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Inés Macho-Stadler
David Pérez-Castrillo
Reinhilde Veugelers

Licensing of University Inventions:

The Role of a Technology Transfer Office

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[1] **Inés Macho-Stadler**
[1] **David Pérez-Castrillo**
[2] **Reinhilde Veugelers**

[1] *AUTONOMOUS UNIVERSITY OF BARCELONA*
[2] *CATHOLIC UNIVERSITY OF LOUVAIN*

Abstract

We provide a theoretical model which helps to explain the specific role of TTOs. Using a framework where firms have incomplete information on the quality of inventions, we develop a reputation argument for the TTO to reduce the asymmetric information problem. Our results indicate that a TTO is often able to benefit from its capacity to pool innovations across research units (and to build a reputation) within universities. It will have an incentive to "shelve" some of the projects, thus raising the buyer's beliefs on expected quality, which results in fewer but more valuable innovations being sold at higher prices. We explain the importance of a critical size for the TTO in order to be successful as well as the stylized fact that TTOs may lead to fewer licensing agreements, but higher income from innovation transfers.

Key words

Industry-science relations; technology transfer offices; technology licensing.

Resumen

Proponemos un modelo teórico que ayuda a explicar el papel de las Oficinas de Transferencia de Tecnología (OTRI). Utilizando un marco en el que las empresas tienen información incompleta respecto a la calidad de las innovaciones, desarrollamos un argumento de reputación por el que las OTRI reducen el problema de asimetría de información. Nuestros resultados indican que una OTRI es capaz de aprovechar su capacidad para agrupar innovaciones de los distintos centros de investigación (y construir una reputación) en su universidad. Tendrá incentivos para "archivar" algunos de sus proyectos, aumentando de este modo las creencias del comprador sobre la calidad esperada, lo que le llevará a vender menos pero mejores innovaciones, a un precio más elevado. Explicamos la importancia del tamaño mínimo para que una OTRI sea exitosa así como el hecho estilizado de que una OTRI puede llevar a menos contratos de licencias pero a mayores ingresos por las trasferencias de tecnología.

Palabras clave

Relaciones industria-ciencia; oficinas de transferencia de tecnología; licencia de tecnología.

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C O N T E N T S

1. Introduction

THEORETICAL and empirical work in innovation economics suggests that setting up and maintaining good industry-science relations positively affects innovation performance [1]. The link with scientific knowledge is especially important in fast growing technologies like biotechnology, information technology and new materials.

Empirical evidence shows an intensification of the interactions between universities and industry (e.g. Branstetter, 2003 and 3rd E.U. report on S&T indicators, 2003). But despite the surge in industry-science interactions, the empirical evidence is equally clear on showing significant institutional barriers to the commercialization of basic research (OECD, 2001 and E.U., 2002). This has lead to an undersupply of university-industry transfers, which often remain furthermore geographically restricted (Jaffe *et al.*, 1993 and Audretsch & Stephan, 1996). Thursby & Thursby (2002) describe the growth in commercial activities from universities as being mainly growth in patent applications, less in terms of disclosures and even negative in terms of licenses executed [2]. Thursby & Kemp (2002) use a Data Envelop Analysis framework to study the productivity of university licensing. They find substantial evidence of inefficiencies across universities which, despite the growth in commercial activities, seem to persist over time.

Fuelled by the notion that smooth interaction between science and industry is important but not obvious for the success of innovation activities and ultimate economic growth, industry-science links (ISL) have

1. See Adams (1990), Rosenberg & Nelson (1994), Mansfield & Lee (1996), Mansfield (1991), (1996) and (1998), Henderson *et al.* (1998), Branscomb *et al.* (1999), and OECD (2002).

2. The recent surge in university patenting in the U.S. is partly attributed to the Bayh-Dole Act of 1980, which gave the universities the right to license inventions from federally funded research. See the analysis of Henderson et al. (1998), Mowery & Ziedonis (2000), Mowery *et al.* (2001), Hall *et al.* (2000), Nelson (2001) and Sampat *et al.* (2003). See also Decheneux *et al.* (2003) on the importance of the effectiveness of intellectual property rights for firms to engage in industry-science links.

become a central concern in many government policies in recent years. Major benchmarking exercises have been set up in the E.U. in search of effective practices to improve the commercialization of the E.U. science base (Polt, 2001). In the U.S. too, the search for good practices in ISL has received ample attention (see e.g. Branscomb *et al.,* 1999 and Siegel *et al.,* 2003). These studies identify the importance of an appropriate governance and incentive structure within science institutions to gear academic R&D toward exploitation avenues.

In terms of *organizational structure,* creating a specialized and decentralized *technology transfer office (TTO)* within the university is often viewed as instrumental for developing relations with industry. A dedicated transfer unit allows for specialization in supporting services, most notably management of intellectual property and business development. There is however the issue of scale, as smaller universities often lack the resources and technical skills to effectively support such organizational arrangements and investments. At the same time, a separate unit needs to be able to maintain close enough relationships with the researchers in different departments, and have the proper incentive mechanisms in place to ensure generation and disclosure of inventions by the researchers to the *TTO*.

In this paper, we show that, beyond the classical economies of scale in supporting services, a university wide *TTO* can be instrumental in reducing the asymmetric information problem typically encountered in the scientific knowledge market. This problem of asymmetric information has been identified as critical in the market for scientific know-how. We present a model on how the *TTO* can help to alleviate it.

Using a repeated model in a framework where firms it have incomplete information on the quality of inventions, we develop a reputation argument for a *Technology Seller* to reduce the asymmetric information problem. The *Technology Seller,* keen to maintain a good reputation, may have an incentive to "shelve" some of the (bad) projects, thus raising the buyer's beliefs on expected quality, which results in fewer but more valuable inventions being sold at higher prices. We show that when the stream of inventions is slow, no reputation can be built. For intermediary values of the stream of inventions, reputation helps to realize some technology transfers at higher profits. The seller will guarantee a minimum quality of the invention transferred. He will refrain from lying about the quality of the invention, given the future value of reputation. The average quality offered by the seller induces firms to adopt the technology, but some non-profitable inventions are transferred. The quality guaranteed increases along with the stream of inventions. When the stream of inventions is large enough, the first best outcome is achieved since only profitable inventions are transferred.

In our model, a *TTO* can be interpreted as a *Technology Seller* pooling inventions from several research labs within the university. Our results indicate that a TTO is often able to benefit from this pooling capacity and to build a reputation. This is the case when the total innovative activity of the university is large enough, but each research lab is not so large that it is able to build a reputation by itself. However, when the stream of inventions of each research lab is too small and/or the university has just a few of them, even the *TTO* will not have enough incentives to maintain a reputation. We thus explain the importance of a critical size for the *TTO* in order to be successful. We also predict, consistent with the empirical evidence, that a *TTO* may lead to fewer licensing agreements, but higher revenue from invention transfers.

After a literature review in Section 2, Section 3 presents the model and analyzes the situations where reputation can alleviate the asymmetric information problem regarding invention quality. In Section 4, we present the advantages of a *TTO* in the light of the results of the previous section. Section 5 considers the robustness of the result when there is also asymmetric information about the cost to firms of adopting the invention. Section 6 provides concluding remarks. Proofs are included in an Appendix.

2. Literature review

OUR model adds to a recently emerging literature on the organization and performance of university-industry technological transfers. A major problem identified in the literature is the difficulty encountered by the universities to induce researchers, first, to disclose their inventions and, second, to cooperate in further development after the license agreement. Although the Bayh-Dole Act stipulates that scientists must file an invention disclosure with the university, this rule is rarely enforced. Instead, the university needs to have proper license contracts in place as an incentive scheme, specifying a share for the inventors in royalties or equity. This problem is studied in Macho-Stadler *et al.* (1996) and Jensen & Thursby (2001), looking at the moral hazard problem with respect to inventor cooperation in commercialization, and in Jensen *et al.* (2003) with respect to inventor disclosure. Lach & Schankerman (2003) provide strong empirical support for the importance of inventor's royalty shares for university performance in terms of inventions and licence income. They also find that private universities which have higher inventor shares have higher license income, suggesting a Laffer curve effect. The incentive effect seems to work both through the level of effort and the sorting of researchers.

