Outsourcing, Information Leakage and Consulting Firms[1]

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Abstract

This paper offers a general equilibrium model to analyze the problem of investment in R&D of firms that also face the decision between outsourcing and "in-house" production in the presence of R&D information leakage. A contractor hired by a firm learns the firm's technology and can diffuse the information to other firms, either by selling it or by "spilling" it involuntarily. I find that information leakage concerns have the tendency to concentrate the outsourcing market with respect to a situation in which information leakage is not an issue. In particular, despite the fact that the original outsourcing market is perfectly competitive, I find that when a market for information arises in equilibrium, such a market is *always monopolistic*. I show that a market for information arises when contractors have a positive but low degree of control on the information they hold. If contractors do not have any control on the information they hold, the market splits into a positive measure of technologically advanced firms that *never* outsource and a positive measure of low-tech firms that *always* outsource. If contractors have full information control, all firms invest in technology and outsource, and a market for information never arises. As the contractors' degree of control on information increases, the equilibrium technology level decreases and the set of firms that adopt such technology increases. The structure of the equilibria of the model captures several features observable in the management consulting industry.

1 Introduction

This is an era in which R&D development has emerged as one of the firm's most valuable assets. As a consequence, protecting the secrecy of R&D information is a crucial concern in industrial organization.[1] While close monitoring and career concerns can help to mitigate the leakage of information caused by its own employees, a firm is particularly vulnerable to this problem when it interacts with the external world, and in particular when outsiders collaborate in the production process.[2]

On the other hand, a vast literature documents how firms rely on outsourcing for an expanding number of productive activities, including even temporary workers.[3] Increasing specialization and economies of scale induce firms to outsource services that used to be typically performed in-house in the past. When a firm hires an external contractor, information sharing is often a necessity, and, even when it is not, the close relationship with a contractor can result in an involuntary information leakage. Thus, external contractors may end up aggregating valuable information coming from the pool of their clients, and as a result other firms may have an incentive to hire the same contractors to have access to that same information. In light of the possibility of information leakage, it is somehow puzzling that firms with high technology levels still seem to rely on outsourcing.

This paper aims to explore the role of contractors as information intermediaries and the trade-off between hiring efficient contractors and protecting R&D information from expropriation. In particular, this paper addresses the impact of such a trade-off on the R&D investment and information diffusion in an industry and on the size and structure of the outsourcing market. Since the information that contractors

[1] See Levin et al. (1987) for a survey that shows how firms rely on secrecy rather than intellectual property rights to appropriate the returns of their R&D investment.

[2] See Rajan and Zingales (2001), Zabojnik (2002), Baccara and Razin (2002) and Baccara (2002) for analyses of situations in which a firm's employees (or former employees) can leak crucial information outside the firm.

[3] Among others, see Feenstra (1998), Tempest (1996), Helper (1991), Abraham and Taylor (1996), Grossman and Helpman (2000, 2001), World Trade Organization Report (1998). For temporary help supply (THS), see Estevao and Lach (1999).

acquire and how much that information is valued depends on the strategic choices of all their clients, this paper tackles these questions using a general equilibrium approach. The model allows to derive the market value of information and to study the characteristics of the downstream market for information that can endogenously arise in equilibrium.

I develop a model in which firms invest in cost-cutting technology and operate in a monopolistic competitive market. The production of each firm's good includes two stages: the first stage of production consists of a fixed *task*. Such task can be performed either in-house or by a specialized contractor, and it is the same for all firms. The "task" represents any stage of production that can in principle be outsourced, including professional services, IT consulting, accounting, inputs manufacturing, and so on. The contractor is selected among the ones that populate a perfectly competitive *outsourcing market*. If a firm hires a contractor, the contractor learns the technology developed by the firm. The second stage of production can be only completed in-house, and its (variable) cost is determined by the technology available to each firm.

Once a contractor learns a technology, and before the second stage of production takes place, the technology may "leak" to some competing firms. The information leakage can occur in two fundamental ways: first, a contractor may not have perfect control of the information that he learns. This lack of control determines an unintentional *spill* of information to a fixed measure of other firms. Second, each contractor can post a price for the information he holds and sell it to other firms.

The (exogenous) magnitude of the spill measures the ability of the contractors to protect and market the information they hold. Sometimes, contractors may not have the expertise both to understand the value of such information and to sell it on the market. Other times, the geographical concentration of a market (e.g., firms in Silicon Valley), or a high employee turnover (e.g., management consulting firms) could cause a contractor not to be able to fully control the information flows coming from his firm.[4] A more sophisticated contractor may take measures to protect the

[4]The presence of the "spill" is consistent with the observation that the resources present in

value of the information he holds and limit the spill to some degree. A contractor has perfect control of the information when he does not generate any spill. In this model, the magnitude of the information spill endogenously determines the demand for information and the size of the market that the contractors face as information sellers.

I study the equilibria of this model as the magnitude of the information spill varies. First, I analyze the case in which contractors have no control over the information they learn. In this case a market for information cannot arise, and I identify sufficient conditions under which there is a unique equilibrium in which the market splits into a positive measure of firms outsourcing and not investing in technology and a positive measure of firms that have a high technology level but perform all the production in-house.[5]

If a contractor has some degree of control over the information, there always exists a unique equilibrium in which a *market for information arises.* Quite strikingly, despite the fact that the outsourcing market is perfectly competitive, the market for information in equilibrium is *always monopolistic.* The intuition of this result is very general and robust. Consider the problem of a firm that invested in R&D. This firm also has to decide whether to hire a contractor and, in case it does, it has to select a contractor from the ones that populate the outsourcing market. In making these decisions, the firm has to consider the impact of its choice on the market for information that will arise downstream. In particular, the firm always has an incentive to distort such a market by keeping it as concentrated as possible. This is because when the degree of competition in the market for information increases, this competition drives the price for information down, and, as more firms buy

professional firms are not fully appropriable. For example, consulting firms have very high employee turnover as employees often leave the firm to work with a current or a potential client. See Bhide (1996).

[5] Such equilibrium is consistent with the hardware market of the 80's and early 90's, when Apple Computer famously avoided outsourcing and carefully protected its R&D investments, while PC hardware producers adopted arguably lower technology standards and a very intensive outsourcing activity.

information on the market, it generates a larger information leakage. On the other hand, a more concentrated market for information guarantees a higher price for information and more limited leakage to the rest of the market. Thus, information leakage concerns have the tendency to concentrate the outsourcing market with respect to situations and industries in which information leakage is not an issue.[6]

Moreover, when contractors face the financial constraint of posting a non-negative price for the task, the ex-ante competition to become the information monopolist cannot dissipate the entire surplus from the market for information. Thus, the contractor who in equilibrium becomes the information monopolist appropriates all the surplus of the market for information.

Finally, if the contractors have full control over the information (that is, if there is no information spill), I show that there cannot be a market for information in equilibrium. In this case, firms know that if they do not invest in technology, a monopolistic contractor will be their only source to learn cost-cutting technology in the future. If contractors cannot ex-ante commit to a price for information, the information monopolist always prices it to extract all the information surplus. If this is the case, firms always prefer to invest in the technology themselves rather than wait to be charged a high price by the information monopolist. As a result, with full information control, there is only one equilibrium in which all firms invest in technology, outsource, and there is no market for information.[7]

I compare the equilibrium investment and the diffusion of the technology under different degrees of contractors' information control. I show that the technology level reached in the market *decreases* as the degree of control over the information of the

[6]In this model, this intuition translates in the stark equilibrium outcome in which the market for information is always a monopoly. For the generality of this intuition and the robustness of the monopoly result to several modifications of the model, see Section 6.4.

[7]This suggests that, for instance, consulting firms prefer to stay away from a situation in which they have full control over the information they hold and no commitment power over the price for it. This is consistent with well established consulting firms' practices of committing to a high employees' turnover and, until recently, updating the fees they charge their clients once a year on a general (and not per-project) basis.

contractors increases. However, the measure of firms that adopt the technology *increases* with the degree of information control.

1.1 An Example: Management Consulting Firms

While the question addressed in this paper applies to a wide range of outsourcing activities, it can be related in a particularly interesting way to the case of the Management Consulting industry.

In the model, contractors learn R&D information as a by-product of the main activity (or *"task"*) they are hired for. If a contractor realizes the market value of such information, and he has the capabilities to market it, he could try to sell it to other firms.

First of all, it has been documented that several very successful management consulting firms originated as a small consulting practice within a firm specializing in professional services such as accounting, auditing, tax filing or engineering.[8] This suggests that the transition from professional service to consulting may have been carried out to capitalize on the expertise these professionals developed in their previous practice working at close contact with their clients.

Even the current management consulting industry fits the model quite well. It is very difficult to define the products that are traded in this industry. One of these products is identified it with organizational ideas, another one with the necessity to validate some unpopular decisions such as personnel reduction, and so

[8] McKinsey & Co. originated from "James O. McKinsey & Co.", a firm specializing in accounting and management engineering, and its successive merger with "Scovell, Wellington & Co.", another accounting firm. The first years of the partnership were characterized by a heated debate on the decision of keeping the accounting and the consulting practices separate or under the same roof (see Bhide (1996)). Other major accountancy offered consultancy type advice to their clients at a small scale, and from the 1980s onward they expanded these kind of services (see Kipping and Armbruster (2004)). In particular, Arthur Andersen was best known as an audit and accounting firm, but its business consulting practice became its most successful division, growing at around 25% annually in the late '90s. Finally, in Europe the clients of notaries public often refer to them for business advice too.

on.[9] However, one of the products that management consultants explicitly sell is the so-called *"best practice"*.[10] "Best practices" are benchmarks that are usually formulated by aggregating the information that consultants gather from their pool of clients on a given common issue. As McKenna (2001) puts it: "Management consultants have primarily functioned as disseminators of organizational ideas". In the words of sociologists DiMaggio and Powell (1983) "Large organizations choose from a *relatively small set* of major consulting firms which, like John Appleseeds, spread a few organizational models throughout the land".[11]

Suppose that a firm with some good technology related to a given function decides to hire a management consultant for some reason (e.g., to acquire a "best practice" related to some other function, a better organization, to validate some personnel reduction, etc.). Once the management consultants are hired, they typically send a team to work for a period of time that ranges from some months up to years on location at the client's headquarters. During their stay, this team has access to a large portion of the firm's private information. So, it is reasonable to think that the firm may be worried that the good technology they hold becomes part of some other "best practice" sold to some competitor in the future.[12]

Because of its high labor turnover, a management consulting company typically does not have a perfect control of the information it aggregates. Thus, the case of the model this industry seems to match best is the case of imperfect control of information. Quite interestingly, this is the case under which there exists a market for information in equilibrium and information surplus appropriation by the

[9] See McKenna (2001) and Bhide (1996) for some informal theories on the role and added value of management consultants.

[10] Before being aggregated, this information is typically "sanitized" that is, the sources of every piece of information are purged.

[11] For an extensive discussion and literature review on management consultants as knowledge intermediaries, see Kipping and Armbruster (2004).

[12] A common explanation of why firms should not fear information leakage in their relationship with management consultants comes from the consultants' reputation concerns. However, the "best practice" paradigm seems to be well understood and accepted, so the puzzle does not seem to be completely explained by these arguments.

consultant in the long run.[13]

Finally, the results of the paper predict that a monopoly is the only possible equilibrium outcome when a market for information arises. Such result (or, more generally, the intuition that information leakage concerns tend to generate concentration on the market for information) is consistent with the observation that among many accounting or auditing firms, only a few made a transition to become successful consulting firms. Moreover, the management consulting industry is characterized by high market concentration and high growth of a few market leaders. In particular, in 2001, McKinsey had 40.6% of the market share and in the late 1990s it experienced a growth of 20% annually. Moreover, McKinsey and its largest competitor, Booz, Allen & Hamilton, together held almost 60% of the market in 2001.[14]

1.2 Related literature

After Coase (1937) originally identified the "make-or-buy" decisions as the element that defines the boundaries of a firm, and Williamson (1975, 1985) more recently re-explored Coase's fundamental intuition, a vast literature started to analyze such decisions both in individual and in general industry equilibrium settings. Very influential work on this issue has been carried out by Klein et al. (1978), Grossman and Hart (1986), and Hart and Moore (1990), and it has focused mainly on what is known as the "hold-up problem", arising from relation-specific investments and incomplete contracts. However, as Holmstorm and Roberts (1998) have pointed out in a recent article, explaining the boundaries of the firm only in terms of the hold-up problem and asset-specificity seems a too narrow view for a very general issue. The aim of this paper is to introduce a new possible perspective for "make-or-buy" decision, which is based on informational concerns.[15]

[13] Again, see Bhide (1996) for a discussion of high labor turnover in mamagement consulting and the failure to appropriate the entire returns of their resources.

[14] See *Business Week*, 7/8/2002.

