_0$ are even simpler. Since $\beta_0$ does not affect $\Pi^{IH}$, it has no effect on $\overline{OD}$. Therefore, changes in $\beta_0$ does not affect $\overline{OD} - W$.

### 4.3 Boundary between OS and IH: Case II

We next compute the boundary condition between outsourcing and in-house research for case II. In this case, there will be outsourcing iff $\overline{OE} > W$ in Figure 2. We show in the appendix that the boundary is given by,

$$\Gamma(\beta_0, \delta, \frac{L}{T}) \equiv (1-\beta_0)^{\frac{\alpha}{1-\alpha}} - \alpha\,(1-\beta_0)^{\frac{1}{1-\alpha}} - \beta_0(1-\delta) - (1-\alpha)\,(1-\lambda)^{\frac{\alpha}{1-\alpha}}\left(1-\frac{L}{T}\right) = 0 \quad (13)$$

where $\Gamma(\beta_0, \delta, L/T)$ measures the net benefit of outsourcing R&D. That is, R&D would be outsourced iff $\Gamma(\beta_0, \delta, L/T) > 0$; otherwise, it would be conducted in-house. The boundary specified in (13) is upward sloping in $(\beta_0, \delta)$ space. A diagrammatic presentation of this boundary in $(\beta_0, \delta)$ space is given in Figure 3 as $ED$. Note that outsourcing is more likely to occur as $\delta$ or $L/T$ gets larger, or as $\beta_0$ 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 $\Pi^{IH}$ 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 $\mu$ 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 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 $\beta_0$ 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 revenue-sharing component in the outsourcing contract can increase the likelihood of outsourcing. This is possible when $\beta_0$ is sufficiently small, i.e., when the output market is sufficiently competitive so that the agent can only gain a sufficiently small fraction of what the principal loses in case of leakage. The possibility of writing a mixed contract explains why the OS region in Case II shown in Figure 3 extends beyond the region $\delta > (1-\lambda)^{\frac{\alpha}{1-\alpha}}(1 - L/T)$ (which is the condition defining the OS region in Case I). In fact, as Figure 3 shows, as $\beta_0$ gets smaller, the range of $\delta$ that supports the OS equilibrium gets larger.

### 4.4 The boundary between the IH and the OS regimes: Combining all cases

Combining Cases I and II, we can depict the boundary between the IH and OS regimes in $(\beta_0, \delta)$ space (see Figure 3). It is worthwhile to go through the intuition for the impact of a reduction in $\beta_0$. From (12), we see that $\beta_0$ 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 $\beta_0$ decreases. Recall that $\mu_C = \beta_0$. Since a reduction in $\beta_0$ reduces $\mu_C$, it extends curve $AB$ in Figure 1 further down and to the right. Moreover, curve $EF$ in Figure 2 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 $\beta_0$ makes R&D outsourcing more likely. In the extreme case when $\beta_0 \to 0$ (so that $\mu_C \to 0$), curve $AB$ in Figure 2 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 $W = x^{IH}[p(x^{IH}) - c](T - L) - \Pi^{IH}$, 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 3, for any given $\delta$, we would eventually reach the OS region as $\beta_0$ decreases.

Figure 3 essentially contains all the major results of this paper regarding the characterization of equilibrium outcomes. First, it shows that we have the IH regime only when $\beta_0$ is large and $\delta$ is small. This is intuitive because it implies that when the principal's loss and the agent's gain from leakage are both high outsourcing is unlikely. Second, it shows that within the OS regime revenue-sharing is optimal only when $\beta_0$ is sufficiently small. Intuitively, when $\beta_0$ is sufficiently large, the agent's "price" of leaking is smaller than the willingness of the agent to substitute $m$ for $\mu$, and so she always prefers leaking in case of outsourcing. Third, given that $\beta_0$ is sufficiently small so that there is the possibility of revenue-sharing under OS (but not so small as to completely inhibit in-house R&D), there are three regimes, depending on the value of $\delta$. Revenue-sharing is optimal only when $\delta$ is not too large or too small. When $\delta$ is too small, the disadvantage of outsourcing is too big, and so IH is the optimal choice. When $\delta$ is too large, though there is outsourcing, there is no revenue-sharing since leakage does not cause too much loss to the principal. Only when $\delta$ is intermediate in value would outsourcing and revenue-sharing (to prevent leakage) be both beneficial to the principal. Fourth, it shows that as the output demand faced by the principal gets more elastic ($\alpha$ gets larger), the IH regime gets smaller, and the OS (with leakage) regime gets larger (see Figure 3 where point $E$ shifts southwest to $E'$). When $\alpha$ is close to 1 (output demand is very elastic), the probability of outsourcing with lump-sum contract (and leakage) is close to one. Intuitively, when the differentiated goods are more substitutable with each other, a given reduction in cost by a firm can induce more quantity demanded, thereby generating more profit for the firm, granting outsourcing greater advantage. We summarize these results below.