But even when the disclosure problem is remedied through appropriate incentive schemes, not all inventions will be patented and licensed by the university. This relates to the problem of asymmetric information between industry and science on the value of the inventions. Firms can typically not assess the quality of the invention ex ante, while researchers may find it difficult to assess the commercial profitability of their inventions. The literature on markets for technology suggests the use of a menu of fixed fees and royalties or equity to signal the quality of the invention or to separate bad applications of the technology from good ones (Gallini & Wright, 1990, Macho-Stadler & Pérez-Castrillo, 1991, and Beggs, 1992).

Hoppe & Ozdenoren (2002) present a theoretical model to explore the conditions under which innovation intermediaries emerge to reduce the uncertainty problem. Intermediaries may have an incentive to invest in expertise to locate new inventions and sort profitable from unprofitable ones. The sunk costs to acquire this expertise can be overcome if the size of the invention pool is large enough, such that the intermediary can exploit economies of sharing expertise. While the intermediary will reduce the uncertainty problem, nevertheless the authors still find a high probability of inefficient outcomes due to coordination failure. This type of model builds further on the broader literature on intermediation to solve the problem of asymmetric information on product quality between sellers and buyers. Biglaiser (1993) uses an informal reputation argument, which induces infinitely lived middlemen to honor their warranties. Lizzeri (1999) investigates to which extent an intermediary can serve as a certification agency signalling quality, taking into account the potential for information manipulation.

Surprisingly, the organizational structure of technology transfers within science institutions has received little attention in the literature. Bercovitz *et al.* (2001) on a sample of U.S. universities nevertheless provide evidence of the importance of the organizational structure within the university for linking up with industry to explain university performance in terms of patents, licensing, and sponsored research. Universities with a strong record in ISLs most often apply a decentralized model of technology transfer, i.e. the responsibilities for transfer activities are located close to the level of researcher groups and individuals, often through a dedicated *TTO*. Nevertheless, a wide variation in *TTO* efficiency seems to exist. A majority of universities, even those with a *TTO,* do not succeed in securing a positive net income from their intellectual property (Nelsen, 1998 and OECD, 2002). Further evidence from the U.S. in terms of good practices for technology transfer units is provided in Siegel *et al.* (2003). Using a stochastic frontier estimation on AUTM data on 133 universities, the authors find constant returns to scale of *TT*O size with respect to licensing activity, but increasing returns to scale with respect to licensing revenue. Qualitative survey evidence complements their search for organizational practices that increase the productivity of *TTO*s, such as the university's royalty and equity distribution schemes and the quality of the *TTO* staff, mixing lawyers, scientists and entrepreneurs/businessman that are capable of serving as a bridge between firms and scientists.

3. Model

3.1. Model setup

We consider a model of technology transfer between a research institute and the industry. In the remainder we will label the research institute as a university [3]. A university has a technology seller *TS*, infinitely lived. The *TS* may be a research lab itself with a sufficiently large stream of inventions to offer. It may also be a dedicated *TTO* that is able to pool inventions across research labs [4]. In the basic set-up, the *TS* in the university establishes the terms of the technology transfer of any new invention.

We assume that the *TS* has available a sequence of successful inventions at different dates t. It receives only one invention per period. The quality q_t of the invention available at period t is ex-ante uncertain, $q_t \in [0, Q]$. This is in accordance with university inventions being often proof of concepts and lab-scale prototypes. The *TS* learns the quality of the invention once it is available. The quality follows a distribution function $F(.)$, invariant in time, whose density function is $f(.)$, with $f(q) > 0$ for all $q \in [0, Q]$. We will denote by q^e the expected (average) quality:

$$q^e = \int_0^Q q f(q) dq$$

3. Since we only consider the license revenues as the objective function of the university, we can treat universities identically to any other private or public research institute. We ignore the specific trade-off which the university faces, balancing its teaching and basic research with applied research.

4. For the moment we assume no specific advantages or costs for the *TTO* over individual researchers or research labs, meaning that at this stage in the analysis we can interchange both interpretations for the *TS*.

Inventions cannot be commercialized by the *TS* [5]. There is a market for the inventions, where firms are ready to commercialize them. We assume that an invention is transferred to a single firm and that each invention is transferred to a different one [6]. A firm obtains gross profits βq_t when commercializing an invention of quality q_t, with $\beta > 0$. The cost of adopting an invention is a. In order to have a well-defined problem, we assume that at least the best invention is profitable: $0 < a < \beta Q$. The costs of commercializing an invention are included in the parameter β associated to the invention. In the basic model, the parameters a and β are taken to be public information. Section 5 treats the case of private information.

We assume that the technology-transfer contract takes the form of a share in running profits, that is, the *TS* will ask for a share s of the firm's gross profits from the invention [7]. Hence, in a given period, the profits of the *TS* with an invention of quality q that transfers this invention to a firm are:

$$R = s\beta q,$$

while the firm's profits are:

$$\pi = (1 - s)\ \beta q - a$$

We denote the discount rate by $\delta \in [0, 1]$. Our main interpretation of the discount rate is as a measure of the frequency with which the *TS* obtains inventions. If a long period is necessary for the *TS* to obtain a new invention then δ will be small, while when there is a smooth flow of new inventions, δ will be large. In this sense, we interpret different levels for

5. Although the model is not specifically set up to study universities' own commercialization activities through spin-offs, the analysis of spin-offs would nevertheless be along similar lines considering that university spin-offs need private venture capital partners to be able to commercialize their inventions (see e.g. Chan, 1983).

6. Firms are hence short-run players.

7. According to Feldman *et al.* (2002), taking equity positions is one important emerging mechanism for innovation transfer from universities to firms. If we ignore the possible output distortion induced by royalties through their effect on the marginal cost of production, this specification, see also Hoppe and Ozdenoren (2002), covers not only equity contracts, but also royalties (fees per unit of output sold); the two most frequently used licensing methods for university inventions (Jensen & Thursby, 2001 and Jensen *et al.*, 2003). Additionally, Jensen & Thursby (2001) present some empirical evidence showing the dominance of license revenues as a *TTO* objective over alternative measures like the number of patents, the number of inventions commercialized or the number of licences executed.

the discount rate as reflecting different levels of *TS* "size". A "big" *TS* is able to obtain inventions more frequently and hence will have a higher δ. In addition, we can interpret the setting up of a dedicated technology transfer office within the university as offering the benefit of pooling the inventions of individual research labs. From this perspective, the advantage of having a common *TS* (what we could label as a *TTO*) is the possibility at having more frequent inventions to sell than individual *TS*s. We will discuss the case of the *TTO* more extensively in Section 4.

We assume that the *TS* has all the bargaining power in the determination of the licensing contract. This implies that the *TS* makes a take-it-or-leave-it-offer to the firm. The results will be robust to other specifications of bargaining power.

As a first benchmark, we show the outcome when information is perfect. Under *perfect information,* when the *TS* and the firm observe the quality of the invention, the optimal contract at a given period t is determined by two properties: (a) only profitable inventions are sold, where profitable means that this invention does not lead to losses at the commercialization stage; and (b) for profitable inventions, the firm's participation constraint is binding: $\pi = (1 - s)\ \beta q - a = 0$. The contract takes the form:

$$s_t^* = 1 - \frac{a}{\beta q_t} \text{ for } \beta q_t \geq a,$$

and no invention is sold when $\beta q_t < a$ (even if these inventions were free the firm would not wish to commercialize them).