[15] The analysis of the outsourcing decision in this paper is close to the one carried out in two papers by Grossman and Helpman (2000, 2001) as it considers a general equilibrium model. Mayer (2000) carries out an empirical analysis on the use of subcontractors in the IT industry and finds

Jovanovic and MacDonald (1994) analyze the evolution of a competitive industry in which firms reduce costs by innovating or imitating their rivals' technologies. In the steady state, they find that the diffusion of the technology from the investing firms to the imitating ones leads to a low level of investment. This effect is present in this paper as well. However, this paper focuses on endogenizing the mechanism through which the information spreads and on the role of contractors as information intermediaries.[16]

Another paper that analyzes the issue of property information flows in the firm-to-firm service markets is Demski et al. (1999). However, their focus is on the internal organization of the service-providing firm, and the problem of designing incentives to discourage employees from leaking information. In this paper, I abstract from the contractors' internal organization, I explicitly consider the possibility of a market for information arising in equilibrium and I study its properties and its consequences on investment in technology.[17]

Finally, there is a link between the result presented in Section 4 of this paper and the results on common agency of Bernheim and Whinston (1985). In Bernhein and Whinston's paper firms in competition may find it useful to delegate their marketing efforts to a common agent to solve their coordination problem and enjoy a collusive outcome. Although the idea of competitive firms using a common contractor is similar, in this model firms use of a common contractor in the production stage to guarantee a monopoly not in the product market, in which they still compete, but in a *different*, endogenously arising market, i.e. the market for information.

The rest of the paper is organized as follows. The model is introduced in Section 2. In Section 3, I characterize the equilibria of the case in which contractors have no

that the presence of expropriable information lowers the likelihood of observing a subcontractor.

[16] See also Ceccagnoli (2000) for a model in which the equilibrium cost-cutting investment is affected by spill-overs to competitors. Ceccagnoli studies the effect of an increase in the (exogenously given) number of imitating firms and of new firms' entry on the equilibrium investment in R&D.

[17] This paper is also related to the literature on the value and market for information. For very recent contributions to this literature and more references, I refer to Anton and Yao (2002(a) and (b)).

control over the information. The analysis of the equilibria arising when contractors have either some or full degree of control over the information is carried out in Section 4. Section 5 is devoted to some comparative statics, and Section 6 concludes the paper offering some suggestions for further research.

2 A model of outsourcing and information leakage

2.1 Firms and consumers

Consider a monopolistically competitive market populated by a fixed interval of firms $\mathcal{N} = [0, n]$. The preferences of the representative consumer are described by a "Dixit-Stiglitz" utility function[18]

$$u(y) = \int_0^n y(i)^{\alpha}\, di$$

where $y(i)$ is the consumption of the good produced by firm $i \in \mathcal{N}$ and $\alpha \in (0,1)$. As it is well-known, in this case the demand function for good i given its price $p(i)$ is

$$y(i) = Mp(i)^{-\frac{1}{1-\alpha}}$$

with $M \equiv \frac{E}{\int_0^n p(j)^{-\frac{\alpha}{1-\alpha}} dj}$, where E is the total expenditure.

Each firm $i \in \mathcal{N}$ can invest an amount $k(i) \in R_+$ in developing cost-cutting technology.[19] Such investment has the effect of reducing the (constant) marginal cost of production of the firm according to the function $c : R_+ \to (0, 1]$ defined as

[18] See Dixit and Stiglitz (1977).

[19] I focus on cost-cutting R&D rather than product development to abstract from reverse engineering or intellectual property rights issues (it is difficult for patent-holders to monitor that competitors do not adopt their cost-cutting techniques). However, as long as reverse engeneering is not possible and intellectual property rights are absent, the alternative modelling choice would lead to similar results.

$c(k) = (1+k)^{-\rho}$ with $\rho \in (0,1)$.[20] As I describe later, a firm can cut its marginal costs also by learning a technology developed by someone else.

To focus the analysis on the most interesting cases, I assume that the parameters of the model satisfy the following requirements:

Assumption 1 *α and ρ satisfy $\rho < \frac{1-\alpha}{\alpha}$.*[21]

Assumption 2 *The parameters of the model satisfy $E\alpha\rho > n$.*[22]

Before carrying out any amount of production, each firm has to perform a fixed *task*. A task represents any function that can be outsourced. Examples of tasks can be the production of intermediate products, assembly, photocopying, typing, etc. The (fixed) cost of the task, which I will denote by τ, is either equal to $t > 0$, if the task is performed in-house, or $\tau(j)$ if it is outsourced from contractor j, where $\tau(j)$ is the price posted by contractor j (see below).[23]

2.2 Contractors

The outsourcing market is populated by a finite set $\mathcal{M}$ of identical contractors. Let $m \geq 2$ be the cardinality of the set $\mathcal{M}$. Since contractors specialize in the task, they can perform it more efficiently than the firms. By simplicity, I assume that contractors have zero marginal cost when performing the task for one additional firm.[24]

[20] Notice that I do not require all the firms to develop the same technology, but I assume that two technologies developed with the same investment k cut the costs to the same level $c(k)$. Also, I focus on a particular functional form for $c(\cdot)$ for the sake of simplicity. None of the results of the paper crucially depend on the specific characteristics of this functional form.

[21] Assumption 1 guarantees that the Second Order Conditions of the optimal investment problem are satisfied.

[22] Assumption 2 guarantees that, unless they anticipate learning some technology developed by competitors, firms always invest in equilibrium. To see this, notice that the first order condition of the optimal investment problem is $\frac{E(1-\alpha)}{\int_n (1+k(j))^{\frac{\alpha\rho}{1-\alpha}} dj} \frac{\alpha\rho}{1-\alpha} (1+k^*)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} - 1 = 0$. By symmetry, we get that $k^* > 0$ if $E\alpha\rho > n$.

[23] Alternative assumptions of the cost of the task t being variable and $\tau(j)$ representing a per-unit price for the task would not change the quality of any of the results of the paper.

[24] Alternatively, it is possible to assume that contractors have increasing returns of scale in the measure of firms they serve. This alternative assumption reinforces the main results presented in this paper and does not significantly alters any of the other results.

Thus, the parameter t measures the efficiency of the contractors in performing the task. Each contractor $j \in \mathcal{M}$ sets a price $\tau_j \in R$ to perform the task for a client.[25]

As long as firms do not outsource from a contractor, the cost-cutting technology that they develop is known only within their boundaries.[26] When a firm hires a contractor, I assume that the contractor learns the cost-cutting technology developed by the client perfectly.[27] As a contractor can be hired by many firms simultaneously, he may learn different pieces of information.

For simplicity, I make the following assumptions regarding information aggregation: first, I assume that technology knowledge *cannot be cumulated*, in the sense that if a contractor learns two cost-cutting technologies c_1 and c_2 such that $c_2 > c_1 \geq 0$, the minimum level of costs he can reach with this knowledge is c_1.[28] Moreover, technologies are assumed to be *perfectly divisible*, in the sense that if a contractor knows how to reach the cost level c, he knows how to reach any level of costs $\widetilde{c} \in [c, 1]$.

As a contractor learns the technology adopted by his clients, there are two ways through which this information diffuses to the rest of the market. First, a contractor who knows some information can sell any portion of it to other firms. Let $\underline{c}_j$ be the be the best technology developed within the set of the clients of contractor j. Then, contractor j learns how to cut the marginal cost of a firm up to $\underline{c}_j$. By the perfect divisibility assumption, contractor j can sell information that allows a firm to cut

[25] Notice that, even if in Corollay 8 explore the case in which contractors face a borrowing constraint that require $\tau_j \geq 0$, such Assumption is not made in any other part of the paper. Thus, any contractor j is allowed to post any $\tau_j \in R$.

[26] Employees may be loyal for career concerns, because they are given the right incentives, or because they are easily monitorable. See Baccara and Razin (2002 and 2003) and Rajan and Zingales (2001) for frameworks in which employees can expropriate the information developed within a firm.

[27] For a discussion of the implications of relaxing this assumption, see Section 6.

[28] These assumption could be substituted with alternative ways to aggregate information, e.g. by assuming that innovations are complementary (that is, by knowing a technology c_1 and a worse technology $c_2 > c_1$, the contractor knows how to cut costs up to some $\widetilde{c} < c_1$). This extension is briefly discussed in Footnote 41.

costs to any level $c_j \in [\underline{c}_j, 1]$. After performing the task for his clients, a contractor decides the quality c_j and the price ψ_j of the information he wants to sell.

Second, contractors may not have perfect control on the information they learn. This lack of control can be caused by several factors, as an imperfect understanding of the relevance of the technology, imperfect monitoring of the employees, employees' turnover, etc. For simplicity, I capture this loss of control by assuming that the *best technology* learned by contractors (i.e., the technology $\underline{c} \equiv \min_{j \in \mathcal{M}} \underline{c}_j$) spills to a *fixed* subset of measure s of the firms that do not have learned any technology yet (i.e., they did not invest in technology nor have they bought any information from the contractors).[29] The parameter s measures the degree of control that contractors have on the information they hold. When $s = n$, contractors always generate a spill that can reach the entire market. I refer to this situation as a *"perfect spill"*, and I analyze it separately in Section 3. When $s \in (0, n)$ contractors have some degree of information control, but they still generate a positive information spill. When $s = 0$, there is *no spill* and contractors have full control over the information they hold.[30,31]

Remark 1 *An important assumption of this model is the fact that firms do not participate directly to the market for information, i.e. they are not allowed to sell information directly to their competitors. This assumption and the consequences of relaxing it are discussed in detail in Section 6.*

[29] The modelling assumptions regarding the information spill are discussed in further detail in Section 6.

[30] One may wonder why firms investing in technology never generate any information spill, while contractors do if $s > 0$. Although it would be possible to introduce in the model a spill generated by firms as well without changing the quality of the results, this paper focuses on the role of contractors as information intermediaries. Also, one may argue that a firm that develops a technology is aware of its importance and is also able to protect it better than a contractor.

[31] It would be possible to model the spill as an increasing function of the measure of the set of the firms that either invest or buy the technology, i.e., the more firms know a technology, the highest the probability that other firms learn it. The choice of modelling the measure of the set of firms that receive the spill as fixed simplifies the analysis and does not change the quality of the results.

2.3 The game

2.3.1 Timing of the game

The timing of the game is the following:[32]

(1) Each firm i simultaneously decides the amount $k(i) \in R_+$ to invest in research. At the same time, each contractor j posts a price for the task $\tau_j \in R$.[33] Let γ the measure of the set of firms making a positive investment in technology.

(2) All firms simultaneously decide whether to perform the task in-house or to outsource it from an external contractor. In the last case, a firm also decides which contractor to outsource the task from.

(3) Contractors perform the task for their clients and they learn the technologies developed by them. Let $\underline{c}_j$ be the best technology learnt by contractor j.

(4) Every contractor j decides the quality $c_j \in \left[\underline{c}_j, 1\right]$ and the price ψ_j of the information he wants to sell.

(5) Each firm decides whether to buy information from some contractor.[34] Let β be the measure of the set of firms buying information from some contractor.

(6) The best technology learned by contractors "spills" to a measure $s \in [0, n]$ of the firms remaining without a technology. Since the measure of the set of firms without a technology is $n - \gamma - \beta$, the spill reaches a measure of firm $\sigma \equiv \min[s, n - \gamma - \beta]$.

(7) Each firm i adopts the best technology it has learned $c(i)$ and decides how much to produce by choosing $q(i) \in R_+$. The production is sold on the market and profits are realized.

In this paper I adopt Subgame Perfect Nash Equilibrium (SPNE) as the solution concept, and I focus on pure strategy SPNE.

[32] The game is described here in an informal fashion. See the Appendix for a more formal version of the game.

[33] In Section 4 I analyze the consequences of restricting the price for the task to be non-negative.

[34] Observe that, even that we will never observe such behavior on the equilibrium path, in this model nothing prevents a firm that invested a positive amount in technology k to buy a better technology later.

Remark 2 *I refer to the information diffusion from some firms to others by means of the contractors as "information leakage". I also refer to a situation in which some technology diffuses to all firms that did not invest in technology as a "perfect leakage" (i.e. $\beta + \sigma = n - \gamma$), to a situation in which $0 < \beta + \sigma < n - \gamma$ as an "imperfect leakage"and to a situation in which $\beta + \sigma = 0$ as "no leakage". Observe that a perfect spill, i.e. $s = n$ (i.e., contractors do not have control over the information) is a sufficient condition to have perfect leakage. In fact, if $s = n$, then I have $\beta + \sigma = n - \gamma$ for any γ and β. The analysis of the case $s = n$ is carried out in the next section.*

2.3.2 Payoffs

The payoff of a generic firm $i \in \mathcal{N}$ on the monopolistic competitive market is:

$$\widetilde{\pi}(i) = [p(i) - c(i)]\, y(i) - k(i) - \tau - \psi_h$$

where $\pi(i) \equiv [p(i) - c(i)]\, y(i)$ is the economic profit, $k(i)$ is the investment in technology, τ is the cost paid for the task (that could be either equal to t if the task has been performed in-house or τ_j if the task has been outsourced from some contractor j) and ψ_h (if any) is the price paid for some technology bought on the market for information from some contractor h.[35]

After solving for the equilibrium on the final product market, it is easy to check that

$$\widetilde{\pi}(i) = \frac{E(1-\alpha)}{\int_0^n c(j)^{\frac{-\alpha}{1-\alpha}}\, dj} c(j)^{\frac{-\alpha}{1-\alpha}} - k(i) - \tau - \psi_h$$

from which it is possible to observe immediately that the payoff of firm i is decreasing in the technology level of its competitors. This is because the technology level of the other firms affects the other firms' prices and, via monopolistic competition, the demand that firm i faces on the final product market.

[35] Notice that the model allows firms to hire a contractor to perform the task and a different one to buy information from.