**Proposition 3:** *Under Assumptions 1-4, the equilibrium possesses the following properties.*

**(i)** *R&D is outsourced when the degree of market erosion due to information leakage is low ($\delta$ large), the subcontractor's benefit from leaking is not too high ($\beta_0$ small), or the output demand faced by the principal is sufficiently elastic ($\alpha$ high); otherwise, R&D is conducted in-house.*

**(ii)** *Revenue-sharing is the optimal contractual arrangement only when the subcontractor's benefit from leaking ($\beta_0$) is sufficiently small; given that $\beta_0$ lies in a range where revenue-sharing and in-house R&D are both supportable as equilibrium, revenue-sharing is optimal only when the degree of market erosion due to information leakage ($1-\delta$) is not too large or too small.*

## 5 Intellectual Property Protection and R&D Outsourcing

Does R&D outsourcing result in higher economic welfare? Suppose there is no information leakage. Since the research firm can do R&D faster and better, 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 a socially coordinated outcome.

This suggests a role for policy. Can appropriate policies alleviate the economic inefficiency resulting from the information leakage problem? Suppose policy makers have no direct control over the actions of research firms. Now consider a policy of tighter protection of trade secrets. Such a policy would reduce the principal's loss associated with information leakage (i.e., higher $\delta$).[33] For example, it would be easier for the principal to stop intellectual property (IP) rights infringement or seek compensation after the trade information is leaked by the agent, even though one cannot verify whether the agent indeed leaked the information (Assumption 2). Proposition 3 states that this effect increases the likelihood of R&D outsourcing, which is an economically more efficient "institutional arrangement" to conduct R&D (as compared to in-house R&D). Therefore, stronger protection of trade secrets tends to improve economic efficiency on this account.

Does stronger IP protection inhibit technology diffusion? Our answer is "No". If stronger IP protection induces more R&D outsourcing with no leakage (e.g., when $\beta_0$ is small), it does not inhibit or enhance diffusion of the developed technology. However, if it induces more R&D outsourcing with leakage (e.g., when $\beta_0$ is large), it actually enhances technology diffusion. In the conventional IP protection literature, the optimal degree of IP protection balances the marginal benefit of inducing more R&D investment against the deadweight loss arising from inhibiting imitation or technology diffusion (see Grossman and Lai 2004 and papers cited therein). In contrast, the benefit of IP protection in our model does not arise from increased R&D investment, but rather, from a better institutional arrangement of R&D (i.e., outsourcing versus in-house). In this context, we show that increased IP protection induces more efficient conducting of R&D *without* inhibiting technology diffusion.

If one goes beyond the narrowly focused policy on trade secrets and considers the strengthening of the entire IP protection system,[34] then one realizes that the above analysis ignores the possibility that stronger IP protection may have other effects that may favor in-house R&D. For example, stronger IP protection can 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) making in-house

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

[34] That is, a strengthening of all aspects of IP protection, including trade secrets, patent length, patent breadth, patent enforcement, copyrights, trademarks, and so on.

R&D more attractive – it can be referred to as the *product cycle effect.* This is because stronger IP protection makes it more costly for other firms to conduct future quality-improvement innovations based on the existing patents. This is discussed in 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. This slows down the creative destruction process and lengthens the product cycle. The lengthened duration of monopoly power of the incumbent not only discourages R&D outsourcing but also hurts consumers. Thus, it reduces welfare.[35] One may therefore argue, that the TRIPS (Trade-Related Aspects of Intellectual Property Rights) agreement, which strengthens IP protection of many less developed countries, could result in less R&D outsourcing from the North to the South.[36]

These results are summarized in:

**Proposition** 4**:** *Under Assumptions 1-4,*

**(i)** *if the product cycle effect is small, strengthening IP protection increases economic efficiency by encouraging more R&D outsourcing — it will enhance technology diffusion if the equilibrium features a lump-sum outsourcing contract ($\beta_0$ is large), but it will not inhibit or enhance technology diffusion if the equilibrium features a mixed contract ($\beta_0$* is small)*;*

**(ii)** *if the product cycle effect is strong, strengthening IP protection would reduce the incentive to outsource R&D and lower economic efficiency.*

[35] To be more specific, consider Case I. Figure 5 illustrates the tension between the information leakage effect via $\delta$ and the product cycle effect via $L/T$ as IP protection strengthens. Suppose we begin from point E in Figure 5 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 the principal can now enjoy no leakage for a larger fraction of the product's life if it keeps R&D in-house. Thus, strengthening IP protection hurts welfare on two counts: R&D is not outsourced and the duration of monopoly power of the incumbent is lengthened. On the contrary, when the product cycle effect is weak, one moves from point E to point B in Figure 5. In this case, the production firm outsources R&D in equilibrium since there is a smaller loss in the market share in case of leakage, which makes R&D outsourcing more attractive. Similar analysis applies to Case II.

[36] This is more likely when the information leaked is of the general tacit knowledge type that is difficult to protect.