Our second benchmark is the situation where there is *imperfect information* on the quality of the invention, that is, when only the *TS* observes the quality, but there is only invention at *one period* (equivalently, $\delta = 0$). In this case, the invention is sold if its *expected quality* is high enough, i.e., if the invention is profitable in expected terms. When the *TS* can sell the invention, the optimal contract is also determined by the firm's participation constraint in expected terms: $(1 - s)\ \beta q^e - a = 0$. Indeed, the *TS* is interested in selling any (good or bad) invention, so the expected quality of the proposed invention is q^e [8]. Hence, the optimal contract is:

8. Note that there is no room for signalling in this model in the one-shot game. All the innovations are "pooled" and firms commercializing the innovation are only willing to pay the share corresponding to the expected quality of the innovation.

$$s^I = 1 - \frac{a}{\beta q^e} \text{ for } \beta q^e \geq a,$$

and no invention is sold for $\beta q^e < a$. When the expected quality is high enough, all inventions, profitable or not, will be sold. When the invention process is such that the invention is not profitable in the expected terms, no invention will be sold. In the case $\beta q^e < a$, there are also equilibrium contracts, equivalent for the *TS,* in which the *TS* sells the best inventions at $s^I = 0$ by guaranteeing that the invention has at least quality q^I, $\beta E\,[q \,/\, q \geq q^I] \geq a$. Given that $s^I = 0$, the *TS* has no incentive to lie since no revenue can be obtained.

We now consider the *repeated game under imperfect information* where the TS has one invention at each period *t* and it cares about earning revenues from the stream of inventions ($\delta > 0$). We note that without reputation the only possible contract is s^I for all q [9]. We will show under what conditions the *TS* can build up a reputation for honesty. Also, we will analyze how this changes the quality of the inventions sold and the shares charged.

We assume that a firm that buys an invention observes the quality of the invention when adapting it and will make this information public [10]. This means that, before taking the decision whether to buy an invention at period *t,* the firm knows the quality of (and the contracts signed for) the inventions sold by the *TS* to other buyers at any period before *t.* This flow of information to the market is the mechanism that may allow the *TS* to build up a reputation by affecting the beliefs about its honesty when transferring the invention.

In what follows, we will be looking at the *Perfect Bayesian Equilibria* (BPE) of the infinite-horizon model. In particular, we will concentrate on a particular type of equilibrium which is simple and very intuitive. We

9. Given that only the *TS* knows the quality of the innovation before licensing it and we do not consider a repeated game between the *TS* and a firm, since each firm only buys once, honesty cannot be achieved by a mechanism where the firm can punish a deviation by the *TS* in the future through not buying.

10. This is the simplest set-up, requiring that true quality is revealed ex post to the buyer and that all potential technology buyers keep track of the *TTO*'s performance. Similar results can be obtained assuming that the market learns about the true quality of the innovation only with a certain probability. However in these cases, reputation will be a less powerful force.

will analyze the equilibria where the *TS* guarantees a certain quality for the invention (i.e., the *TS* "assures" the firm that the invention is at least as good as a certain quality threshold), and the firm believes the *TS* except if the *TS* has lied in the past. If the *TS* lied at any date before t then the firm believes that the *TS* will sell any invention (hence, the expected quality of the invention is q^e). Since we are looking for equilibria where the *TS* only "commits" to any offered invention being above the threshold, all such inventions will invariably be offered under the same contract. There are, of course, other types of equilibria. For example, the repetition of the static contract s^I and no reputation is another possible equilibrium of the dynamic game. Also, there are other equilibria where the *TS* can build a reputation.

In order to solve the sequential problem, where the *TS* can build up a reputation, we concentrate on *stationary equilibria,* i.e., on contracts that do not depend on the period but only on the quality of the invention. The contracts will take the following form:

$$s_t = s^o \text{ for } q_t \in [q^o, Q],$$

and no contract will be offered if $q_t \in [0, q^o)$. These contracts set a profit-sharing rule and "guarantee" a minimum quality for the invention [11]. Note that a big advantage of the type of contracts proposed is that they are very easy to implement (almost bureaucratic): at the onset, the *TS* sets the share s^o it will ask for any invention it offers, (this sharing rule can also be decided at the university level); then the *TS* will only have to determine at each period whether to sell the invention.

To induce honesty, that is, to be an equilibrium of the sequential game, the contract (s^o, q^o) has to be such that the *TS* has no incentive to lie to the firm. We denote by V the ex-ante value of the relationship for the TS in an honest equilibrium when the contract is (s^o, q^o):

$$V = s^o \beta \int_{q^o}^{Q} q f(q)\, dq + \delta V.$$

11. We restrict attention to this class of contracts because looking for the optimal contract $(s(q), q)$ seriously increases the computational complexity and requires identifying functional forms. The optimal contract would not have a constant sharing rule for all quality levels. A rough way of capturing this non-linearity is to impose two regimes on the sharing rule: 0 and s^o.

Then, we can obtain

$$V = \frac{1}{(1-\delta)} s^o \beta \int_{q^o}^{Q} q f(q)\, dq. \tag{3.1}$$

The *Incentive Compatibility Constraint* requires that the *TS* has no incentive to try to sell the invention when its quality is lower than q^o. This constraint can be written as:

$$\delta V \geq s^o \beta q + \frac{\delta}{(1-\delta)} s^I \beta q^e \text{ for all } q \in [0, q^o).$$

In other words, no profit today plus the future value of the reputation is higher than the short-term profits of cheating but destroying the reputation for the future. Cheating implies selling any future invention at the profit share that corresponds to the expected quality: s^I, where for notational convenience we use $s^I = 0$ when the *TS* does not sell under asymmetric information. Note that the inequality is less likely to be satisfied the higher the value of q, that is, the inequality holds for all q if and only if it holds for $q = q^o$. Hence, we can write this condition as:

$$\delta V \geq s^o \beta q^o + \frac{\delta}{1-\delta} s^I \beta q^e. \tag{3.2}$$

We will look for the optimal contract (the threshold quality q^o and the sharing rule s^o) that maximizes the *TS* payoff V among the contracts that are compatible with equilibrium behavior (i.e., the *TS* must not have incentives to cheat on quality, and the firm must obtain non negative profits).

3.2. Solving the model

We will distinguish two cases: $\beta q^e < a$ and $\beta q^e \geq a$

3.2.1 (a). $\beta q^e < a$

In the case when the expected quality of the inventions is low, $\beta q^e < a$, then no invention is sold in a static set up. Taking into account (3.1), condition (3.2) leading to honest behavior can be rewritten as:

$$\frac{\delta}{(1-\delta)} s^o \int_{q^o}^{Q} qf(q)dq \geq s^o q^o. \tag{3.3}$$

Note that the incentive compatibility constraint does not depend on s^o, when $s^o > 0$. The contract offered by the *TS* must also satisfy the *participation constraint* for the firm that commercializes the invention at period *t*. Since the firm, being a short-run player, is unconcerned about future payoffs, at any equilibrium each period's choice of adopting the invention has to be a best response to the expected behavior of the *TS*. Given the equilibrium beliefs that the quality of the invention offered by the *TS* is at least q^o, the participation constraint for the firm is:

$$(1 - s^o)\ \beta E\ (q\ /\ q \geq q^o) \geq a, \tag{3.4}$$

where

$$E(q / q \geq q^o) = \frac{1}{(1-F(q^o))} \int_{q^o}^{Q} qf(q)dq$$

is the expected quality of an invention whose quality is higher than the threshold q^o. The participation constraint asks for the *TS* to set s^o and q^o in such a way that the firm does not make expected losses in equilibrium.