Since the contractors operate at zero marginal cost for the task, the payoff for a generic contractor is the sum of the revenue generated on the outsourcing market and the revenue generated on the market for information.[36]

3 Perfect spill $(s = n)$

In this Section I analyze the situation in which contractors do not have any control over the information they learn from their clients that is, the best technology learned by the contractors always spills to the entire market. This situation corresponds to the particular case of the model in which $s = n$. This case fits situations in which, for instance, the market geographical concentration and the labor mobility are very high (e.g. Silicon Valley), or the contractors are not sophisticated enough to market the information they hold (e.g. contractors who provide lower-level tasks).

To start the analysis of the perfect leakage case, observe that if $\underline{c}_j$ is the best technology learned by contractor j from his clients, each firm on the market has the choice to adopt the technology $\underline{c} \equiv \min_{j \in \mathcal{M}} \underline{c}_j$ at no cost. This implies that there can be no market for information, as firms know that they are going to receive the spill and learn the best technology for free.

The following Lemma (whose proof is presented in the Appendix) guarantees that, if $s = n$, none of the outsourcing firms can invest in technology in equilibrium.

Lemma 1 *If $s = n$, no outsourcing firm invests in equilibrium.*

To understand the intuition of Lemma 1, notice first of all that the competition among contractors and the absence of a market for information guarantees that the price charged for the task is always $\tau_j = 0$ for all $j \in \mathcal{M}$.[37] Let us analyze the (simultaneous) choices of the firms about technology investment and outsourcing. Since $\tau_j = 0$ for all $j \in \mathcal{M}$, it is obviously the case that if a firm does not invest in

[36] See the Appendix for a formal definition of the contractors' payoffs.

[37] More precisely, the competition among contractors guarantees $\tau_j \leq 0$ for all j. However, the absence for a market for information guarantees that no contractor would pay to have the chance to access some information, so that it has to be $\tau_j = 0$ for all j.

R&D, it always outsources (as there is no cost associated with hiring a contractor). Suppose that there is a non-empty set of firms outsourcing and another non-empty set of firms not outsourcing. If one of the outsourcing firms invests in technology, no other firm in the same set can invest in equilibrium as they anticipate receiving the leakage with probability 1, and learning the technology for free. This implies that no more than one firm among the outsourcing ones can invest in equilibrium. Now, is it possible to have an equilibrium where exactly one outsourcing firm also invests some positive amount in technology? In this case, since this firm has to pay the cost of the investment in technology and all the others free-ride on the investment, this firm has a payoff lower than any other outsourcing firm. On the other hand, in equilibrium it must be the case that outsourcing and not outsourcing firm have the same payoffs. Thus, the only investing and outsourcing firm would have a profitable deviation by not outsourcing. This implies that in equilibrium it must be the case that all the outsourcing firms operate at the maximum cost level, i.e., they do not invest in technology. This guarantees that, if $s = n$, research is carried out only in non outsourcing firms.

The next Proposition (whose proof is also presented in the Appendix) describes the pure strategies equilibria in the perfect leakage case.

Proposition 2 *If $s = n$, there exist $\overline{T}$ and $\underline{T}$ such that $\overline{T} > \underline{T}$ and: (i) if $\overline{T} \leq t$ in the unique SPNE all firms always outsource and there is no investment. (ii) if $\underline{T} < t < \overline{T}$, then there is a unique SPNE in which a positive measure of firms γ_n, invest $k_n > 0$ and do not outsource, and a positive measure of firms, $n - \gamma_n$, outsource and do not invest. (iii) if $t \leq \underline{T}$, there are no pure strategy equilibria.*

Proposition 2 guarantees that if $s = n$, there is *never information leakage* in equilibrium. The first part of Proposition 2 states that if the advantage from outsourcing is high enough (i.e. if t is higher than the upper bound $\overline{T}$), all firms outsource from contractors and, by Lemma 1, no firm can invest in equilibrium.

The second part of Proposition 2 describes the *"no leakage"* equilibrium. In this equilibrium the market splits into two separate segments of firms. The firms in the first set invest in technology and never outsource, while the ones in the second set do not invest and outsource. For this equilibrium to exist, the measure of these two sets of firms has to guarantee the equality of the profits of the firms within each group. As it is shown in the Appendix, there is a *unique measure* γ_n which satisfies such condition. This equilibrium occurs if t is in between the two bounds $\underline{T}$ and $\overline{T}$. The condition of t being lower than $\overline{T}$ rules out the equilibrium in point (a), since it guarantees that if all firms outsource and do not invest, one firm has a profitable deviation in investing in technology and performing the task in-house. On the other hand, t being higher than $\underline{T}$ guarantees that in the case in which a n-measured set of firms do not contract and invest, outsourcing and *not investing* represents a profitable deviation.

Observe that Proposition 2 guarantees that there is no equilibrium where all firms invest and do not outsource. This is because, in such candidate equilibrium, one firm would have a profitable deviation in outsourcing and investing as the leakage would not hurt its profits.

Proposition 2 suggests that if the outsourcing market is populated by contractors who, because of labor mobility, low sophistication or geographical concentration have very scarce control over the information they hold in equilibrium we shouldn't observe information leakage. In particular, depending on the efficiency level of the contractors, we should observe cases in which all firms outsource and the market is characterized by low R&D investment levels and cases in which the market splits into a set of low-tech firms that outsource and a high-tech set of firms which do not.

In the analysis of the next Section contractors have more control of the information, and we address the question of whether information leakage can occur in equilibrium and a market for information can eventually arise.

4 Market for Information

From Proposition 2 in the previous Section we know that if $s = n$, there is never information leakage in equilibrium and R&D development is carried out only by firms that do not outsource. The focus of this Section is to explore whether a market for information can arise when $s < n$, and, if it can, to study its structure. If $s < n$, once contractors learn some technology, it is not necessarily the case that this technology diffuses to the entire market through the spill. This implies that the information that contractors learn may have a market value, and contractors can find it profitable to sell it to other firms. This is the case in the subgames in which the parameters n, s and the (endogenous) measure of the set of investing firms, γ, satisfies $\gamma \in [0, n-s)$. On the contrary, in the subgames in which $\gamma \in [n-s, n]$, the resulting leakage is perfect, and a market for information cannot arise.

In this Section, I first focus on the subgames in which firms have already made their investment and outsourcing decisions and *only one contractor* has learned some technologies, i.e., the market for information is a monopoly. For those subgames, I study the demand for information and the contractors' optimal pricing of information. Then, I step back and I solve for the equilibrium of the entire game, showing that such subgames are the only relevant ones for the equilibrium. The structure of the equilibria of the game changes as I consider two different cases: $s > 0$, i.e. contractors do not have perfect control of the information, and $s = 0$, i.e. the information spill disappears, and the contractors have perfect control of the information.

4.1 Monopolistic Market for Information

In this Subsection I focus on the subgames in which all the knowledge leaked from the firms to the outsourcing market is concentrated in the hands of just one contractor. This happens when all investing firms hire the same contractor, say $j \in \mathcal{M}$. The technology that spills, i.e. the best technology learned by contractors is then the best technology learned by contractor j from the set of his clients, i.e., $\underline{c} = \underline{c}_j$.

4.1.1 Demand for Information

To analyze the market for information, let us start from the demand side. Recall that the set of investing firms has measure γ. Let us focus now on the set of firms that did not invest in technology. These firms have two ways to learn some technology: first, they could decide to buy it. If a firm buys a technology c from contractor j, this firm will be able to adopt technology c for sure. Second, each firm could decide not to buy any technology and wait for the information spill, which in this case is $\underline{c}_j$. If they do, each firm receive the spill with probability $\frac{\sigma}{n-\gamma-\beta}$.[38] This implies that the willingness to pay a technology $c \leq 1$ is $\phi(c,\beta)$ defined as

$$\phi(c,\beta) = A(c,\beta)\left\{c^{-\frac{\alpha}{1-\alpha}} - \left[\frac{\sigma}{n-\gamma-\beta}\underline{c}_j^{-\frac{\alpha}{1-\alpha}} + \frac{n-\gamma-\beta-\sigma}{n-\gamma-\beta}\right]\right\}$$

where $A(c,\beta)$ is a function of c and β that captures how much the market profit of a firm is negatively affected by the technology level of its competitors, that are represented by c and β.[39] Notice that $\phi(c,\beta)$ can be positive only if $n-\gamma-\beta-\sigma > 0$, i.e. a firm faces a positive probability to remain without any technology if it does not buy technology c. In other words, $\phi(c,\beta)$ can be positive only if the leakage is not perfect. Also, notice that the demand for technology is downward sloped in β as it is easy to check that $\frac{\partial\phi(c,\beta)}{\partial\beta} < 0$. Finally, observe that if $\sigma = 0$ the willingness to pay any technology $c < 1$ is positive for any β. This means that if the control on the information is perfect and there is no spill, firms are always willing to pay a positive amount to acquire any technology $c < 1$.

4.1.2 The Information Monopolist's Problem

If $\gamma > n - s$, all the firms that did not invest learn technology $\underline{c}_j$ through the spill with probability 1. If this is the case, they are not willing to buy any technology from contractor j at any positive price. On the other hand, if $\gamma < n - s$, the firms that did not invest in technology are not sure to receive the spill from the contractor,

[38] Recall that β is the measure of firms buying technology from some contractor. In this case $\beta = \beta_j$.

[39] See the Appendix for the definition of the function $A(k,\beta)$.

and the contractor's technology has a positive market value. The problem of the monopolistic contractor j is to choose a level of technology $c_j \geq \underline{c}_j$ to sell and a price ψ_j for it (or, equivalently, a measure of firms to sell it to). Formally, given that selling information has zero cost for the contractor, he has to solve the following profit maximization problem

$$\max_{\substack{c \in [\underline{c}_j, 1] \\ \beta \in [0, n-\gamma-s]}} \beta \phi (c, \beta) \tag{1}$$

Let (c^*, β^*) be a solution for the problem (1). Observe that the monopolistic contractor may have an incentive to limit the "quality" c of the technology sold. In fact, for a given measure β of information buyers, the better is the technology contractor j sells (the lower is c), the lower is $A(c, \beta)$, i.e., the higher is the competition on the product market. This tends to decrease the willingness to pay the information. On the other hand, the better is the technology he sells, the lower will be the cost level of the firms who buy the technology from him, and this tends to increase the willingness to pay the information. Once the quality of the technology to sell is fixed, the contractor faces a similar trade-off in deciding his pricing strategy, i.e., in deciding the measure of firms he wants to sell the technology to. Proposition 3 (whose proof is presented in the Appendix) shows that the monopolistic contractor always chooses to sell the best technology available, i.e. $c^* = \underline{c}_j$ and, as long as $s > 0$, he never sells it to the entire market, i.e. he never generates a perfect leakage.

Proposition 3 *The monopolistic contractor's problem has a unique solution* (c^*, β^*) *such that he sells the best technology he learned, i.e.* $c^* = \underline{c}$ *and, if* $s > 0$*, the information leakage he generates is not perfect, i.e.* $\beta^* < n - s - \gamma$*.*

The next Corollary states that if a monopolistic contractor has perfect control over the information, i.e. if $s = 0$, the information leakage he generates is perfect (i.e., $\beta^* = n - \gamma$). This result is due to the fact that if the control of information is perfect, a not investing firm's only way to get a low-cost technology is to buy it from the contractor. This keeps the demand for information relatively high and guarantees the fact that the marginal revenue of information of the monopolist remains positive *for any* $\beta \in [0, n - \gamma]$. The result is that the monopolist sells the information to the entire market and generates a perfect leakage.

Corollary 4 *If* $s = 0$, *the information leakage generated by a monopolist for information is perfect, i.e.* $\beta^* = n - \gamma$.

4.2 Information Market Structure

In this Section I first discuss the consequences of a competitive market for information, and then I derive a result that guarantees monopoly on the market for information in equilibrium.

4.2.1 Competitive Market for Information

Let us focus now on a subgame in which several contractors learn the same technology c, and a market for information can arise, i.e. $\gamma < n - s$. Then, in such subgame the market for information is competitive, and all contractors post *a price for information* c *equal to zero* (i.e., equal to the marginal cost of information). This implies that the resulting information leakage is perfect, i.e. $\beta + s = n - \gamma$. To see this, observe that c is the same technology firms would receive through the spill. Thus, if $\beta + s < n - \gamma$, a firm not buying c on the competitive market would not be sure to learn it through the spill, and would have a profitable deviation in buying it at zero cost. Thus, a perfect information leakage always occurs. The previous observation guarantees the following Lemma:

Lemma 5 *In the subgames in which more than one contractor learn the same technology* c, *a perfect information leakage occurs, i.e.,* $\beta + s = n - \gamma$.