# 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 even though it is economically efficient to do so. 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 involve revenue-sharing. With revenue-sharing, there is no leakage of information. Interestingly, under certain circumstances, manufacturing firms outsource R&D with a lump-sum contract, despite knowing that leakage will occur. In-house R&D is the optimal institutional arrangement only if the principal's loss and the agent's gain from leakage are both large. Outsourcing with revenue-sharing is optimal only when the agent's gain from leakage is sufficiently small and the principal's loss from leakage is neither too large nor too small. Although stronger IP protection does not inhibit technology diffusion, it needs not encourage more R&D outsourcing nor improve welfare since other aspects of the market, such as the length of the product cycle, can be affected.

What happens if we introduce demand uncertainty (or, what is mathematically equivalent, uncertainty in the relative cost reduction measured by $\lambda$)? If both the principal and the agent have linear value functions, our findings remain the same. Suppose the research firm (the agent) is 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. As illustrated by Figure 6, this causes an upward shift of the boundary $DEB$. Moreover, since a revenue-sharing contract generates uncertain reward to the agent, it must provide a higher share of revenue to compensate the agent for each unit reduction in lump-sum payment (i.e., the indifference curves are steeper). As a result, the boundary between Case I and Case II (curve $AEC$ in Figure 6) must rotate clockwise. These arguments imply an equilibrium point $E''$ as depicted in Figure 6. Comparing to the case without demand or cost-reduction uncertainty (point $E$), the introduction of uncertainty increases the likelihood of in-house R&D and reduces the likelihood of R&D outsourcing with a mixed contract. This suggests an additional explanation for the reluctance of manufacturing firms to outsource R&D despite its advantages of speed and specialization.

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# Appendix A
(A major portion is not intended for publication)

This appendix proves that the slope of the agent's indifference curve is always steeper than that of the iso-profit curve of the principal at any given $\mu$. 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 $\epsilon$ 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 $\Pi^{IH} = x[p(x) - c](T-L) - W = (R - cx)(T-L) - W$, where $T$, $L$ and $W$ 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 $\mu$. In choosing the optimal $x$, the principal treats $m$, $\mu$, $\lambda$, $c$ 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 $\mu$ in (2) for any $\mu$ less than a critical value that is beyond $\mu_C$. 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 $(m, \mu)$ space, meaning that an increase in $\mu$ 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. However, even in this case, our main results would not change; therefore, we will focus primarily on the case with downward sloping indifference curves throughout the rest of our analysis.

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 $\mu$ 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 $\mu$ for $\phi = 1$.

# Appendix B
# (A major portion is not intended for publication)

This appendix derives the boundary between Case I and Case II and the boundaries between the two modes of R&D (in-house vs. outsourcing).

**(I) Boundary between Case I and Case II**

All iso-profit curves have the same slope for any given $\mu$. Similarly, all indifference curves have the same slope for any given $\mu$. Let point $B$ in Figures 1 and 2 be represented by $(m, \mu) = (m_0, \mu_C)$, point $D$ in Figures 1 and 2 by $(m, \mu) = (m_1, 0)$, and point $E$ in Figure 2 by $(m, \mu) = (m_2, 0)$.

Since a typical iso-profit curve $\Pi(\mu, m) = \Pi_0$ passes through both $(m_0, \mu_C)$ and $(m_1, 0)$, we can apply (5), (14) 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 $\Pi_0$ 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 $(m_0, \mu_C)$ 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 $D(\beta_0, 1) = (1-\beta_0)^{\frac{\alpha}{1-\alpha}}[1-\alpha(1-\beta_0)] - (1-\alpha) \leq 0$ (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 $\beta_0$ 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 $\beta_0$ is sufficiently small (less than $\beta_0^*$ where $\beta_0^*$ satisfies $D(\beta_0^*, 0) = 0$), Case II becomes more likely to emerge as $\delta$ gets smaller. In summary, the boundary between the two regimes in $(\beta_0, \delta)$ space is downward sloping with horizontal intercept at $\beta_0^* < 1-\alpha$ and vertical intercept at 1, as depicted in Figure 3.

**(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 (12) and depicted in $(\beta_0, \delta)$ space in Figure 3 and in $(\delta, \frac{L}{T})$ space in Figure 5.

**(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 (13).

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 (13) is upward sloping in $(\beta_0, \delta)$ space and downward sloping in $(\frac{L}{T}, \delta)$ space. In $(\beta_0, \delta)$ 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 (12) and (13), we have the kinked boundary between outsourcing and in-house as depicted in Figure 3.