In order to present the optimal contract in the class of contracts we are considering, we will simplify the expressions from now on, using the notation $A = a/\beta$. Let us define the following values:

- $\hat{q} \in [0,Q)$ is implicitly defined by $\hat{q} = \frac{\delta}{1-\delta} \int_{\hat{q}}^{Q} qf(q)dq$
- $\tilde{q} \in [\hat{q},Q)$ is implicitly defined by $\int_{\tilde{q}}^{Q} qf(q)dq = (1-F(\tilde{q}))A.$

Proposition 1. *Assume* $A > q^e$. *Then, there exist* δ_1 and δ_2, *with* $0 < \delta_2 < \delta_1 < 1$, *such that:*

1. *For* $\delta \in [0, \delta_2]$, *the TS either does not transfer any invention or it transfers for free the invention guaranteeing a quality between* $\tilde{q}$ *and Q. That is,* $q^o \in [\tilde{q}, Q]$ *and* $s^o = 0$.

2. *For* $\delta \in (\delta_2, \delta_1)$, *the optimal contract guarantees a positive quality* $q^o = \hat{q}$, *which is increasing with* δ, *lower than A. It sets* $s^o = 1 - \dfrac{A}{E(q / q \geq \hat{q})} > 0$, *which is also increasing in* δ.
3. *For* $\delta \in [\delta_1, 1]$, *the optimal contract guarantees that the quality is at least* $q^o = A$ *and sets* $s^o = 1 - \dfrac{A}{E(q / q \geq A)} > 0$.

Proposition (1) presents the characteristics of the contract for a given $A = a/\beta$ as a function of the parameter δ, when A is larger than q^e. Remember that in this case no invention is sold, or at zero price, if we consider a one-period situation with imperfect information (or an equilibrium where the *TS* is not building any reputation). When the information is imperfect, but the *TS* is able to build a reputation concerning the quality of the invention it is offering, Proposition (1) distinguishes three different regions concerning the best contract that the *TS* can achieve.

If the discount rate is very low (region 1), there is no reputation building: the invention is never sold, or it is offered for free [12]. This is the situation of those *TS* whose stream of inventions is not very large, for instance, because a laboratory is not so big as to produce a continuous sequence of inventions, or because it is the *TTO* of a small university. In this case, the *TS*'s expected future profits are low. This means that the incentives for the *TS* to cheat at any period are very strong since it does not lose much by lying: the expected future benefits if it keeps a good reputation are low. In fact, there is no incentive-compatible contract where the share is positive. The only possible contract involves selling (high-quality) inventions for free, or not selling inventions at all.

If the parameter δ has an intermediate value (region 2), reputation helps to realize at least some technology transfers at a profit. The *TS* guarantees a certain quality threshold q^o, positive but smaller than *A*. Given this guaranteed threshold, the expected quality of the invention is

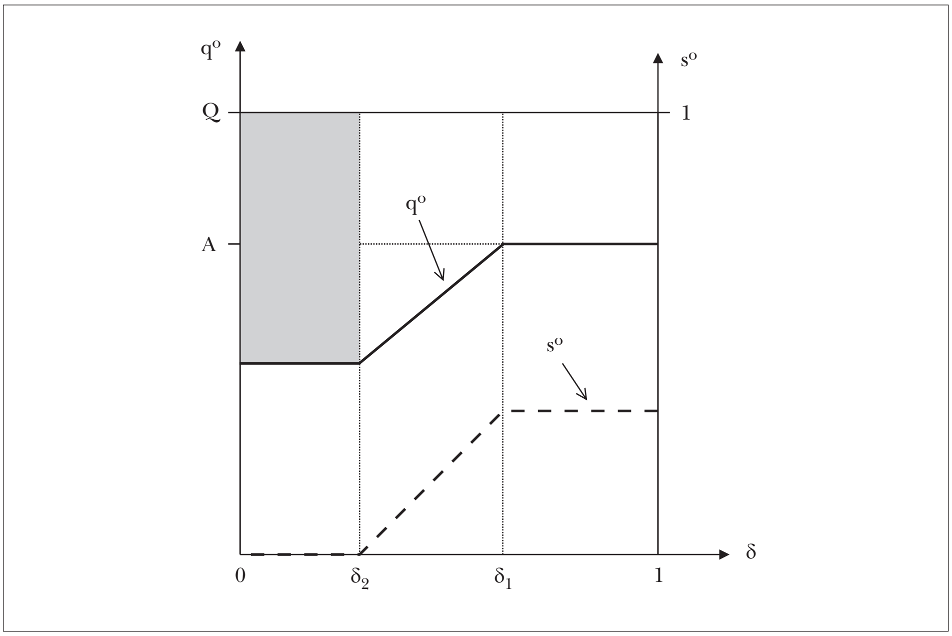
12. The OECD (2002) survey results indicate that a low number of transactions is quite common for many research organisations. E.g. the majority of sampled research organisations negotiate less than 10 licenses per year. In addition, only 20-40% of patents are licensed and only about half of these earn income. Note also that transferring ideas for free does not necessarily have to be interpreted as contracts with zero price, but rather as free information transmission through publications for instance.

higher than both q^e and A. Therefore, the firm is ready to adopt the technology (and pay some share of the profits to the *TS*). Notice that, at equilibrium, the threshold q^o is below A, hence some inventions which are sold turn out to be unprofitable.

Finally, if the discount rate is very large (region 3), the temptation for the *TS* to cheat is low. Since the *TS* will be able to sell many inventions in the future, losing the reputation of guaranteeing a certain quality would turn out very costly. Given that the *TS* is able to extract all the surplus, it is interested in the relationship being as efficient as possible. Hence, only profitable inventions (and they all are) are transferred to the market, i.e., $q^o = A$.

Figure 3.1 summarizes the results in Proposition (1).

FIGURE 3.1: **Contracts when $A > q^e$**



It is interesting to check how the optimal contract depends on the cost of adapting the invention (a) or the commercial attractiveness of the invention (β), both of which are analyzed through the parameter A. These comparative statics are the following:

Corollary 2. *Assume* $A > q^e$:

1. *If* $\delta \in [0, \delta_2]$ *then*

$$\frac{\partial s^o}{\partial A} = 0, \quad \frac{\partial q^o}{\partial A} > 0.$$

2. *If* $\delta \in (\delta_2, \delta_1)$ *then*

$$\frac{\partial s^o}{\partial A} < 0, \quad \frac{\partial q^o}{\partial A} = 0.$$

3. *If* $\delta \in [\delta_1, 1]$ *then*

$$\frac{\partial s^o}{\partial A} >< 0, \quad \frac{\partial q^o}{\partial A} > 0.$$

The effects have the expected direction. In the extreme case where no invention is sold in equilibrium because the discount rate is too low, $\delta \leq \delta_2$, marginally increasing the cost parameter does not matter much for the profit share, but the quality guaranteed by the *TS* needs to be higher for the firm to accept it. In the other extreme case, when the inventions are sold via the first-best contract, $\delta \geq \delta_1$, an increase in A leads to an increase in the quality guaranteed by the *TS* (in order for the contract to still be first best) and has an ambiguous effect on the profit share (the inventions sold are of higher quality, but the firm pays a higher adaptation cost). The most interesting case is for the intermediary values of the discount factor δ. In this region, the quality guaranteed does not depend on A while the profit share is decreasing in A. This allows the *TS* to extract a higher profit, making an honest reputation more valuable when inventions are more attractive.