4.2.2 Information Market Structure in Equilibrium

In Section 3, Proposition 2 shows that a perfect leakage cannot be an equilibrium outcome if the leakage is due to a spill. Is it possible to sustain an equilibrium in which a competitive market for information arises and generates a perfect leakage? I just argued that if the market for information is competitive, the equilibrium price for the technology held by contractors is zero. If there are more than two firms investing and outsourcing from at least two different contractors, at least one firm has a profitable deviation in not investing and waiting to buy such technology at a zero price. Then, the number of investing and outsourcing firms in such equilibrium has to be exactly two, and they have to outsource from two different contractors. If this is the case, and $s > 0$, we know form Proposition 3 that one of these firms has a profitable deviation in outsourcing from the same contractor of the other, as, if $s > 0$, this contractor would generate an imperfect leakage instead of a perfect one. Proposition 6 (whose proof is presented in the Appendix) formalizes these considerations, and states that in equilibrium *the market for information is never competitive.*

Proposition 6 *All the firm that invest in equilibrium outsource from the same contractor. Thus, when a market for information arises in equilibrium, it is always a monopoly.*

Proposition 6 offers an important prediction of this model. Despite the fact that the original outsourcing market is perfectly competitive, if a market for information arises in equilibrium, it is always the case that *this market is a monopoly.*

The result of Proposition 6 has a very general intuition and it is very robust to different specifications of the model.[40] Proposition 6 says that information leakage concerns tend to concentrate the outsourcing market with respect to the structure it would have otherwise. This is because when a high-tech firm has to choose the contractor to hire, it will anticipate the impact of its decision on the downstream market for information. If it hires a contractor that has a critical mass of other high-tech clients (say, contractor j) rather than a contractor with no or fewer other high-tech clients (say, contractor h), the high-tech firm accomplishes a double result. First, the information the firm will bring to contractor j is negligible as the

[40] The robustness of this result to several modifications of the model is discussed in Section 6.4.

contractor is already collecting information from all his other clients, while the same information would be very relevant for contractor h. Second, by hiring contractor j, the firm preserve a high concentration on the downstream market for information. If the firm hired contractor h instead, contractor h would become a stronger competitor on the market for information for contractor j. As a result, the price for information would decrease and the information leakage would increase.[41]

In Section 4.4, I identify the conditions under which a monopolistic market for information is indeed an equilibrium outcome of the game.

4.3 Equilibrium analysis

4.3.1 Equilibrium if $s > 0$

In this Section I analyze the case $s \in (0, n)$, i.e. the contractors do not have full control of the information they hold, but the spill is not perfect.

If $s \in (0, n)$, the structure of the equilibria changes as s crosses a cut-off level $\overline{s}$. In the next result I show that if s is positive but small enough, there is a unique SPNE in which a market for information arises. Because of Proposition 6, we know that such a market has to be a monopoly.

Proposition 7 *There is $\overline{s} \in (0, n)$ such that if $s \in (0, \overline{s})$ there is a unique equilibrium in which a set of measure $\gamma_{mi} > 0$ of firms invest $k_{mi} > 0$ in technology, a set of measure $\beta_{mi} > 0$ of firms buy the information, and a set of measure of firms $n - \gamma_{mi} - \beta_{mi} > s$ receive the spill or produce at the highest cost level. In this equilibrium all the investing firms outsource from the same contractor.*

[41] The extension of the model with complementary innovations (introduced in Footnote 28) adds a trade-off from the point of view of the firms when choosing a contractor: the more concentrated the market for information is, the smaller the set of firms that will buy information on the market. On the other hand, the more concentrated the market for information is, the better the technology sold on such market. If the complementarities are low enough, all our results still hold. Notice that this extension will make the monopolistic surplus on the market for information, and thus the willingness to pay of the contractors to become the monopolist, higher than in the model presented in the paper.

Proposition 7 guarantees the existence (and uniqueness) of an equilibrium in which a market for information arises. In this equilibrium the firms are divided into two main sets: the firms that invest $k_{mi} > 0$ in technology, and the firms that do not. A crucial feature of this equilibrium is that all investing firms outsource the task from the *same* contractor. This implies that the market for information is a monopoly. This, together with Proposition 3, guarantees that an *imperfect leakage* is generated, i.e. the information is not going to diffuse to the entire market. The set of the firms that do not invest in technology is divided into three subsets: the firms that buy technology $c_{mi} \equiv (1 + k_{mi})^{-\rho}$ from the contractor, the firms that learn the technology through the spill and the set of firms that remain without any technology.

One of the equilibrium conditions is that firms have to be indifferent between investing and not investing in technology. If they invest in technology, they bear the cost of the investment but they are sure to produce at a low cost level. On the other hand, if they do not invest, they face some uncertainty on the cost level they will have in production. In particular, with some probability they receive the spill and are able to carry out production at a low cost level. If they buy the technology from the contractor, they produce at low costs, but the contractor appropriates the surplus from a low-cost production. If they neither receive the spill nor buy the technology, they produce at the highest possible cost level. As it is illustrated in the Appendix, the indifference condition between investing and not investing identifies the equilibrium measure of investing firms, i.e. γ_{mi}.

For this equilibrium to exists, the spill s cannot be higher than the upper bound $\overline{s}$. Such upper bound is identified by the condition that, if a zero-measured set of firms invest in technology, investing in technology represents a positive deviation for a not investing firm.[42]

[42] It is easy to show that if $s \in [\overline{s}, n)$, two cases are possible. If $t \geq \widetilde{T}$, we still have an equilibrium in which a monopolistic market for information arises as at most one firm invests in technology and outsources. A second firm cannot invest and outsource since it would have a profitable deviation in not investing. If $t < \widetilde{T}$, only no leakage equilibria, similar to the $s = n$ case one, are possible.

Notice that the equilibrium under consideration does not require contractors to be very efficient in performing the task, i.e. t does not need to be large for a market for information to arise. In particular, as all firms in this equilibrium outsource, the structure of this equilibrium is independent on the parameter t. Thus, even in a market populated by contractors that are *not more efficient than in-house production (i.e., $t = 0$)*, one of them can emerge as the monopolist of the market for information.[43]

Contractors face a two-stage market. First, they compete in the outsourcing market, and then, in the market for information. The competition among them guarantees that no surplus from the contractor market can be appropriated by any of them. However, there is a potential surplus to be realized in the market for information, i.e. $\beta_{mi}\phi(c_{mi}, \beta_{mi})$. In the equilibrium analyzed in Proposition 7 the competition among contractors drives the appropriation of that surplus to zero as well. In fact, the contractor that becomes the information monopolist anticipates to appropriate the surplus of the market for information. This implies that contractors compete to be in that position when they post the price for the task. In other words, contractors are willing to run a deficit in the first stage of the game to appropriate the surplus in the second stage.

However, contractors may find difficult to get the liquidity necessary to run such deficit in the first stage. In this model, a borrowing constraint for contractors amounts to requiring the price of the task to be non-negative.

Definition 1 *There is a borrowing constraint in the outsourcing market if no contractor can post a negative price for the task, i.e. $\tau_j \geq 0$ for all $j \in \{1, .., m\}$.*

If a borrowing constraint is present in the outsourcing market, one contractor appropriates all the surplus generated in the market for information. In fact, if the contractors cannot lower the price of the task below zero, all investing firms will

[43] Of course, this is because with the extremely simple information aggregation assumptions we have, every single firm does not have any impact on the knowledge of the monopolistic contractor. Still, even in a situation in which every firm's technology has a (decreasing) impact on the knowledge of the contractor, we could support a similar equilibrium for an arbitrarily low t.

outsource from the same contractor, say j, for $\tau(j) = 0$. This implies that such contractor appropriates the entire market for information surplus $\beta_{mi}\phi(c_{mi}, \beta_{mi})$. This result is formalized in Corollary 8.

Corollary 8 *If $s \in (0, \overline{s})$ and there is a liquidity constraint in the outsourcing market, one contractor appropriates all the market for information surplus, i.e. he realizes the profit $\beta_{mi}\phi(k_{mi}, \beta_{mi})$.*

Corollary 8 guarantees that if a market for information occurs in equilibrium, not only one contractor among many identical ones becomes the monopolist for the information, but, if contractors are unable to charge negative prices for the task, he appropriates the entire surplus generated by the market for information.

4.3.2 Equilibrium if $s = 0$

In Corollary 4 I already started to study the case in which contractors have a perfect control over information, i.e. $s = 0$. In this case there is no information spill and all the firms that neither invest in technology nor buy the information from the contractor always produce at the maximum cost level. Corollary 4 states that if $s = 0$, the not-investing firms are always willing to pay a positive amount to get the information from a contractor. This keep the demand for information high enough to guarantee that a monopolistic contractor always prefer to exhaust the market selling to all his potential customers. This implies that if $s = 0$, a monopolistic contractor generates a perfect leakage. In Proposition 9, I analyze the implications of perfect information control on the equilibria of the game.

Proposition 9 *If $s = 0$ there is a unique equilibrium in which all firms outsource and invest $k_0 \geq 0$ in technology. No firm buys information from a contractor.*

Proposition 9 guarantees that if $s = 0$, then no market for information arises, as firms always prefer to invest themselves rather than buying the information from the contractor. This is due to the fact that the optimal investment problem that investing firms solve when deciding how much to invest guarantees that the total return on the optimal investment is strictly positive. This implies that no firm can find it optimal to buy the information from the contractor (who in the transaction extracts all the surplus generated by the technology), rather than to invest at the beginning of the game. Proposition 9 suggests that when information sellers have perfect control over the information they sell, they face a hold-up problem generated by the lack of commitment power. As contractors cannot commit to sell the information at a low price, all the firms find optimal to develop their own technology rather than rely on the market for information.

5 Comparative statics

In Sections 3 and 4, I analyzed the equilibria arising as s varies in the interval $[0, n]$. Recall that the parameter s measures the amount of control a contractor has over the information he learns from his clients. In a situation in which $s = n$ a contractor cannot become an information seller. This may happen for several reasons. Not having the resources or the expertise to sell technology, and not being aware of the information held by the employees (and consequently not taking measures to protect and control it) are the two main ones. A contractor can become an information seller only when he becomes aware of the information he holds, he protects and controls it to some extent and he has the ability to market and sell it to other firms. In our model this corresponds to a situation in which s is small enough. When contractors reach full control of the information they hold, we are in a situation in which $s = 0$. It is interesting to analyze the change in the level of technology developed by the investing firms and the change in the diffusion of such technology in the market as the parameter s varies from n to 0, i.e. as contractors have more and more control over the information they hold.

When contractors have no control over the information they hold, i.e. when $s = n$, Proposition 2 shows that there exists a not-empty interval $\left[\underline{T}, \overline{T}\right]$ such that if $t \in \left[\underline{T}, \overline{T}\right]$ there is a unique pure strategy equilibrium where a positive measure of firms invest and do not outsource. Recall that we named as k_n and γ_n the (maximum) investment level in such equilibrium and the measure of firms that carry it out, respectively. Recall also that in such equilibrium there is no information leakage. This implies that only the firms that invest have a low-cost technology.[44] When $s \in (0, \overline{s})$, I showed that a perfect leakage never occurs in equilibrium, and there is an equilibrium in which a market for information arises. Recall that k_{mi}, γ_{mi} and β_{mi} are the investment carried out by the investing firms in such equilibrium, the measure of firms that carry it out and the measure of firms that buy the technology, respectively. Notice that the total measure of firms adopting the technology developed by the investment k_{mi} in such equilibrium is $\gamma_{mi} + \beta_{mi} + s$. Finally, when $s = 0$, I showed that in the unique equilibrium all firms invest k_0 in R&D (using a notation consistent with the other cases, let $\gamma_0 = n$). Proposition 10 compares the maximum investment levels and the measure of the diffusion that the technologies reach as the parameter s varies.

Proposition 10 *The equilibrium maximum investment levels are such that* $k_n > k_{mi} > k_0$. *The measures of firms adopting such technologies are such that* $\gamma_n < \gamma_{mi} + \beta_{mi} + s < \gamma_0 = n$.

Proposition 10 describes the effect of an increased sophistication of contractors as information sellers on the technology maximum level and diffusion in the market. When contractors do not have any control of the information that they hold the level of technology reached in equilibrium is the maximum one. However, such information is adopted by the minimal possible measure of firms. The possibility of contractors becoming information sellers depresses the maximum level of technology, but increases the size of the set of firms that adopt such technology. Finally, if contractors have full control on the information, the level of technology is the minimal possible and everybody adopts it.

The last result allows us to analyze the inefficiency due to duplication of investment. Duplication occurs when we have many firms investing resources to develop

[44]When $t > \overline{T}$, we showed that there is a unique equilibrium in which all firms outsource and no firm invests. This implies that k_n is the highest R&D investment in any pure strategy equilibrium for $s = n$.

technologies that are equivalent to each other. In the absence of an information leakage problem, all firms would outsource and invest in R&D, so that there is a high level of duplication of investment. One may wonder whether the presence of contractors acting as information intermediaries allows information to diffuse and mitigates this inefficiency. Our results predict that when contractors *do not* have full control of the information, duplication is indeed mitigated. In particular, we have that γ_{mi} is smaller than n. However, when $s = 0$, a market for information cannot arise, and the inefficiency due to duplication reappears as all firms invest in R&D to develop their own technologies.

6 Discussion and further research

6.1 Information sellers

An important feature of the model presented in Section 2 is the fact that firms cannot participate directly in the market for the information by selling their technology to competitors. This assumption allows to simplify the analysis of the game and to focus on the role of contractors as information intermediaries.

In reality, we sometimes observe firms that trade technologies with their competitors through licencing. In this paper I focus on technologies whose implementation is difficult to monitor (such as cost-cutting technologies) and on which Intellectual Property Rights are harder to enforce. Firms are less likely to start diffusing such technologies through licences, as a further diffusion on the market is hard to prevent. Also, if an innovative firm can choose on which markets they want to sell their technologies, they are more likely to choose markets that are not populated by their direct competitors. This imples that firms are less likely to participate their market directly as information sellers.