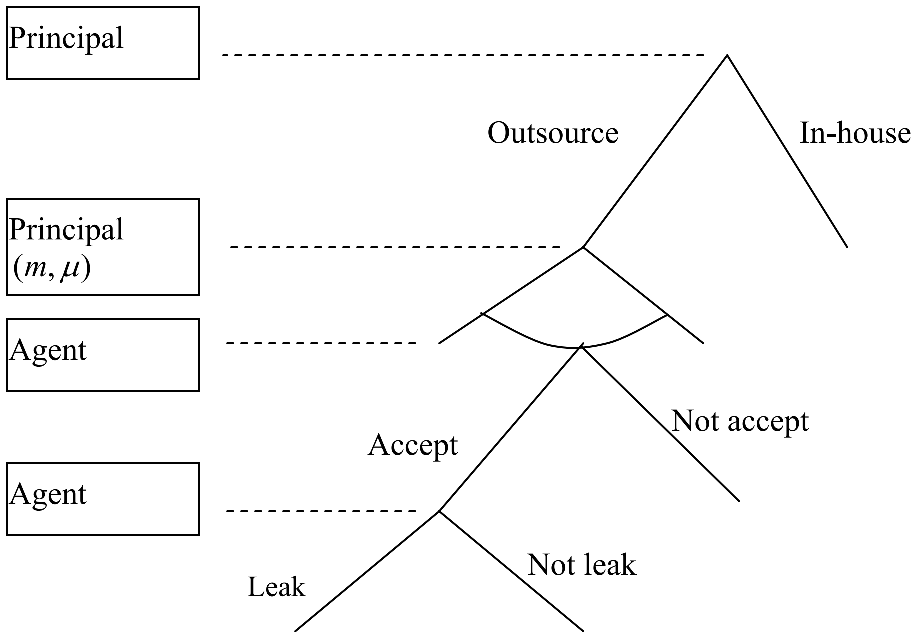



Chart 1. The Game Tree.

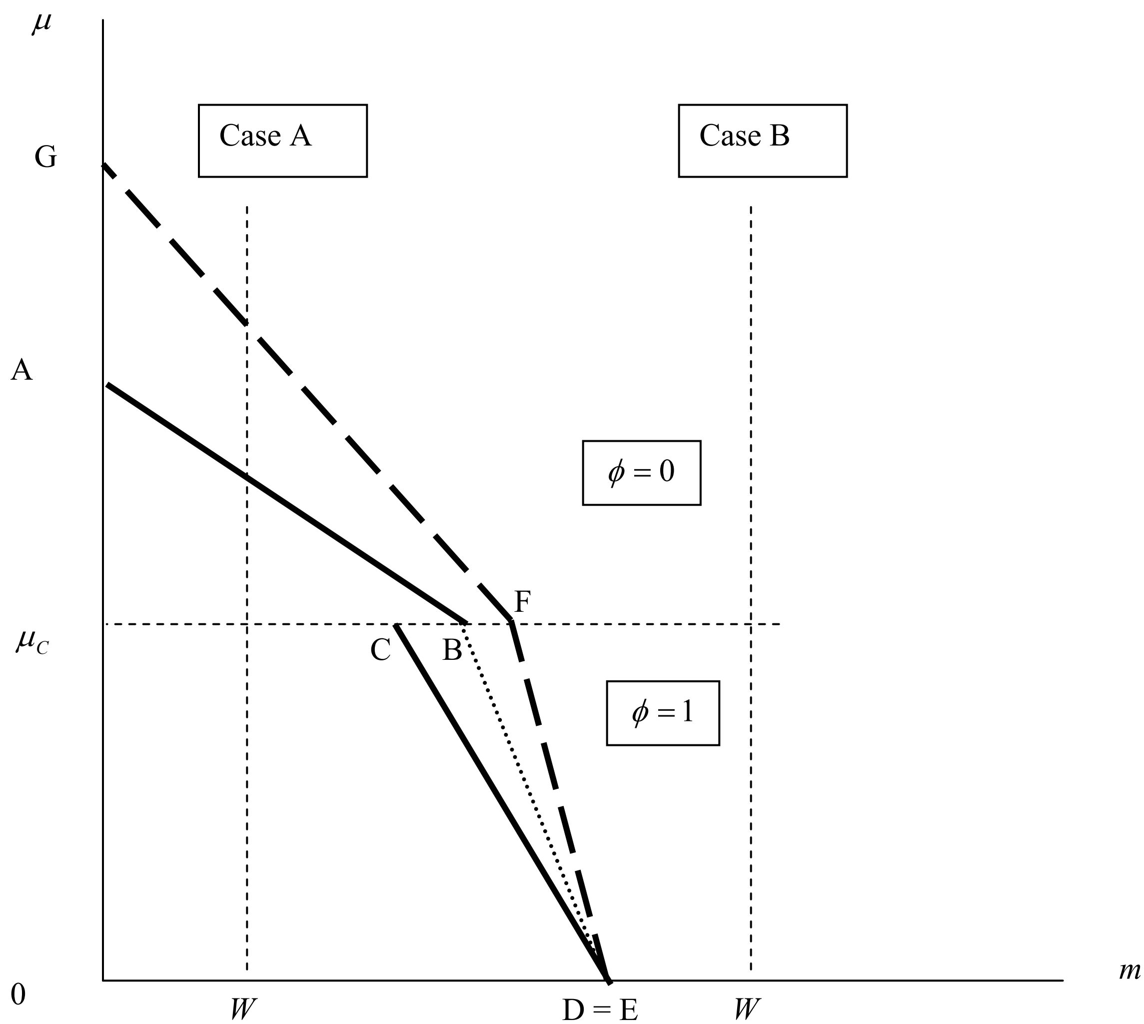



Figure 1. Case I:

A. $\overline{OE} > W$ : Outsource with $\mu = 0$.

B. $\overline{OE} < W$ : In-house R&D.

Indifference curve of the agent with payoff equal to $V_0$

Iso-profit curve of the principal with profit equal to $\Pi^{IH}$.