3.2.2 (b). $\beta \boldsymbol{q}^e \geq \boldsymbol{a}$

Let us now consider the case in which the expected quality of the inventions is large: $q^e \geq A$. In this case, if the firm believes that the *TS* is offering any invention (because the *TS* lied in the past), it is ready to accept the invention if the share is lower or equal than $s^I = 1 - A \,/\, q^e$, which is the share that the *TS* will indeed offer. Since we are looking for a *PBE* where the *TS* does not cheat and only offers inventions of quality above a threshold q^o, the incentive compatibility constraint asks for the *TS* not to have an incentive to try to sell the invention when its quality is lower than q^o. The condition leading to honest behaviour (3.2) can be rewritten in this case as:

$$\frac{\delta}{1-\delta}\left[s^o\beta\int_{q^o}^{Q} qf(q)dq-(q^e-A)\right]\geq s^o\beta q^o. \tag{3.5}$$

As it is easy to see comparing equations (3.3) and (3.5), the *Incentive Compatibility Constraint* is more demanding when $q^e \geq A$ than when $q^e < A$. This is reflected in the term $\frac{\delta}{1-\delta}(q^e - A)$. Indeed, in this case reputation is more difficult to build because, in case of deviation, the *TS* is able to still sell the invention post-cheating at the profit share that corresponds to the expected quality, s^I, and hence will still obtain positive gains in the future when cheating. This implies that when the expected quality of inventions is high, reputation building matters less.

Proposition 3. *Assume $A \leq q^e$. Then there exist δ_3 and δ_4, with $0 < \delta_4 \leq \delta_3 <$ < 1, such that*

1. *For $\delta \in [0, \delta_4]$, the TS transfers any invention asking for a share $s^o = s^I$. That is, $q^o = 0$ and $s^o = 1 - \frac{A}{\bar{q}}$.*
2. *For $\delta \in (\delta_4, \delta_3)$, the optimal contract guarantees a positive quality, increasing with δ, lower than A, $q^o = \bar{q} \in (0, A)$, and sets*

   $$s^o = 1 - \frac{A}{E(q/q \geq \bar{q})} > 0,$$

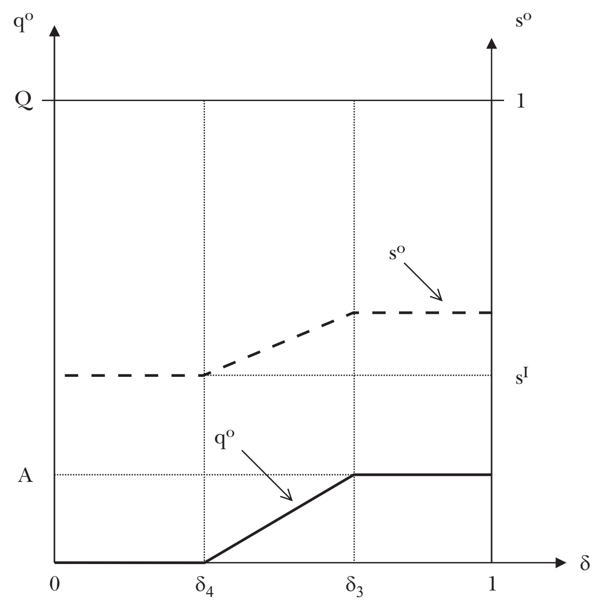
   also increasing in δ. This region does not always exist.
3. *For $\delta \in [\delta_3, 1]$, the optimal contract guarantees a quality $q^o = A$ and sets*

   $$s^o = 1 - \frac{A}{E(q/q \geq A)} > 0.$$

Proposition 3 summarizes the result when the average quality of the invention is high compared with its cost of being adopted by the firm. Again, given *A*, for very low δ no reputation can be built and all inventions are transferred at the static optimal equity share. As the discount rate δ increases, the inventions are less often sold but their average quality is higher, and hence the profits for the *TS* are also higher as compared to the no-reputation outcome. In this area, there are clear returns to reputation building by the *TS*. When δ is close to one the first best situation is achieved.

Figure 3.2 summarizes the results of Proposition (3).

FIGURE 3.2: Contracts when $A \leq q^e$



The next result summarizes how the optimal contract depends on the cost of adapting the invention or its commercial value.

Corollary 4. *Assume $A \leq q^e$:*

1. *If* $\delta \in [0, \delta_4]$ *then*

$$\frac{\partial s^o}{\partial A} < 0, \frac{\partial q^o}{\partial A} = 0.$$

2. *If* $\delta \in (\delta_4, \delta_3)$ *then*

$$\frac{\partial s^o}{\partial A} > 0, \frac{\partial q^o}{\partial A} > 0.$$

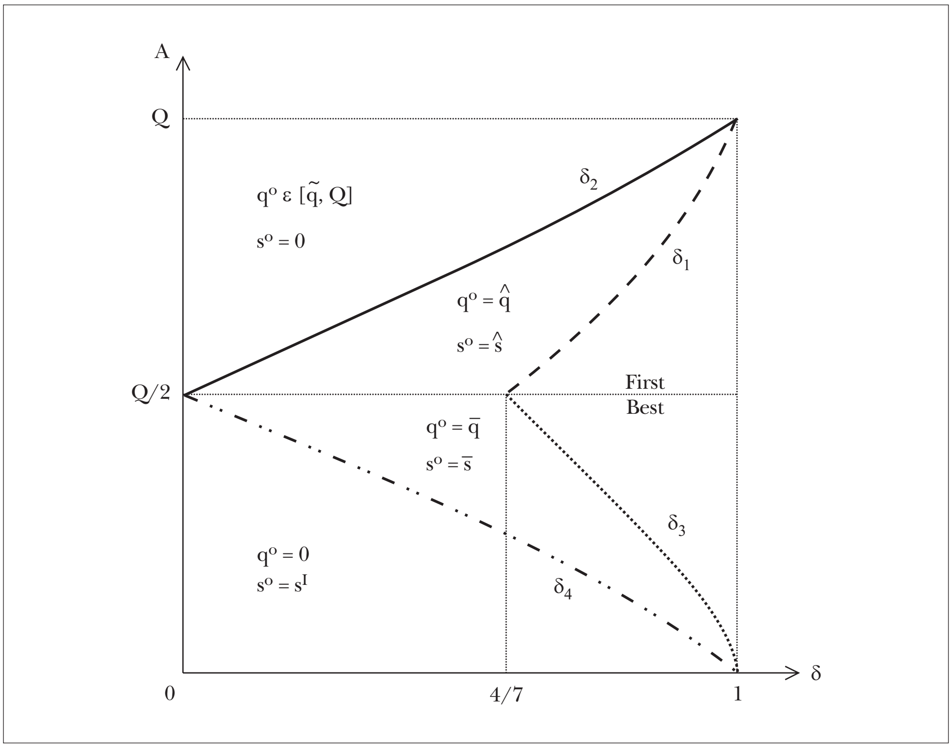
3. *If* $\delta \in [\delta_3, 1]$ *then*

$$\frac{\partial s^o}{\partial A} >< 0, \frac{\partial q^o}{\partial A} > 0.$$

The effects are as expected given that $A \leq q^e$. When there is no reputation (δ very small), all inventions are sold and the equity share is decreasing in the costs of commercialization of the invention and increasing in its value. For very high levels of δ, when reputation has a very high value, the first best is achieved. The quality guaranteed is increasing in A and the effect on the equity share is undetermined. For intermediate values of δ, the quality guaranteed by the *TS* increases with A and the equity share does too.

Figure 3.3 illustrates, in the (δ, A) space, the contracts that the *TS* offers as a function of the frequency of the inventions produced by the *TS* (represented through the discount rate parameter δ) and the cost/benefit parameter A. The figure is set for the case of a uniform distribution function over the possible qualities: $f(Q) = 1/Q$, for any $q \in [0, Q]$. Similar figures would be obtained for any other distribution function.