Let us discuss the consequences of removing such assumption from the model.[45] If one considers a market for information populated both by contractors and firms, the

[45] Of course, this discussion is relevant for the case $s < n$ only (as there is no room for a market for information at all if $s = n$).

reliability of information sold by contractors is likely to be considered by potential customers higher than the one sold by their own competitors. This is because firms may have incentives to distort the information to damage their competitors on the product market (and thus, via monopolistic competition, to stimulate their own demand). On the other hand, contractors do not participate in the competition on the product market, and they do not have incentives to distort the information they sell. Thus, in order to sell information to a rival, a firm may have to incur an extra cost to certify the information and convince the buyers to make the purchase. When this cost is big enough, the main results of this paper still hold. If such cost is small or non-existent, with the model presented in this paper, it is easy to check that sometimes (for instance, for $s = 0$), the existence of a pure-strategy equilibrium may fail.[46] Notice however that this problems are mainly due, via Proposition 6, to the extreme characteristics of the Bertrand competition on the market for information. Other modules of competition on the market would make the magnitude of the leakage sensitive to the number of participants on the market for information when this number is higher than 2. Then, the main intuition of our results, that is, the possibility that contractors generate an information leakage tends to make the outsourcing market more concentrated of how it would be otherwise, would still hold.

6.2 Information spill

A second feature of the model worthwhile discussing here is the presence and the features of the information spill. Here, I first discuss the presence of the information spill in the model, and then I discuss its features in the modelling choices made in Section 2.

[46] This is because, as arguments very similar to the ones made for Proposition 6 apply here as well, competition on the market for information difficult to sustain in equilibrium. Then, the only situation possible to be sustained as equilibrium would be the one in which only one firm invests and sells the information to the rest of the market (with some spill $s > 0$ to deter the other firms from investing themselves rather than wait for the information leakage).

As discussed in Section 4.3.2, the presence of a positive information spill guarantees that in equilibrium not all the firms invest in R&D. One may argue that this is the consequence of the way in which R&D investment is modeled in this paper. If we modeled R&D as a fixed investment rather than a continuous choice variable of the firms, one may conjecture equilibria in which, even if $s = 0$, a market for information arises. Unfortunately, this conjecture turns out to be not true. To see this, consider a model in which a *fixed* investment $\overline{k}$ is required to develop a R&D technology, and $s = 0$. Suppose that if no other firm on the market has such technology, it is worthwhile for a firm to incur the cost of developing it, but if too many firms on the market have it, then the return on such R&D will be too small to justify the cost of developing it. Let the price for information be ϕ. Notice that if $\phi < \overline{k}$, in equilibrium at most one firm can develop R&D, as a second one would have a profitable deviation by buying it later in the market for information. Then, this firm anticipates the contractor selling the information to a certain measure of competitors. However, it is easy to check from the monopolist profit maximization problem (1) that, if $s = 0$, the contractor always generates a perfect leakage, i.e. $\beta = n$. Then, the firm that develops technology is completely expropriated of it, and it has a profitable deviation in non developing it. If $\phi > \overline{k}$, every firm buying technology form the contractor would have a profitable technology by developing it by itself. Suppose finally that $\phi = \overline{k}$. This is possible only if the willingness to pay $\phi\left(\overline{k}, n\right)$ (since n is the solution of the monopolist maximization problem (1)) happens to coincide with $\overline{k}$. This can be true at most for a zero-measured set of parameters of the model. Then, we can conclude that generically there are no pure strategy equilibria in this version of the model.

As it is apparent from the description of the timing of the game, an important assumption of this model is the fact that firms have to decide whether to invest in technology and whether to buy technology before knowing whether they receive the information spill. This is because the information spill is a phenomenon that should be interpreted as taking place in the long-run: as contractors experience labor turnover, the technologies start diffusing through the market and more and more firms start adopting it.

Finally, let us discuss the assumption that the spill can be received only by firms that neither invest in technology nor bought information from contractors. This assumption is made to guarantee that, in a market in which all the firms but a zero-measured set are adopting a certain technology, the firms that are not adopting it will learn it through the spill with probability one, and are thus willing to pay zero to buy it from a contractor. This fact guarantees that, as it is reasonable to expect from a monopolist, the contractor will not sell the information to all firms. It is easy to guess that this result could have been achieved with different assumptions about the spill (for instance, any firm receives some spill with a probability that is increasing in the measure of firm already adopting some technology, with this probability going to 1 as the measure tends to n), and the specific assumption made in Section 2 does not affect the results in any significant way.

6.3 Monopolistic Competition

The choice of using a monopolistic competitive model in this paper is motivated by its tractability and the fact that it allows us to focus on the strategic concerns of the firms in generating information leakage while abstracting from all the others. However, the main results of this paper do not depend on this modeling choice and can be easily replicated in a different competitive environment in which at least four firms produce differentiated yet substitute products.[47] The drawback of a monopolistic competitive environment is the fact that, as it was seen in Section 4, a monopolistic seller of information generates a perfect leakage if $s = 0$. This is because, when $s = 0$, the marginal revenue of information is positive and constant. As the marginal cost is zero, the monopolistic problem always has a corner solution in $\beta^* = n - \gamma$. Then, an alternative competitive environment, together with a fixed investment level $\overline{k}$, is likely to generalize our result for the case $s = 0$ as well.

[47] We need 2 firms to hire the same contractor as an illustration of the monopolistic outcome on the market for information, and 2 other firms that do not invest in R&D to have the possibility to differentiate a perfect leakage from an imperfect one.

6.4 Robustness of Proposition 6

There are three basic observations that underlie the result of Proposition 6. First, as we showed in Proposition 3, a monopolistic market for information generates a more limited leakage than a competitive market for information. Second, in equilibrium there cannot be more than two high-tech firms outsourcing from two different contractors as otherwise one of these firms would have a profitable deviation in not investing in R&D and waiting to buy the information on the competitive market for information (where, as the marginal cost of selling information is zero, the equilibrium price is going to be zero as well). Finally, there cannot be exactly two firms investing in R&D and outsourcing from two different contractors as one of these firms would have a profitable deviation in selecting the same contractor of the other and generating a more limited information leakage instead of a perfect one.

Here I discuss the robustness of these three points to alternative specifications of the model and of the competition module adopted in the paper. The first observation is obviously very general as it relies on the fact that as the degree of competition on a market increases, the quantity traded increases as well. The second and third observations rely on the fact that contractors *compete on price* on the market for information. Thus, the only situation in which a firm is pivotal for the market structure of the market for information, is the situation in which exactly two high-tech firms are outsourcing from two contractors. Thus, as in competition the equilibrium price of the information is zero, a firm that is not pivotal for the competition on the market for information strictly prefers to buy the information on the market rather than investing. On the other hand, a firm that is pivotal for the competition on the market for information prefers to decrease the degree of competition by outsourcing from a contractor that already holds information.

Although with alternative modules of competition on the market for information the distinction between a pivotal and a non-pivotal firm may become more blurred, the basic intuition of this result is still very strong. Suppose that, once they hold some information, the contractors compete on quantities on the market for information (thus, it is not necessarily the case that the price for information on the competitive market is zero). In particular, suppose that a number $2 \leq h \leq m$ of contractors hold some technology $c(k)$. Let $p(k,h) > 0$ be the price on the market for information if h contractors compete to sell technology $c(k)$. Suppose that one of these contractors has at least 2 clients that developed technology $c(k)$. Thus, one of these clients is non-pivotal to the structure of the downstream market for information. Observe that this firm would be better off by buying the information on the market, as in equilibrium it must be the case that $p(k,h) < k$.[48] Then, it must be the case that exactly h firms are investing in R&D and hire each one of the h contractors. In particular, consider one of these h firms and observe that this firm would have a profitable deviation in hiring a contractor that another firm is already using as we have $p(k,h-1) > p(k,h)$ (the equilibrium price is decreasing in the number of competitors on the market).[49]

Thus, we can still conclude that the firms that invest in R&D have an incentive to distort the downstream market for information by making it as concentrated as possible.

6.5 Further research

The most natural follow-up to this analysis is to explore the welfare implications of the role of contractors as information intermediaries. The socially optimal outcome of the model is a situation in which there is no duplication of investment (i.e. only one firm invests in technology), and both the investment level and the set of firms that adopt the corresponding technology maximize social welfare.

In this model I assumed that a contractor working for a firm always perfectly learns

[48] Notice that it is not possible to sustain an equilibrium in which $p(k,h) > k$ and firms buy information from contractors as firms would have a profitable deviation in investing themselves k rather than paying $p(k,h)$ on the market for information. So, to sustain an equilibrium with a market for information it has to be the case that $p(k,h) < k$.

[49] Recall that in equilibrium all the contractors must post the same price for the task. Also, notice that here the presence of information leakage acts exactly as an entry barrier on the market for information.

the technology developed by the client. This is obviously a strong assumption, and it is due to the fact that the focus of this paper is to understand the implications of the *ability* of the contractors (captured by the parameter s) as information sellers, and not the access they happen to have to the technologies of their clients. An alternative version of this model is a situation in which a contractor hired by a firm learns the technology with some probability $\alpha \in (0, 1)$. The parameter α captures the degree to which cost-cutting technology may be transferred or copied, and it varies across industries. One can show that is contractors have no information control (i.e., $s = n$), in equilibrium an interesting phenomenon arises: the market segments into three sets of firms: a positive-measured set of firms that invest in R&D and do not outsource, a positive-measured set of firms that do not invest in R&D and outsource and a finite number of firms that both outsource and develop R&D technology. It is interesting to note that, in the early 90s, Sun Microsystems was outsourcing most of its production; however, it was still able to innovate and compete effectively, both with workstation manufacturers who, by and large, were not outsourcing but were also investing in R&D (e.g. HP), and with "second-tier" firms who did not invest in R&D and relied on outside contractors. The proposed extension of the model seems to capture this situation quite well. By making the parameter α vary, one can derive testable predictions about the structure of industries which differ in the possibility to replicate cost-cutting technology. Also, one may try to predict which of these industries are likely to display a higher reliance on outsourcing in general and management consultants in particular.[50]

[50] See Bartel, Lach and Sicherman (2004) for some recent empirical research on the link between outsourcing and innovation.

7 Appendix

7.1 The game

7.1.1 Timing

Let us repeat the timing of the game to introduce some useful notation:

(1) All firms $i \in \mathcal{N}$ simultaneously decide how much to invest in research by paying $k(i) \in R_+$. Simultaneously, each contractor $j \in \mathcal{M}$ posts a price for the task $\tau_j \in R$. Let us denote by γ the measure of the set of firms investing in technology, i.e. the set $K \equiv \{i \mid k(i) > 0\}$

(2) All firms $i \in \mathcal{N}$ simultaneously decide whether to perform the task in-house or to outsource it from an external contractor. In the last case, a firm also decides which contractor to outsource the task from. Let us denote by H_j the set of firms outsourcing from contractor j, and $H \equiv \bigcup\limits_{j \in \mathcal{M}} H_j$.

(3) Contractors perform the task for their clients and they learn the technologies developed by the clients. Let $\underline{c}_j$ be the best technology learned by contractor j, i.e. $\underline{c}_j \equiv \inf_{\{i|i \in H_j\}} c(k(i))$.

(4) Every contractor j decides how much information to sell, i.e. he chooses a technology level $c_j \in [\underline{c}_j, 1]$ and post a price ψ_j for it.

(5) Each firm decides whether to buy technology c_j from contractor j.Let us denote by B_j the set of all firms that buy a technology from contractor j, let $B \equiv \bigcup\limits_{j \in \mathcal{M}} B_j$ and let β_j and β be the measure of the sets B_j and B, respectively.

(6) The maximum level of technology learned by contractors (i.e., the technology $\underline{c} \equiv \min_{j \in \mathcal{M}} \underline{c}_j$) spills to a measure $\sigma = \min[s, n - \gamma - \beta]$ of firms. Each firm in the set $N \backslash (K \cup B)$ receive the spill with probability $\frac{\sigma}{n-\gamma-\beta}$.

(7) Each firm $i \in N$ adopts the best technology it has learned $c(i)$ and decides how much to produce by choosing $q(i) \in R_+$. The production is sold on the market and profits are realized.

7.1.2 Payoffs

The payoff of a generic firm $i \in \mathcal{N}$ on the monopolistic competitive market is:

$$\widetilde{\pi}(i) = [p(i) - c(i)]\, y(i) - k(i) - \tau - \sum_{h \in \mathcal{M}} \psi_h 1_{\{i \in B_h\}}$$

where $[p(i) - c(i)]\, y(i)$ is the economic profit, $k(i)$ is the investment in R&D, τ is the cost paid for the task and ψ_h (if any) is the price paid for some technology bought on the market for information.[51] From the model presented in Section 2, one can derive the profit function of firm i as a function of the technology level of its competitors, i.e.

$$\widetilde{\pi}(i) = \frac{E(1-\alpha)}{\int_{\mathcal{N}} c(j)^{\frac{-\alpha}{1-\alpha}} dj} c(i)^{\frac{-\alpha}{1-\alpha}} - k(i) - \tau - \sum_{h \in \mathcal{M}} \psi_h 1_{\{i \in B_h\}} \tag{2}$$

The payoff for a generic contractor $j \in \mathcal{M}$ is

$$\pi(j) = \mu_j \tau_j + \beta_j \psi_j$$

where μ_j is the measure of firms outsourcing from contractor j, $\mu_j \tau_j$ is the revenue generated on the outsourcing market, β_j is the measure of the set of firms buying information from contractor j, and $\beta_j \psi_j$ is the revenue generated on the market for information.