Convexified part of the iso-profit curve of the principal

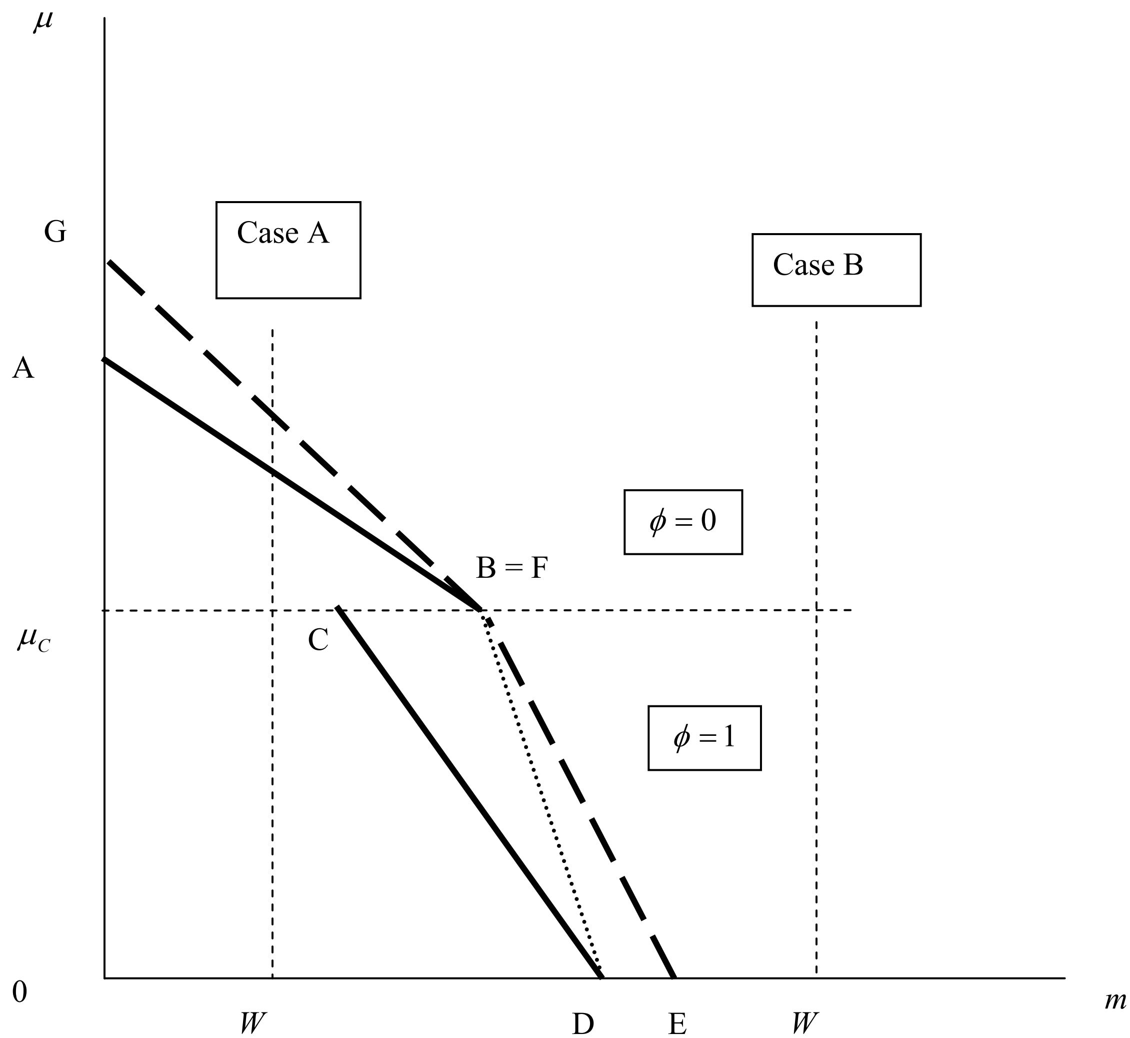



Figure 2. Case II:

A. $\overline{OE} > W$ : Outsource with $\mu > 0$.

B. $\overline{OE} < W$ : In-house R&D.



Indifference curve of the agent with payoff equal to $V_0$



Iso-profit curve of the principal with profit equal to $\Pi^{IH}$.