FIGURE 3.3: Contracts for the uniform distribution in the (δ, A) space



4. The role of a specialized Technology Transfer Office

IN this section we discuss how our results contribute towards explaining when it is beneficial for a University to have a specialized Technology Transfer Office and whether having a *TTO* improves the efficiency of the university licensing market. The model focuses on the advantage the *TTO* has in pooling projects across research labs within the university. From this perspective, the advantage of having a *TTO* is the possibility to have more frequent inventions to sell. Hence, increasing δ can be interpreted as having a larger pool of inventions available for the *TTO* as compared to individual *TS*s. Moreover, beyond the pooling effect, a *TTO* may also enjoy a higher δ compared to individual *TS*s, when its specialized personnel can actively screen research labs for projects that hold commercial potential. We ignore for the moment any other benefits the *TTO* might offer in terms of specialized services or capabilities that may directly improve the value of the invention (in the model by increasing q^e or β or reducing *a)* or reduce uncertainty about the value of the invention for firms [13]. Finally, we ignore any fixed costs of setting up a *TTO*. We will nevertheless discuss how the costs associated with the setting up of a *TTO* should be shared between the research labs.

For the sake of clarity, we start our discussion assuming a university with very similar research labs (*RL*), all of them with the same stream of

13. The model can also be used to discuss the effect of increasing the quality of the invention or its commercial value. A higher expected quality and/or a higher commercial value (a lower value for *A)* result in a higher probability of being in case (b) when reputation building is still present but less powerful as compared to case (a). Lower values for *A* also affect the optimal contract (s^o, q^o) as discussed in corollaries (2) and (4). Depending on the region, a lower value results in no effect or a lower q^o, while the effect on s^o is less clear-cut.

inventions. We use δ^R and δ^T to denote the discount rates representing the stream of inventions of, respectively, each *RL* and the *TTO*. Clearly, $\delta^T > \delta^R$, δ^T being much larger than δ^R if the number of *RL*s is very large.

When δ^T is low, i.e. the stream of inventions within the whole research organization is not large enough, ($\delta^T \leq \delta_2$) [14], having a *TTO* will not be enough to induce reputation building. A *TTO* achieves the same (inefficient) outcome as the *RL*s themselves. Hence, "very small" universities or universities with not very innovative departments do not gain from pooling innovations in a common *TTO*.

When δ^R is high ($\delta^R \geq \delta_1$) the stream of inventions of each individual *RL* is already so large that there is no incentive to pool inventions, given that "large" *RL*s are able to build a reputation by themselves and sell their inventions in an efficient way. This, however, may only be the case of very large *RL*s.

It is clear that in the two previous cases, with high δ^R or low δ^T, incurring the extra cost of having a *TTO* is not interesting for a university, unless the *TTO* is able to offer other advantages.

Most science-oriented universities are likely to be in the region where the size and inventive activity of the whole university is substantial enough so that δ^T is larger than δ_2 but each individual *RL* is not so large, hence δ^R is smaller than δ_1. In this situation, a *TTO* helps to sell the inventions in a more efficient and profitable way. A *TTO* will not try to sell all inventions. It will have an incentive to "shelve" some inventions, thus raising firms' beliefs on expected quality, which results in fewer, but more valuable inventions being sold at higher prices. Individual *RL*s, having too small a stream of inventions, do not have a similar incentive. They will either be unable to sell (in case $A > q^e$) or they will try to sell inventions of any quality. In this case it pays for the university to have a *TTO* if only because of the reputation building argument.

When we interpret the *TS* as a common *TTO* we abstract from any principal-agent problems between the *TTO* and the *RL*s, i.e. we assume that an appropriate internal contract scheme is in place that alleviates all possible moral hazard and asymmetric information problems between the *TTO* and researchers, such that there is generation and disclosure of

14. Most of the explanation that follows will be independent of the parameter A being larger or smaller than q^e. Therefore, we simplify notation by writing δ_2 and δ_1 all the time, although they refer to "either δ_2 or δ_4" and "either δ_1 or δ_3".

inventions by the researchers to the *TTO*. That is, the *TTO,* like the *RL,* is able to assess the quality of the invention [15]. Note that when the expected quality of the stream of invention is low, any internal sharing of s^o between the *TTO* and the *RL,* to alleviate moral hazard problems with respect to invention, generation, and disclosure, will not affect the incentive for the *TTO* to build a reputation. Indeed, sharing the returns with the researchers and hence having a lower s^o dedicated to the *TTO,* does not affect its Incentive Compatibility Constraint [as can be observed in equation (3.3)]. However, the sharing of s^o may affect the incentives to build a reputation when the expected quality of inventions is high, as is shown in equation (3.5).

Our reputation story for a *TTO* is able to explain the importance of a critical size for the *TTO* in order to be successful. Size, expressed in terms of a large stream of inventions at university level, is important to establish the incentives for reputation building. But the size relationship is not linear. Initially, starting at low values for δ^T ($< \delta_2$) having a *TTO* that pools *RL*s may not be sufficient to move the university to the area where reputation benefits can be cashed. But if we are in higher levels for δ^T ($\geq \delta_2$), with not too high levels of δ^R ($< \delta_1$), the pooling of *RL*s will lead to higher revenues per invention sold. We thus have increasing returns to scale in this area. These increasing returns are only in revenues. In terms of number of licenses, we have no scale effects, since the *TTO* will shelve some inventions to build up its reputation. Hence the model results are consistent with the supra reported empirical results from Siegel *et al.* (2003) who found increasing returns to scale for license revenues, but not for number of contracts. A simple explanation based on returns to scale in specialized services would not be able to explain both results. Similarly, our model is able to explain why despite the growth in patents after the Bayh-Dole Act in the US, the growth in licenses executed has been smaller (see Thursby & Thursby, 2002). Finally, Friedman & Silberman (2003) find, on AUTM data, the number of years of the *TTO* being operational as a strong, significant factor explaining *TTO* output, measured by the number of licenses executed. They attribute

15. Besides having proper incentive contracts between the *TTO* and the *RL,* the presence among *TTO* personnel of specialists with a strong scientific background can help the *TTO* to value the quality of the inventions. This has been indicated as a critical success factor for *TTO*s (see Siegel *et al.,* 2003).

this to experience effects, but it is also consistent with a reputation argument. In addition, location in a region with a high concentration of technology-intensive firms is found to be significant, again a factor which favors reputation building.

Having indicated the conditions in which a *TTO* would be beneficial to a *RL* within the university, and given the extra cost typically involved in running a *TTO,* the question remains within the research organization as to how this cost should be allocated to the various *RLs*. If all *RLs* have the same δ^R, as in the explanation above, they benefit equally, leaving an equal split of costs as a natural outcome. However, if there are differences among *RLs* in terms of the size of the stream of inventions generated, i.e. differences in the parameter δ^R, the benefits of having a *TTO* are no longer identical for all *RLs*. For instance, a very large lab, with $\delta^R \geq \delta_1$ already obtains its first best, while a small lab with $\delta^R \leq \delta_2$ would very much benefit from having a *TTO* pooling all inventions. The university as a whole wins from having a *TTO* that allows for reputation building, but in view of the differences in participation constraints of individual *RLs*, costs should in this example be borne by the small *RL* [16]. Hence, with a reputation story for the *TTO,* the labs who use the *TTO* less for transactions should pay more of the cost, since they benefit most from the reputation building. This is different from a standard allocation of costs proportional to the use of services, which would be predicted by a *TTO* model that only considers the supply of specialized services as rationale for a *TTO.*

16. The most prolific universities might have multiple *TTOs*, with the most active *RLs* having their own dedicated technology transfer unit, when the potential of pooling across the remaining *RLs* is still important enough to warrant setting up a *TTO*. E.g. LeuvenR&D, the *TTO* of the K.U. Leuven, deals with technology transfer activities from all K.U. Leuven departments except for IMEC and VIB groups, which are in ICT and bio-tech respectively, and have their own dedicated *TTO* activities.