7.2 Proofs

Proof of Lemma 1: From (2), denoting by $\pi(i)$ the *economic* profit of a firm, we have

$$\begin{aligned} \pi(i) &= \frac{E(1-\alpha)}{\int_{\mathcal{N}} c(j)^{\frac{-\alpha}{1-\alpha}} dj} c(i)^{\frac{-\alpha}{1-\alpha}} \\ &= \frac{E(1-\alpha)}{\int_{\mathcal{N}} (1+k(j))^{\frac{\alpha\rho}{1-\alpha}} dj} (1+k(i))^{\frac{\alpha\rho}{1-\alpha}} \end{aligned}$$

From now on, let

$$A \equiv \frac{E(1-\alpha)}{\int_{\mathcal{N}} (1+k(j))^{\frac{\alpha\rho}{1-\alpha}} dj}$$

[51] I denote by 1_E the indicator variable equal to 1 is the event E occurs and zero otherwise.

Consider first the case in which the set of outsourcing firms, H, includes at least two firms, and the set of non-outsourcing firms, $\mathcal{N}\backslash H$ is non-empty. Notice that in the set H there can be at most one firm investing in technology. Indeed, a second firm would have a profitable deviation in not investing and learning the technology through the spill. Now, is it possible to have an equilibrium with exactly one investing and outsourcing firm? Suppose it is, and let $k_H > 0$ be the investment of such firm, say firm i. Notice that that each not-investing firm in H must be at least as well off as each firm in $\mathcal{N}\backslash H$, since if this is not the case, that firm would be better off following the strategy of the firm in $\mathcal{N}\backslash H$ (notice that these firms' behavior does not have any significant influence on A). Notice also that each firm in $\mathcal{N}\backslash H$ must be at least as well off as any non-investing firm in H, since if the opposite is true, it would have a profitable deviation in outsourcing and not investing. If only one firm i in H invests $k_H > 0$, i has to be worse off than the others firms in H, which we just claimed are at least as well off as the not outsourcing firms. Firm i is then worse off than the ones not outsourcing, so it would have a profitable deviation by following their strategy. Indeed, if we denote by $k_{\mathcal{N}\backslash H}$ the optimal investment of the not-outsourcing firms, we have

$$
\begin{aligned}
A_L\left(1+k_H\right)^{\frac{\alpha\rho}{1-\alpha}} - k_H &< A_L\left(1+k_H\right)^{\frac{\alpha\rho}{1-\alpha}} \\
&= A_L\left(1+k_{\mathcal{N}\backslash H}\right)^{\frac{\alpha\rho}{1-\alpha}} - k_{\mathcal{N}\backslash H} - t \\
&< A_{NL}\left(1+k_{\mathcal{N}\backslash H}\right)^{\frac{\alpha\rho}{1-\alpha}} - k_{\mathcal{N}\backslash H} - t
\end{aligned}
$$

where γ is the measure of the set of investing firms, A_L is defined as

$$
A_L \equiv \frac{E\left(1-\alpha\right)}{\left(n-\gamma\right)\left(1+k_H\right)^{\frac{\alpha\rho}{1-\alpha}} + \gamma\left(1+k_{\mathcal{N}\backslash H}\right)^{\frac{\alpha\rho}{1-\alpha}}}
$$

and A_{NL} as

$$
A_{NL} \equiv \frac{E\left(1-\alpha\right)}{n+\gamma\left(1+k_{\mathcal{N}\backslash H}\right)^{\frac{\alpha\rho}{1-\alpha}}} > A_L
$$

By avoiding the leakage, and then increasing the demand for all firms (higher A), firm i would improve everybody's profits in the set $\mathcal{N}\backslash H$, and a fortiori, it would be better off than by outsourcing and investing k_H.

In the case in which there is only one outsourcing firm, if this firm invests, the investment has to be at the same level of all other non-outsourcing firms (as they solve the same maximization problem). Then, one non-outsourcing (and investing) firm has a profitable deviation in outsourcing and not investing. Finally, if all firms outsource, at most one firm can invest in equilibrium k_H (as all the others would free-ride on that investment). However, this implies

$$\frac{E(1-\alpha)}{n(1+k_H)^{\frac{\alpha\rho}{1-\alpha}}}(1+k_H)^{\frac{\alpha\rho}{1-\alpha}} - k_H < \frac{E(1-\alpha)}{n}$$

i.e., the investing firm is completely expropriated from its investment (i.e., its economic profit is the same it would get without investment). Thus, the firm has a profitable deviation in not investing ■

Proof of Proposition 2: (i) The profit of a not-outsourcing firm is

$$\pi(i) = A(1+k(i))^{\frac{\alpha\rho}{1-\alpha}} - k(i) - t$$

The first order condition of the optimal investment problem is

$$A\frac{\alpha\rho}{1-\alpha}(1+k(i))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} - 1 = 0 \tag{3}$$

which is such that $\frac{dk(i)}{dA} > 0$. By Lemma 1, if everybody else outsource, A is the maximum possible, i.e. $\overline{A} = \frac{E(1-\alpha)}{n}$, which implies that $\overline{k} \equiv \left(\frac{n}{E\alpha\rho}\right)^{\frac{1-\alpha}{\alpha\rho-1+\alpha}} - 1$ is the maximum possible investment. If

$$\frac{E}{n}(1-\alpha)\left(1+\overline{k}\right)^{\frac{\alpha\rho}{1-\alpha}} - \overline{k} - t \leq \frac{E}{n}(1-\alpha)$$

or

$$t \geq \left(\frac{n}{E\alpha\rho}\right)^{\frac{1-\alpha}{\alpha\rho-1+\alpha}}\left(\frac{1-\alpha}{\alpha\rho} - 1\right) - \frac{E}{n}(1-\alpha) + 1 \equiv \overline{T}$$

then the firms strictly prefers outsourcing and not investing rather than not outsourcing and investing. Since the profit of a not outsourcing firm is increasing in A, if the maximum possible A does not refrain a firm to contract, any lower A, corresponding to different strategies chosen by the other firms do not refrain such firm to contract either, so that the equilibrium is unique.

(ii) Let $t < \overline{T}$. *First step*: Let us first show that there cannot be an equilibrium in which two firms invests two strictly positive but different amounts $k' \neq k''$. To see this, suppose that there exists an equilibrium in which this is the case. Let $A' \equiv \frac{E(1-\alpha)}{\int_{\mathcal{N}} c(k(j))^{-\frac{\alpha}{1-\alpha}} dj}$ in this equilibrium. Observe that, but Lemma 1, it must be the case that the two firms are both not outsourcing. But then, at least one would have a profitable deviation in investing k^* uniquely defined as

$$k^* \equiv \arg\max_{k \in R_+} A' (1+k)^{\frac{\alpha\rho}{1-\alpha}} - k$$

Second step: Recall from (i) that in this case, if all (or all but a zero-measured set of) the firms outsource, there is a profitable deviation in not outsourcing and investing $\overline{k}$. Then, in equilibrium it must be the case that a positive measured set of firms invest and do not outsource (i.e., $\gamma < n$). On the other hand, notice that for any A there is a unique level of $k(i)$ which satisfies (3), and since all the not-outsourcing firms face the same A, they must invest the same in R&D. This implies that in equilibrium a positive measured set of firms outsources ($\gamma > 0$). In fact, if $\gamma = 0$, they would all invest the same k in R&D. In this case, one non-outsourcing firm would be better off outsourcing because it would gain t and the leakage cannot lower its profit (not having any impact on A). This implies that in the only possible equilibrium left there must be some positive measure $\gamma \in (0, n)$ of firms not outsourcing and a positive measure $n - \gamma$ of outsourcing firms. By Lemma 1, we have that there is no $i \in H$ such that $c(i) < \overline{c} = 1$, so in equilibrium it must be the case that $c(i) = \overline{c} = 1$ for all $i \in H$.

The considerations made so far allow us to write A as a function of the measure of investing firms, γ, i.e.,

$$\begin{aligned} A(\gamma) &\equiv \frac{E(1-\alpha)}{(n-\gamma) + \int_{\mathcal{N}/H} c(k^*(j))^{-\frac{\alpha}{1-\alpha}} dj} \\ &= \frac{E(1-\alpha)}{(n-\gamma) + \gamma (1+k_{-i})^{\frac{\alpha\rho}{1-\alpha}}} \end{aligned}$$

where the fact that, by symmetry, all the not-outsourcing firm invest the same amount in R&D guarantees the second equality. Then, for a given γ to find the equilibrium $k(i)$ for $i \in \mathcal{N}/H$, we need to find the solution $k_{-i} = k(i)$ of

$$\frac{E(1-\alpha)}{(n-\gamma)+\gamma(1+k_{-i})^{\frac{\alpha\rho}{1-\alpha}}}(1+k(i))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}\left(\frac{\alpha\rho}{1-\alpha}\right)-1=0$$

or

$$\frac{E\alpha\rho}{(n-\gamma)+\gamma(1+k_{-i})^{\frac{\alpha\rho}{1-\alpha}}}(1+k(i))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}-1=0$$

Such solution $k_{-i} = k(i) = k^{*}(\gamma)$ is unique for each γ since

$$\frac{dk(i)}{dk_{-i}}=-\frac{\frac{\partial A}{\partial k(\gamma)}c(k(i))^{-\frac{1}{1-\alpha}}\left(-\frac{\alpha}{1-\alpha}\right)c'(k(i))}{\frac{d^2\pi(i)}{dk(i)^2}}<0$$

Now, the equilibrium condition that outsourcing and not outsourcing firms must have the same payoff allow us to determine the equilibrium measure γ. Recall that if we denote by $\pi_H(\gamma)$ the profit of an outsourcing firm, we have

$$\pi_H(\gamma)=A(\gamma)=\frac{E(1-\alpha)}{(n-\gamma)+\gamma(1+k^{*}(\gamma))^{\frac{\alpha\rho}{1-\alpha}}}$$

On the other hand, if $\pi_{\mathcal{N}\setminus H}(\gamma)$ denotes the profit of a not-outsourcing firm, we have

$$\begin{aligned}\pi_{\mathcal{N}\setminus H}(\gamma) &= A(\gamma)(1+k^{*}(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-k^{*}(\gamma)-t\\ &= \frac{E(1-\alpha)}{(n-\gamma)+\gamma(1+k^{*}(\gamma))^{\frac{\alpha\rho}{1-\alpha}}}(1+k^{*}(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-k^{*}(\gamma)-t\end{aligned}$$

The equilibrium γ is a solution of the equation $\pi_H(\gamma) = \pi_{\mathcal{N}\setminus H}(\gamma)$. For $\gamma = 0$, we have that, as $t \leq \overline{T}$, $\pi_H(0) < \pi_{\mathcal{N}\setminus H}(0)$. On the other hand, notice that for $\gamma = n$, we have $k^{*}(\gamma) = \frac{E\alpha\rho}{n} - 1$, and $A(n) = (1-\alpha)\left(\frac{E}{n}\right)^{\frac{-\alpha\rho+1-\alpha}{1-\alpha}}(\alpha\rho)^{-\frac{\alpha\rho}{1-\alpha}}$. This implies

$$\pi_H(n)=(1-\alpha)\left(\frac{E}{n}\right)^{\frac{-\alpha\rho+1-\alpha}{1-\alpha}}(\alpha\rho)^{-\frac{\alpha\rho}{1-\alpha}}$$

and

$$\pi_{\mathcal{N}\backslash H}(n) = (1-\alpha)\left(\frac{E}{n}\right)^{\frac{-\alpha\rho+1-\alpha}{1-\alpha}}(\alpha\rho)^{-\frac{\alpha\rho}{1-\alpha}}\left(\frac{E\alpha\rho}{n}\right)^{\frac{\alpha\rho}{1-\alpha}} - \frac{E\alpha\rho}{n} + 1 - t$$

This implies that $\pi_H(n) \geq \pi_{\mathcal{N}\backslash H}(n)$ if and only if

$$t \geq \frac{E}{n}\left[1-\alpha-\alpha\rho-\left(\frac{E\alpha\rho}{n}\right)^{-\frac{\alpha\rho}{1-\alpha}}(1-\alpha)\right] + 1 \equiv \underline{T}$$

Let us now show that there is a unique γ^* satisfying the condition $\pi_H(\gamma) = \pi_{\mathcal{N}\backslash H}(\gamma)$, and thus there is a unique equilibrium for $t \in \left[\underline{T}, \overline{T}\right]$. The proof of uniqueness consists of two steps: (a) I first show that $\frac{\partial A(\gamma)}{\partial\gamma} < 0$ for all γ, (b) then I show that $\frac{\partial A(\gamma)}{\partial\gamma} < 0$ for all γ implies uniqueness.