Convexified part of the iso-profit curve of the principal

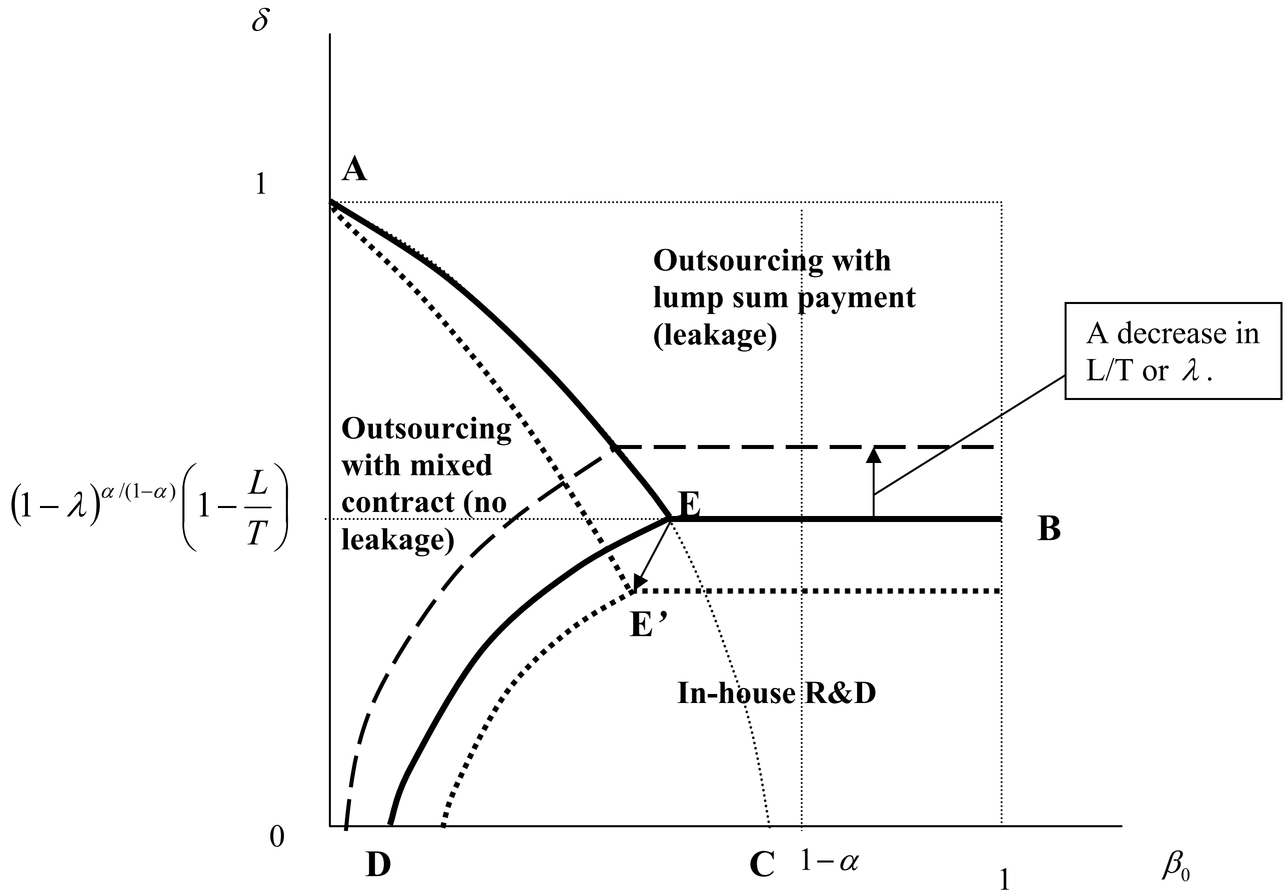
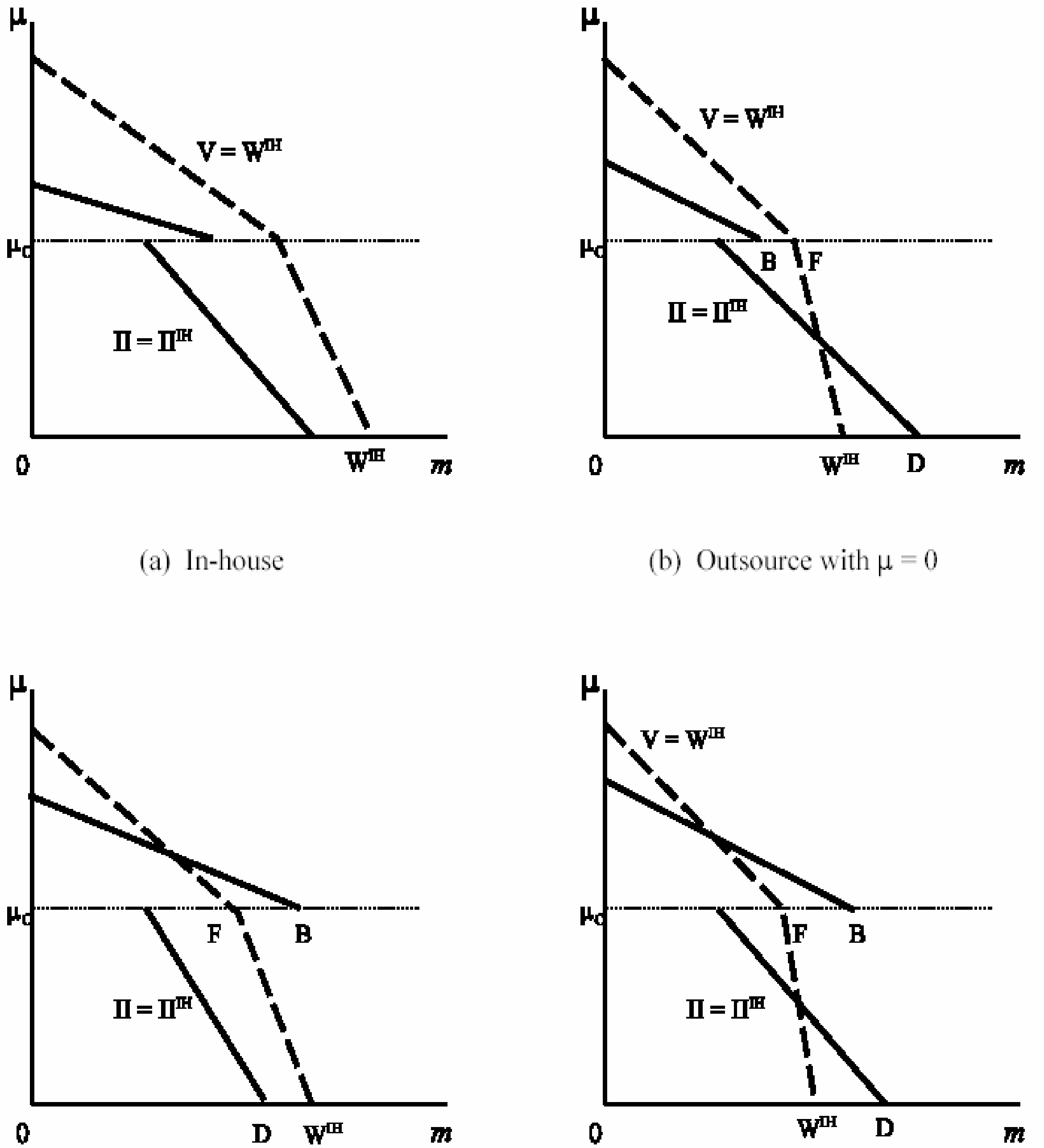