5. Asymmetric information on the firm's cost of adopting the invention

IN this section we will show that the results derived in Section 4 are robust and still hold when there is two-sided asymmetric information, i.e. in addition to the firm not knowing the quality of the invention, the *TS* does not know the parameter A that characterizes the firm buying the invention at date t. This parameter measures the cost of commercialization a and/or the commercial value of invention β. We assume that the firm's characteristic A takes values in $A \in [0, Q]$, according to a density function $g(A)$, with $g(A) > 0$ for all A, and a distribution function $G(A)$. We take for simplicity $\beta = 1$. (Note that even if we discuss the results in terms of A, β still appears in the *TS* objective function). The analysis is cumbersome, so we will do it in the simplest framework, with uniform distributions for both the quality of the invention q and the firm's parameter A. However, it is easier to understand the conditions for general distributions, and we will proceed by explaining the expressions in general and then providing the solution for the uniform case.

We will show that when the *TS* does not have complete information about A and takes decisions in expected terms, it is still true that a *TS* with a higher δ will be more efficient and obtain more profits. In addition, we can show that complete information about the firm's type allows higher profits to be obtained.

Before dealing with the formal analysis of this case, there are two important points to note. First, the analysis of the incomplete information case about A is not straightforward, since now the participation constraint is very different. Second, considering that the seller has an informational advantage on the quality of the invention, and the buyer on the cost of adopting it, induces a two-sided asymmetric information problem. In our model, the buyer cannot signal its information, nor establish a reputation on it being a one-shot player. We also assume that the seller cannot offer a menu of self-selecting contracts [17].

In the two-sided asymmetric information set-up, the first best is not well defined since the *TS* decides on expected terms and the first best would require setting a zero payment. The second best situation is defined as the situation that generates the maximum surplus in expected terms. Formally, the solution maximizes the following objective function:

$$\int_{q^*}^{Q}\left[G(A^*)q-\int_0^{A^*}Ag(A)dA\right]f(q)dq.$$

The maximum of this expression is reached at the point (q^*, A^*) that satisfies

$$\int_{q^*}^{Q} qf(q)dq = A^*\left[1-F(q^*)\right]$$

$$\int_0^{A^*} Ag(A)dA = q^*G(A).$$

This system of equations always has a solution. For the uniform distribution (both on q and A), the second best solution is reached at $\left(q^*=\frac{Q}{3}, A^*=\frac{2Q}{3}\right)$.

We now briefly analyze the static benchmark (corresponding to $\delta = 0$). The *TS* will try to sell all the inventions, hence the expected quality will be q^e. The only decision it has to take concerns the share s it will seek from any firm accepting the contract. A firm with parameter A buys the invention if and only if $A \leq (1-s)\, q^e$. Consequently, the *TS*'s profits are:

$$sq\int_0^{(1-s)q^e} g(A)dA = sqG((1-s)q^e).$$

17. See Gallini & Wright (1990), Macho-Stadler & Pérez-Castrillo (1991), and Beggs (1992) for analyses of optimal licensing contracts under asymmetric information in a static framework.

The first order condition with respect to s is [18]:

$$qG((1-s)q^e) - sqq^e\, g((1-s)q^e) = 0,$$

that is $G((1-s)q^e) - sq^e\, g((1-s)q^e) = 0$, for any $q > 0$. Let us call s^D the solution implicitly defined by this condition, which does not depend on the particular q that the *TS* has for selling at this date. For the uniform distribution $\left(g(A) = \frac{1}{Q}\right)$, $s^D = \frac{1}{2}$, the *TS*'s profits for a given q are:

$$R^D = s^D\, qG((1-s)q^e),$$

and in expected terms:

$$R^E = s^D\, q^e G((1-s)q^e).$$

For the uniform case, these values are $R^D = \frac{q^e q}{4Q}$ and $R^E = \frac{(q^e)^2}{4Q}$.

Now let us consider the dynamic case, for $\delta > 0$ and a "contract" (s^o, q^o). A firm with parameter A that believes that the *TS* is only offering inventions with quality above q^o agrees to pay a share s^o if and only if:

$$A \leq (1-s^o)\; E\,(q \,/\, q \geq q^o).$$

As in Section 2, for the strategies behind the "contract" (s^o, q^o) to be a *PBE,* the Incentive Compatibility Constraint for the *TS* must be satisfied. Now, if the *TS* cheats by offering an invention with quality below q^o, it will only be discovered if the contract is accepted, that is, if the firm has low cost A. The Incentive Compatibility Constraint is then:

$$\frac{\delta}{1-\delta} s^o G((1-s^o)E(q/q \geq q^o)\int_{q^o}^{Q} qf(q)dq \geq s^o q + \frac{\delta}{1-\delta} R^E \text{ for all } q < q^o.$$

The Incentive Compatibility Constraint can be written as:

$$\frac{\delta}{1-\delta}(s^o G((1-s^o)E(q^o))\int_{q^o}^{Q} qf(q)dq - R^E) \geq s^o q^o. \tag{5.1}$$

18. The second order condition is satisfied if $2sg'((1-s)\,q) < g((1-s)\,q)$.

In the next proposition, we state the optimal contract as a function of the discount rate:

Proposition 5. *Assume that q and A are uniformly distributed in the interval* $[0, Q]$. *Then,*

1. *For* $\delta \in \left[0, \frac{8}{9}\right]$ *the TS transfers the invention with the optimal static contract:* $s^o = \frac{1}{2}$ *and* $q^o = 0$.
2. *For* $\delta \in \left(\frac{8}{9}, \frac{72}{77}\right)$ *the optimal contract guarantees a positive quality (increasing with* δ*) and sets* $s^o > 0$ *(first decreasing and then increasing in* δ*).*
3. *For* $\delta \in \left[\frac{72}{77}, 1\right]$ *the optimal contract is the second best situation:* $s^o = \frac{1}{2}$ and $q^o = \frac{Q}{3}$.

Let us now consider welfare as a function of δ. Welfare is equal to the profit of the *TS* plus the profit of the firm (note that the *TS* cannot extract all the surplus since it does not known the exact characteristic of the firm). Obviously, the profit of the *TS* is increasing in δ, but the profit of the firm needs not to be increasing in δ. Formally, in general terms, welfare takes the form:

$$W(s^o(\delta), q^o(\delta)) = \int_{q^o}^{Q} \left[G((1-s^o)E(q^o))q - \int_0^{(1-s^o)E(q^o)} Ag(A)dA \right] f(q)dq,$$

which for the uniform distribution and depending on the region of the discount rate leads to:

$$\text{For } \delta \in \left[0, \frac{8}{9}\right] W\left(s^o = \frac{1}{2}, q^o = 0\right) = \frac{3}{32}Q.$$

$$\text{For } \delta \in \left(\frac{8}{9}, \frac{72}{77}\right) W(s^o, q^o) = \frac{Q}{8}\left(1 - \left(\frac{(1+2q^{2-}q)}{(2+q^2-q)}\right)^2\right)(1+q)(1-q^2).$$

$$\text{For } \delta \in \left[\frac{72}{77}, 1\right] W\left(s^o = \frac{1}{2}, q^o = \frac{Q}{3}\right) = \frac{1}{9}Q.$$

The buyer's profits for the uniform distributions are:

$$\text{For } \delta \in \left[0, \frac{8}{9}\right] \prod\left(s^o = \frac{1}{2}, q^o = 0 \right) = \frac{1}{32} Q.$$

$$\text{For } \delta \in \left(\frac{8}{9}, \frac{72}{77}\right) \prod(s^o, q^o) = \frac{Q}{8}(1-q)^3 \frac{(1+q)^4}{(2+q^2-q)^2}.$$

$$\text{For } \delta \in \left[\frac{72}{77}, 1\right] \prod\left(s^o = \frac{1}{2}, q^o = \frac{Q}{3} \right) = \frac{1}{27} Q.$$

For $\delta \in \left(\frac{8}{9}, \frac{72}{77}\right)$ the firm's profits are first increasing and then decreasing. In this region, for some values of δ the firm has a higher profit than in the second best situation. The profits of the firm in this region are always superior to the ones obtained in the static set-up (those obtained for any δ lower than 8/9).