(a) To show that $\frac{\partial A(\gamma)}{\partial\gamma} < 0$ for all γ, let us first compute the derivative $\frac{\partial k^*(\gamma)}{\partial\gamma}$. Recall that from (3), we have

$$\frac{E\alpha\rho}{(n-\gamma)+\gamma(1+k^*)^{\frac{\alpha\rho}{1-\alpha}}}(1+k^*)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} - 1 = 0$$

which implies

$$\frac{\partial k^*(\gamma)}{\partial\gamma} = \frac{\left[(1+k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-1\right]}{\frac{\alpha\rho-1+\alpha}{(1-\alpha)(1+k^*(\gamma))}\left\{n+\gamma\left[(1+k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-1\right]\right\} - \frac{\alpha\rho\gamma}{1-\alpha}(1+k^*(\gamma))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}} \tag{4}$$

Now, we have that

$$\frac{\partial A(\gamma)}{\partial\gamma} = -E(1-\alpha)\frac{\left[(1+k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-1\right] + \frac{\gamma\alpha\rho}{1-\alpha}(1+k^*(\gamma))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}\frac{\partial k^*(\gamma)}{\partial\gamma}}{\left[n+\gamma\left[(1+k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-1\right]\right]^2}$$

which implies that $\frac{\partial A(\gamma)}{\partial\gamma} < 0$ if and only if

$$\left[(1+k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}}-1\right] + \frac{\gamma\alpha\rho}{1-\alpha}(1+k^*(\gamma))^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}\frac{\partial k^*(\gamma)}{\partial\gamma} > 0 \tag{5}$$

By plugging (4) into (5) and after some manipulations, one can see that condition (5) reduces to

$$
\begin{aligned}
\frac{\gamma\alpha\rho}{1-\alpha}\left(1+k^{*}(\gamma)\right)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} &< \frac{\gamma\alpha\rho}{1-\alpha}\left(1+k^{*}(\gamma)\right)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} \\
&\quad +\frac{1-\alpha-\alpha\rho}{1-\alpha}\left[n+\gamma\left[\left(1+k^{*}(\gamma)\right)^{\frac{\alpha\rho}{1-\alpha}}-1\right]\right]
\end{aligned}
$$

which is satisfied because, by Assumption 1, we have $\frac{1-\alpha-\alpha\rho}{1-\alpha}>0$.

(b) Since $\frac{\partial A(\gamma)}{\partial\gamma}<0$, and $t\in\left[\underline{T},\overline{T}\right]$, there is a unique SP equilibrium in which $n-\gamma$ firms contract and do not invest and γ firms do not contract and invest. To see this, notice that for any γ it must be

$$
\begin{aligned}
\frac{\partial\pi_{\mathcal{N}\setminus H}(\gamma)}{\partial\gamma} &= \frac{\partial A(\gamma)}{\partial\gamma}\left(1+k(\gamma)\right)^{\frac{\alpha\rho}{1-\alpha}}+ \\
&\quad +\left[A\left(1+k(\gamma)\right)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}\frac{\alpha\rho}{1-\alpha}-1\right]\frac{\partial k(\gamma)}{\partial\gamma} \\
&= \frac{\partial A(\gamma)}{\partial\gamma}\left(1+k(\gamma)\right)^{\frac{\alpha\rho}{1-\alpha}} \\
&< \frac{\partial\pi_{H}(\gamma)}{\partial\gamma}<0
\end{aligned}
$$

Since $\pi_{H}(n)<\pi_{\mathcal{N}\setminus H}(n)$, there must be a unique $\gamma\in[0,n]$ such that $\pi_{H}(\gamma)=\pi_{\mathcal{N}\setminus H}(\gamma)$.

The last thing left to show is that $\underline{T}<\overline{T}$. To see that, recall that $A(n)<A(0)$ and notice that

$$
\frac{\alpha\rho}{1-\alpha}A(n)(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}-k<\frac{\alpha\rho}{1-\alpha}A(0)(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}-k \tag{6}
$$

for any $k\in R_{+}$. Equation (6), since $k(n)<k(0)$, implies

$$
\begin{aligned}
\underline{T} &= A(n)\left(1+k(n)\right)^{\frac{\alpha\rho}{1-\alpha}}-k(n)-A(n) \\
&= \int_{0}^{k(n)}\left(\frac{\alpha\rho}{1-\alpha}A(n)(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}-k\right)dk \\
&< \int_{0}^{k(0)}\left(\frac{\alpha\rho}{1-\alpha}A(0)(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}-k\right)dk \\
&= A(0)\left(1+k(0)\right)^{\frac{\alpha\rho}{1-\alpha}}-k(0)-A(0)=\overline{T}
\end{aligned}
$$

From the analysis carried out so far, it follow also that, if $t<\underline{T}$, we have no pure strategies equilibria ■

Proof of Proposition 3: Let $\underline{c}$ be the best technology learned by the monopolistic contractor, and $n-\gamma$ be the measure of firms that did not invest in technology. To show the first part of the claim we need to show that $c^{*}=\underline{c}$. The demand for technology is given by

$$\phi(c,\beta)=A(c,\beta)\left\{c^{-\frac{\alpha}{1-\alpha}}-\left[\frac{\sigma}{n-\gamma-\beta}\underline{c}^{-\frac{\alpha}{1-\alpha}}+\frac{n-\gamma-\beta-\sigma}{n-\gamma-\beta}\right]\right\}$$

where$\underline{c}$ is the technology spilling from the monopolistic contractor to a measure σ of firms and

$$A(c,\beta)=\frac{E(1-\alpha)}{(\gamma+\sigma)\underline{c}^{\frac{-\alpha}{1-\alpha}}+\beta c^{\frac{-\alpha}{1-\alpha}}+(n-\gamma-\sigma-\beta)}$$

Notice that the monopolist of information, contractor j, has to solve the problem (1). For a given $\beta\in[0,n-\gamma-\sigma]$, observe that the problem becomes

$$\max_{c\geq\underline{c}}\frac{\left\{c^{\frac{-\alpha}{1-\alpha}}-\left[\frac{\sigma}{n-\gamma-\beta}\underline{c}^{\frac{-\alpha}{1-\alpha}}+\frac{n-\gamma-\beta-\sigma}{n-\gamma-\beta}\right]\right\}}{(\gamma+\sigma)\underline{c}^{\frac{-\alpha}{1-\alpha}}+\beta c^{\frac{-\alpha}{1-\alpha}}+(n-\gamma-\sigma-\beta)}$$

The derivative of the objective function is

$$\frac{\left(\frac{-\alpha}{1-\alpha}\right)c^{\frac{-1}{1-\alpha}}\left[\left(\gamma+\sigma+\frac{\sigma\beta}{n-\gamma-\beta}\right)\underline{c}^{\frac{-\alpha}{1-\alpha}}+\frac{(n-\gamma)(n-\gamma-\sigma-\beta)}{n-\gamma-\beta}\right]}{\left[(\gamma+\sigma)\underline{c}^{\frac{-\alpha}{1-\alpha}}+\beta c^{\frac{-\alpha}{1-\alpha}}+(n-\gamma-\sigma-\beta)\right]^{2}}<0$$

As the derivative is always negative, we have $c^{*}=\underline{c}$.

To prove the second part of the claim, observe that, if $c^{*}=\underline{c}$ for any given β, we have

$$\phi(\beta)=A(\underline{c},\beta)\frac{n-\gamma-\beta-\sigma}{n-\gamma-\beta}\left\{\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right\}$$

where

$$A(\underline{c},\beta)=\frac{E(1-\alpha)}{(\gamma+\sigma+\beta)\underline{c}^{\frac{-\alpha}{1-\alpha}}+(n-\gamma-\sigma-\beta)}$$

However, since $\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]$ is a constant at the time the monopolist solves the profit maximization problem, the problem (1) is equivalent to

$$\max_{\beta\in[0,n-\gamma-s]} \frac{\beta^{\frac{n-\gamma-\beta-s}{n-\gamma-\beta}}}{(\gamma+s+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n} \tag{7}$$

It is easy to check that the second order condition of problem (7) is satisfied. Let us define $\Phi(\beta) \equiv \phi'(\beta)\beta + \phi(\beta)$. As the second order conditions of (7) is satisfied, $\Phi'(\beta) < 0$. Then, the monopolist chooses β^* such that $\Phi(\beta^*) = 0$. As from the definition of $\phi(\beta)$ it is easy to check that $\phi(n-\gamma-s) = 0$, we have that $\Phi(n-\gamma-s) < 0$, thus $\beta^* < n-\gamma-s$ ■

Proof of Corollary 4: If $s = 0$, since we still have that by Proposition 3 we have that $c^* = \underline{c}$, the demand for information becomes

$$\varphi(\beta) = \frac{E(1-\alpha)\left[c^{\frac{-\alpha}{1-\alpha}}-1\right]}{(\gamma+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n}$$

The monopolist has to maximize the revenue $\varphi(\beta)\beta$. However, notice that $\varphi'(\beta)\beta + \varphi(\beta) > 0$ for any β. In fact, $\varphi'(\beta)\beta + \varphi(\beta) > 0$ if

$$-\frac{\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]\beta}{(\gamma+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n}+1>0$$

which is equivalent to

$$\beta < \frac{(\gamma+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n}{\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]}$$

which is always satisfied. This guarantees that $\beta^* = n-\gamma$ ■

Proof of Proposition 6: First of all, notice that the competition on the contractor market guarantees $\tau_j = \tau_h$ for all $j, h \in \mathcal{M}$.

Suppose there is a SPNE in which there is a competitive market for information. This implies that there are at least two investing firms that outsource from two different contractors. If the firms are more than two, there is at least one firm that would have a profitable deviation in not investing and buying the technology at zero price. This implies that there can only be exactly two investing firms outsourcing from two different contractors. However, by Proposition 3, if $s > 0$, one of these two firms would have a profitable deviation hiring the same contractor of the other firm, as this would produce an imperfect leakage instead of a perfect one. To conclude the proof, it remains to show that we cannot have a competitive market for equilibrium with $s = 0$. To see this, observe that if there are more than two firms investing and outsourcing from different contractors, one would have a profitable deviation in waiting to buy the information for free. Then, there must be at most two firms investing and outsourcing from two different contractors, say A and B. The price of the task in this situation has to be the same for both firms, say $\widetilde{\tau}$. Let S be the surplus on the market for information that a monopolist would appropriate. If $\widetilde{\tau} > -S$, contractor A would have a profitable deviation in lowering the price of the task to $\widetilde{\tau} - \varepsilon$ to attract the client of contractor B, become the information monopolist and appropriate S later. If $\widetilde{\tau} = -S$, then one of the two contractor would have a profitable deviation in raising the price of the task (or equivalently, drop out of the market), as he is not going to appropriate S, and he is offering the task at a negative price■

Proof of Proposition 7:

First step: Let us show that if in equilibrium there are *more than one firm* that outsource and invest in R&D, then all firms outsource. To see this by contradiction, suppose that more than one firm contract and invest, and someone does not outsource. From Proposition 6 we know that all the investing firms must outsource from the same contractor, say j. Since all the outsourcing and investing firms face the same decision problem, in equilibrium they have to invest the same. This implies that none of the the outsourcing firms is adding any information to the level of knowledge of contractor j. Thus, the outsourcing and the not outsourcing firm face the same problem when deciding how much to invest.

Since τ is a constant, we have that all the firms invest the same. This implies that the non outsourcing firms would be better off outsourcing, since, with other firms already outsourcing and investing, they would not affect the information learned by the contractor, and then the quality and size of the leakage.

Second step: We have to build an equilibrium in which γ_{mi} firms invest and outsource from the same contractor, β_{mi} firms buy the technology from this contractor and $s < n - \gamma_{mi} - \beta_{mi}$ firms receive the spill. First of all, notice that the competition on the contractor market guarantees $\tau_j = \tau_h$ for all $j, h \in \mathcal{M}$. If a set of measure γ_{mi} of firms invest and outsource from a contractor, observe that an investing firm is better off hiring the same contractor (this is because, from Proposition 3 we know that if the market for information is a monopoly the leakage is not perfect, while competitive market for information would produce a prefect leakage). For this equilibrium to exist, three conditions need to be satisfied. First, it must be the case that the firms that invest have the same expected profit of the firms that do not invest. Second, the equilibrium investment k_{mi} has to be the optimum one for the investing firms and finally the price for information and the measure of firms buying information (β_{mi}) have to be the profit maximizing ones for the monopolist of information, say contractor j. Given γ, from the information monopolist's problem, from Proposition 3 and from the optimal investment problem we know that $c^*(\gamma) \equiv (1 + k^*(\gamma))^{-\rho}$ and $\beta^*(\gamma) \in (0, n - s - \gamma)$ satisfy

$$\beta^* = \arg\max_{\beta \in [0, n-s-\gamma]} \frac{\beta^{\frac{n-\gamma-\beta-s}{n-\gamma-\beta}}}{(\gamma + s + \beta)\left[(1 + k^*)^{\frac{\alpha\rho}{1-\alpha}} - 1\right] + n}$$

(where we know from Proposition 3 that $\beta^* < n - s - \gamma$) and

$$\frac{E\alpha\rho\,(1 + k^*)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}}{(\gamma + s + \beta^*)\left[(1 + k^*)^{\frac{\alpha\rho}{1-\alpha}} - 1\right] + n} - 1 = 0$$

Now, we need to find γ such that the expected profits of the investing firms, i.e. $\pi_{\mathcal{I}}$ is the same as the one of the not-investing firms, i.e. $\pi_{\mathcal{N}\setminus\mathcal{I}}$. For this to be true, γ has to satisfy

$$\begin{aligned}
\pi_{\mathcal{I}}(\gamma) &= A(\gamma)\,(1 + k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}} - k^*(\gamma) = \\
&= A(\gamma)\left\{1 + \frac{s}{n - \beta^*(\gamma) - \gamma}\left[(1 + k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}} - 1\right]\right\} \\
&= \pi_{\mathcal{N}\setminus\mathcal{I}}(\gamma)
\end{aligned} \tag{8}$$

where

$$A(\gamma) = \frac{E(1-\alpha)}{n + (\gamma + \sigma + \beta^*(\gamma))\left[(1 + k^*(\gamma))^{\frac{\alpha\rho}{1-\alpha}} - 1\right]}$$