Figure 3. The boundary between in-house R&D and outsourcing R&D. An increase in $\alpha$ leads to a shift of point E to point E'.




(a) In-house

(b) Outsource with $\mu = 0$

(c) Outsource with $\mu = \mu_C > 0$

(d) Outsource with either $\mu = 0$ or $\mu = \mu_C$

Figure 4. Outsourcing vs. in-house from the point of view of the threat points facing the principal ($\Pi = \Pi^{IH}$) and the agent ($V = W^{IH}$)

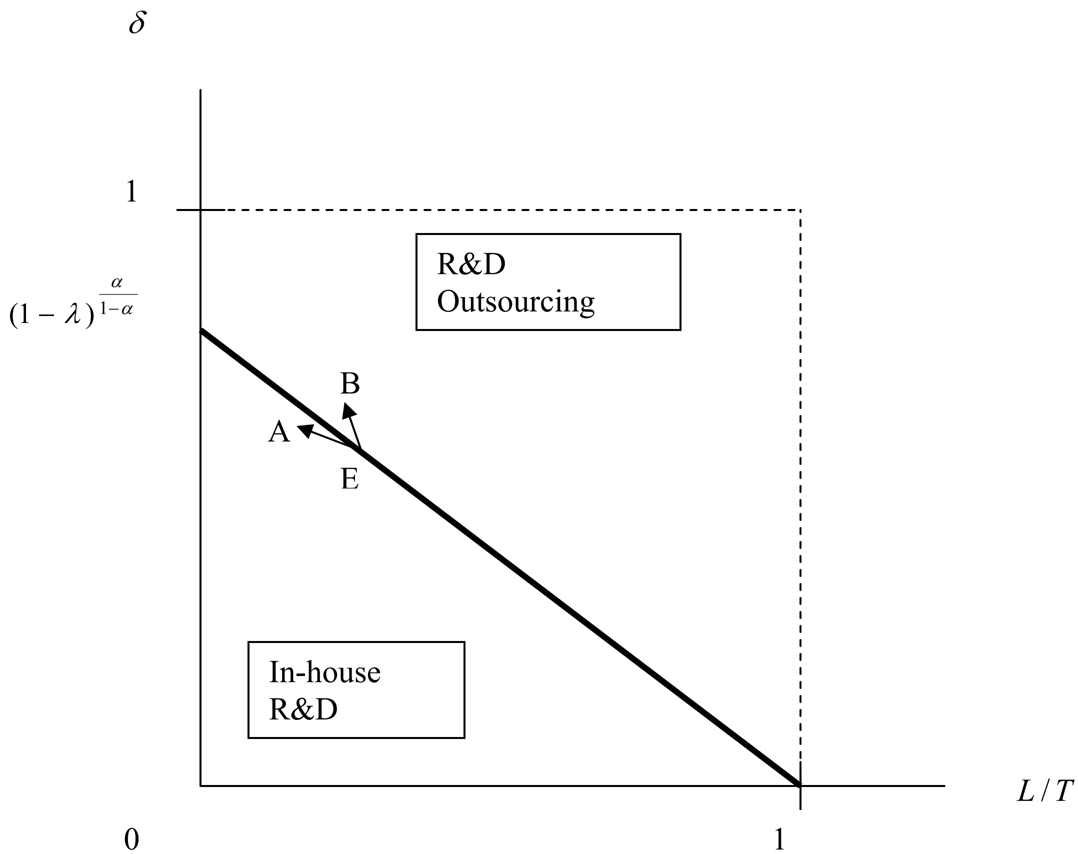



Figure 5. Outsourcing vs. in-house in Case I and responses to stronger IP protection.

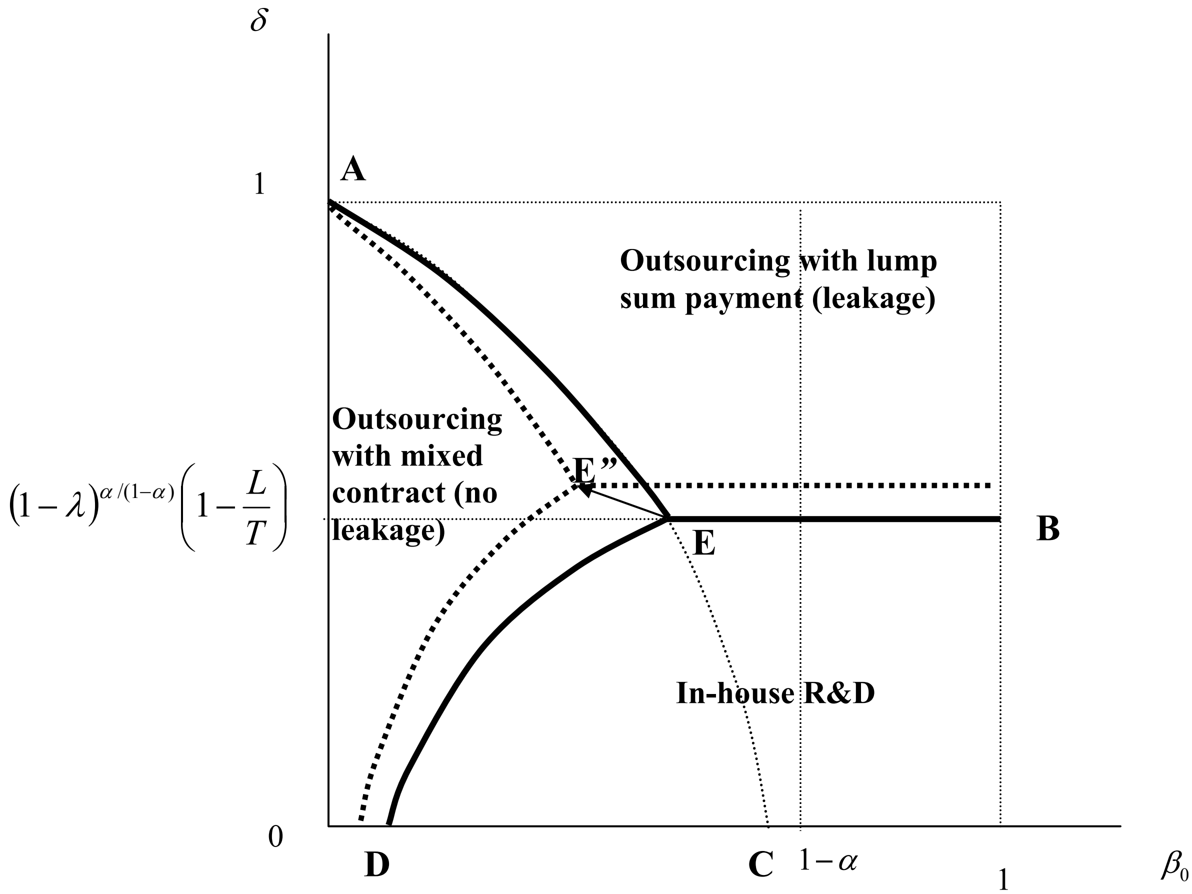



Figure 6. Changes in the equilibrium outcomes as a result of introducing demand/cost-reduction uncertainty, leading to a shift of point E to point E”.