Notice that if $\gamma = n - s$, we have that $\beta^* (n-s) = 0$. On the other hand, we have that $k^* (n-s) > 0$. In fact, the optimal investment k in this case satisfies

$$\frac{E\alpha\rho}{n(1+k)^{\frac{\alpha\rho}{1-\alpha}}}(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}} - 1 = 0$$

Then, we have $k^* (n-s) = \frac{E\alpha\rho}{n} - 1 > 0$ by Assumption 2. This implies

$$\begin{aligned}
\pi_{\mathcal{N}\backslash\mathcal{I}}(n-s) &= A(n-s)(1+k^*(n-s))^{\frac{\alpha\rho}{1-\alpha}} \\
&> A(n-s)(1+k^*(n-s))^{\frac{\alpha\rho}{1-\alpha}} - k^*(n-s) \\
&= \pi_{\mathcal{I}}(n-s)
\end{aligned}$$

i.e., if $\gamma = n-s$ firms are better off not investing as they receive the spill with probability 1. On the other hand, if $\gamma = 0$, we have that

$$\begin{aligned}
\pi_{\mathcal{N}\backslash\mathcal{I}}(0) &= A(0)\left[\frac{s}{n-\beta^*(0)}(1+k^*(0))^{\frac{\alpha\rho}{1-\alpha}} + \frac{n-\beta^*(0)-s}{n-\beta^*(0)}\right] \\
&< A(0)(1+k^*(0))^{\frac{\alpha\rho}{1-\alpha}} - k^*(0) \\
&= \pi_{\mathcal{I}}(0)
\end{aligned}$$

is satisfied for s small enough. So, by continuity there exists $\gamma_{mi} \in [0, n-s]$ such that (8) is satisfied. From γ_{mi}, we can derive $\beta_{mi} \equiv \beta^*(\gamma_{mi})$ and $k_{mi} \equiv k^*(\gamma_{mi})$. Finally, one can determine the price charged by contractor j to perform the task. Observe that the chosen contractor will extract $\beta_{mi}\phi\left((1+k_{mi})^{-\rho}, \beta_{mi}\right)$ as a surplus from the market for information. The initial competition among contractors guarantees that the price for the task is $\tau_j = -\frac{\beta_{mi}\phi\left((1+k_{mi})^{-\rho},\beta_{mi}\right)}{n}$.

Third step (uniqueness): To show that the equilibrium described above is unique, let us first show that (1) there cannot be equilibria where some firms both invests and outsources and some others invest and do not outsource, (2) there cannot be equilibria where only a zero-measured set of firms invest, (3) there cannot be equilibria where a zero-measured set of firms do not invest. Points (1), (2) and (3) guarantee that in equilibrium the firms are always divided into two exaustive and positive-measured sets, the investing and the not investing firms, and all the investing firms invest the same amount and they do outsource. Then, in (4), I will show that the measure γ_{mi} that guarantees indifference between the two sets (as determined in the previous step) is uniquely identified.

(1) First of all, recall that if more than one firm invests and outsources, it must be the case they outsource from the same contractor. This implies that these firms invest exactly the same amount (as none of them is relevant to change the knowledge of the monopolistic contractor) of the not-outsourcing firms. Then, any of the not-outsourcing firms would have a profitable deviation in outsourcing. Suppose instead that there is exactly one firm, say firm i, that invest and outsources. In its optimal investment problem, firm i will have to take into account the fact that the monopolistic contractor the firm hires anticipates to learn information from i, and to leak it on the market for information (in the timing of the game we presented, the price paid for the task is not responsive to the investment decision of this contractor because it is posted simultaneously to the investment decision. Then, the optimal investment level of firm i is lower than the investment level of the others). Now, observe that in equilibrium the investing and not-outsourcing firms must have the same expected payoff as the non-investing firms. Firm i cannot be worse off than these two sets of firm (if this were the case, it would have a profitable deviation in not outsourcing and investing more). Also, firm i cannot be better off than these two sets of firms (if this were the case, any investing and not-outsourcing firm would have a profitable deviation in following the same strategy of firm i). Then, firm i must get the same payoff as the two sets of firm. It is easy to verify that such indifference can occurr in equilibrium only for a zer-measured set of parameters of the model.

(2) Recall that for $s < \overline{s}$ we have $\pi_{\mathcal{I}}(0) > \pi_{\mathcal{N}\setminus\mathcal{I}}(0)$, so if a zero-measured set of firms invest in equilibrium, one of the other firms would have a profitable deviation in investing (notice that this is true even if the set of investing firm includes only one firm, so for small s we can rule out an equilibrium in which *only one firm invests* and outsources). (3) Notice that if $s > 0$, then $\pi_{\mathcal{N}\setminus\mathcal{I}}(n-s) > \pi_{\mathcal{I}}(n-s)$, as if a $(n-s)$-measured set of firms invest, a firm would have a profitable deviation in waiting for the spill.

(4) To guarantee that γ is uniquely determined, it is enough to show that the functions $\pi_{\mathcal{N}\setminus\mathcal{I}}(\gamma)$ and $\pi_{\mathcal{I}}(\gamma)$ cannot cross twice. To see this, observe that, by the Envelope

theorem, we have

$$\frac{d\pi_{\mathcal{I}}(\gamma)}{d\gamma}=\frac{\partial A(\gamma)}{\partial\gamma}c^{*}(\gamma)^{-\frac{\alpha}{1-\alpha}}$$

and

$$\frac{d\pi_{\mathcal{N}\backslash\mathcal{I}}(\gamma)}{d\gamma}=\frac{\partial A(\gamma)}{\partial\gamma}K(\gamma)+A(\gamma)\frac{\partial K(\gamma)}{\partial\gamma}$$

where $K(\gamma)\equiv 1+\frac{s}{n-\gamma-\beta^{*}(\gamma)}\left(c^{*}(\gamma)^{-\frac{\alpha}{1-\alpha}}-1\right)$. Notice that $\frac{\partial A(\gamma)}{\partial\gamma}=\frac{\partial A(\gamma)}{\partial(\gamma+\beta^{*}(\gamma))}\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}$ and $\frac{\partial K(\gamma)}{\partial\gamma}=\frac{\partial K(\gamma+\beta^{*}(\gamma))}{\partial(\gamma+\beta^{*}(\gamma))}\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}$. After some algebraic manipulations, one can see that $\frac{\partial A(\gamma)}{\partial(\gamma+\beta^{*}(\gamma))}<0$ and $\frac{\partial K(\gamma+\beta^{*}(\gamma))}{\partial(\gamma+\beta^{*}(\gamma))}>0$. Moreover, notice that it must be the case that $\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}>0$ for all γ (to see this, suppose $\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}<0$ for some interval of γ, and notice that in that interval it should be the case that $\frac{k(\gamma)}{\partial\gamma}>0$, which, together with $\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}<0$, would imply that for a positive change of γ the function $\varphi(\beta)=\frac{E(1-\alpha)\left[c^{\frac{-\alpha}{1-\alpha}}-1\right]}{(\gamma+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n}$ shifts upward, which would imply β^{*} to increase, which is in contradiction with $\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}<0$). All these considerations imply that $\frac{d\pi_{\mathcal{I}}(\gamma)}{d\gamma}<0$ and that for all $\gamma\in[0.n]$ we have

$$\begin{aligned}\frac{d\pi_{\mathcal{N}\backslash\mathcal{I}}(\gamma)}{d\gamma} &> \frac{\partial A(\gamma)}{\partial(\gamma+\beta^{*}(\gamma))}\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}K(\gamma+\beta^{*}(\gamma))\\ &> \frac{\partial A(\gamma)}{\partial(\gamma+\beta^{*}(\gamma))}\frac{\partial(\gamma+\beta^{*}(\gamma))}{\partial\gamma}c^{*}(\gamma)^{-\frac{\alpha}{1-\alpha}}\\ &= \frac{d\pi_{\mathcal{I}}(\gamma)}{d\gamma}\end{aligned}$$

which guarantees that $\pi_{\mathcal{N}\backslash\mathcal{I}}(\gamma)$ and $\pi_{\mathcal{I}}(\gamma)$ cannot cross twice■

Proof of Proposition 9: Let us show first that if $s=0$ it is impossible to have a monopolistic market for information in equilibrium. Let γ be the measure of investing firms and β be the measure of firms that buy the information from a contractor j. The willingness to pay of a non-investing firm for a technology c reachable with investment k is

$$\phi(c,\beta)=\frac{E(1-\alpha)}{(\gamma+\beta)\left[\underline{c}^{\frac{-\alpha}{1-\alpha}}-1\right]+n}\left[(1+k)^{\frac{\alpha\rho}{1-\alpha}}-1\right]$$

where $\underline{c}$ is the level of technology adopted by the investing firms and the other buying firms and reachable with the investment $\overline{k}$. In equilibrium any investing firms invests k such that

$$\frac{E\alpha\rho}{(\gamma+\beta)\left[\left(1+\overline{k}\right)^{\frac{\alpha\rho}{1-\alpha}}-1\right]+n}(1+k)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}=1 \tag{9}$$

Notice that in equilibrium all the investing firms adopt the same technology. This implies that $k=\overline{k}$. Keeping $\overline{k}$ constant, it is possible to integrate the LHS of (9) with respect to k between 0 and $\overline{k}$. We have

$$\begin{aligned}
\varphi\left(\beta,\overline{k}\right) &= \frac{E(1-\alpha)\left[\left(1+\overline{k}\right)^{\frac{\alpha\rho}{1-\alpha}}-1\right]}{(\gamma+\beta)\left[\left(1+\overline{k}\right)^{\frac{\alpha\rho}{1-\alpha}}-1\right]+n} \\
&= \int_0^{\overline{k}}\frac{E\alpha\rho}{(\gamma+\beta)\left[\left(1+\overline{k}\right)^{\frac{\alpha\rho}{1-\alpha}}-1\right]+n}(1+v)^{\frac{\alpha\rho-1+\alpha}{1-\alpha}}dv \\
&> \overline{k}
\end{aligned}$$

where the last inequality is guaranteed by identity (9), by $k=\overline{k}$, and by the fact that the LHS of (9) is decreasing in k (as guaranteed by Assumption 1). This guarantees that if $s=0$ investing in technology always strictly dominates buying a technology from a monopolistic contractor.■

Proof of Proposition 10: The fact that k_0 is the minimal investment level comes from the fact that when the measure of investing firms is maximal, i.e. $\gamma=n$, the marginal return on the investment is the minimum possible, and so is the investment level. To show that $k_n>k_{mi}$, let us first show that $\gamma_n<\gamma_{mi}+\beta_{mi}+\sigma$. To show it, recall that the condition defining γ_n is

$$A(\gamma_n)\left(1+k^*(\gamma_n)\right)^{\frac{\alpha\rho}{1-\alpha}}-k^*(\gamma_n)-t=A(\gamma_n) \tag{10}$$

Let us define a function $\Psi:[0,n]\rightarrow R$ as follows

$$\Psi(x)\equiv A(x)\left(1+k^*(x)\right)^{\frac{\alpha\rho}{1-\alpha}}-k^*(x)-A(x)\left[\frac{s}{n-x+s}\left(1+k^*(x)\right)^{\frac{\alpha\rho}{1-\alpha}}+\frac{n-x}{n-x+s}\right]$$

Observe that from condition (8) we have $\Psi(\gamma_{mi} + \beta_{mi} + s) = 0$. Since $\Psi(0) > 0$ and $\Psi(n) < 0$, if $\Psi(\gamma_n) > 0$, then $\gamma_{mi} + \beta_{mi} + s > \gamma_n$. However, if s is small enough, by (10) we have

$$\begin{aligned}
\Psi(\gamma_n) &= A(\gamma_n)(1 + k^*(\gamma_n))^{\frac{\alpha\rho}{1-\alpha}} - k^*(\gamma_n) \\
&\quad - A(\gamma_n)\left[\tfrac{s}{n-\gamma_n+s}(1 + k^*(\gamma_n))^{\frac{\alpha\rho}{1-\alpha}} + \tfrac{n-\gamma_n}{n-x+s}\right] \\
&> A(\gamma_n)(1 + k^*(\gamma_n))^{\frac{\alpha\rho}{1-\alpha}} - k^*(\gamma_n) - t \\
&\quad - A(\gamma_n)\left[\tfrac{s}{n-\gamma_n+s}(1 + k^*(\gamma_n))^{\frac{\alpha\rho}{1-\alpha}} + \tfrac{n-\gamma_n}{n-x+s}\right] \\
&= A(\gamma_n) - A(\gamma_n)\left[\tfrac{s}{n-\gamma_n+s}(1 + k^*(\gamma_n))^{\frac{\alpha\rho}{1-\alpha}} + \tfrac{n-\gamma_n}{n-x+s}\right] \\
&\rightarrow 0
\end{aligned}$$

which guarantees $\Psi(\gamma_n) > 0$. Since $\gamma_n < \gamma_{mi} + \beta_{mi} + \sigma$, the claim $k_n > k_{mi}$ follows from the fact that in equilibrium, if x is the measure of firms adopting a technology reached by k^*, we have $\frac{dk^*(x)}{dx} < 0$■

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