Having developed the extension of asymmetric information on the firm's cost of adopting the invention, the model is now also able to incorporate another advantage a *TTO* might offer, beyond the pooling of inventions to build reputation. When the *TTO* invests in building a capacity to better screen the value of inventions, for instance by taking on specialized technology officers with a “boundary spanning role”, in the Siegel *et al.* (2003) terminology, it may reduce the asymmetric information the Technology Seller faces on the commercial value of the invention, i.e. on the parameter *A*. In our model this would correspond to a move from the outcome described in Section 5 with two-sided asymmetric information (in the case of no *TTO)* to the outcome of one-sided asymmetric information with a *TTO* described in Section 3. Without explicitly comparing both scenarios, the logic of the results indicate that the benefits of a *TTO* will depend on the value of δ, where we have to distinguish among the three regions. In the region of high and low δ, there is no reputation building in either case and the elimination of the asymmetric information on *A* leads to the classical improvement from second to first best contracts. With intermediary values for δ, the asymmetric information reduction complements the reputation building through a *TTO*.

6. Conclusion

THE current debate on the importance of academic research for invention and welfare creation has identified the lack of smooth interaction between science and industry as a possible bottleneck in invention and growth performance. This paper adds to the recently growing literature analyzing the organizational structure of technology transfers within science institutions. It provides a theoretical model that helps to explain the specific role a technology transfer office *(TTO)* may have in stimulating the transfer of know-how from the science base into commercial applications. The model concentrates on reducing the asymmetric information problem firms face on the quality of inventions.

Our results indicate that a *TTO* is often able to benefit from its capacity to pool inventions across research units within universities and to build a reputation. This is the case when the total innovative activity of the university is large enough (either because there are many, although not very innovative, research labs; or because there are a few active large research labs), but each research lab is not so large that it is able to build a reputation by itself. The *TTO* will have an incentive to "shelve" some of the projects, thus raising the buyer's beliefs on expected quality, which results in fewer but more valuable inventions being sold at higher prices. However, when the stream of inventions of each research lab is too small and/or the university has just a few of them, the *TTO* will not have enough incentives to maintain a reputation. Our reputation model for a *TTO* is thus able to explain the importance of a critical size for the *TTO* in order to be successful as well as the stylized fact that *TTO*s may lead to "shelving" of inventions and hence fewer licensing agreements but higher income from invention transfers. This is consistent with returns to scale in terms of revenues once the size of the total invention activity of the university reaches a certain threshold, but not in the number of inventions sold.

Although the model contributes to explaining the role of *TTO*s in improving the market for university technology licensing, it offers only a partial view of the rationale for such intermediary institutions. Besides the reputation building argument, other benefits from the specialized services that these *TTO*s may offer, such as intellectual property management, need to be accounted for as well. At the same time, the costs involved in setting up *TTO*s need to be traded off with the benefits. Furthermore, these costs need to be allocated to research labs, which may become a non-trivial concern when they have different profiles. Future research on this topic should also incorporate the internal structure of the relationship between the *TTO* and its research labs. Especially when research labs differ in terms of size and quality of inventions, not only the sharing of *TTO* costs but also the design of optimal incentive-based contracts to ensure participation and disclosure by research labs becomes a challenging issue.

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8. Appendix

Proof of Proposition 1. We are considering Perfect Bayesian Equilibria *(PBE)* where the *TS* follows a strategy characterized by the parameters (s^o, q^o). Given the incentive compatibility constraint that the contract must satisfy for the *TS* not to be interested in deviating from its strategy, and the participation constraint for the firm to be interested in buying the invention when it is offered to it, the best contract that is a *PBE* is the one that solves the following program:

$$\underset{(s^o,q^o)}{Max}\{s^o\beta\int_{q^o}^{Q} qf(q)dq\}$$

$$\text{s.t.} \frac{\delta}{(1-\delta)} s^o \int_{q^o}^{Q} qf(q)dq \geq s^o q^o$$

$$(1-s^o)E(q/q \geq q^o) \geq A$$

$$s^o \geq 0$$

$$s^o \leq 1, q^o \geq 0, q^o \leq Q. \tag{A.1}$$

We will forget condition (A.1) for now, and check after that the solution to the program without this condition does satisfy it.

With the previous simplification and substituting $E\ (q\ /\ q \geq q^o)$ by its value, the previous program can be rewritten as:

$$\underset{(s^o,q^o)}{Max}\{s^o\beta\int_{q^o}^{Q} qf(q)dq\}$$

$$\text{s.t.} \frac{\delta}{(1-\delta)} s^o \int_{q^o}^{Q} qf(q)dq \geq s^o q^o \tag{A.2}$$

$$(1-s^o)\int_{q^o}^{Q} qf(q)dq \geq (1-F(q^o))A \tag{A.3}$$

$$s^o \geq 0 \tag{A.4}$$

In the Lagrangian function, we associate multipliers λ, μ and γ respectively to the constraints (A.2), (A.3), and (A.4). From the FOC we obtain:

$$\frac{\partial L}{\partial s^o} = \beta \int_{q^o}^{Q} qf(q)dq + \lambda \left(\frac{\delta}{1-\delta} \int_{q^o}^{Q} qf(q)dq - q^o \right) - \mu \int_{q^o}^{Q} qf(q)dq + \gamma = 0. \quad \text{(A.5)}$$

Hence, $\mu = \beta + \lambda \left(\frac{\delta}{1-\delta} - \frac{q^o}{\int_{q^o}^{Q} qf(q)dq} \right) + \frac{\gamma}{\int_{q^o}^{Q} qf(q)dq}$ and for $s^o < 0$ we have $\mu > 0$ (using (8))

$$\frac{\partial L}{\partial q^o} = -s^o \beta q^o f(q^o) - \lambda s^o \left[\frac{\delta}{1-\delta} q^o f(q^o) + 1 \right] + \mu f(q^o) [A - (1-s^o) q^o] = 0. \quad \text{(A.6)}$$

1. Consider the region where $\lambda > 0$ and $s^o > 0$. Then, $\gamma = 0$, $\mu = \beta > 0$ and q^o and s^o are determined by constraints (A.2) and (A.3) with equality:

$$\frac{\delta}{1-\delta} \int_{q^o}^{Q} qf(q)dq = q^o \quad \text{(A.7)}$$

$$(1-s^o)\beta \int_{q^o}^{Q} qf(q)dq = (1-F(q^o))a. \quad \text{(A.8)}$$

Hence, $q^o = \hat{q}$, where $\hat{q}$ is defined as the implicit solution of equation (A.7). This $\hat{q}$ satisfies the constraint $q^o \in (0, Q)$ since the right hand of the equation is an increasing (and linear) function of q^o that goes from 0 to Q, and the left hand of the expression is a decreasing function of q^o that goes from $\frac{\delta}{1-\delta} q^e$ to 0. Hence the two expressions coincide in a unique interior solution $\hat{q}$. The optimal share is obtained from (A.8):

$$s^o = 1 - \frac{(1-F(\hat{q}))}{\int_{\hat{q}}^{Q} qf(q)dq} A. \quad \text{(A.9)}$$

It is easy to see that s^o defined in (A.9) is lower than 1. On the other hand, $s^o > 0$ ($\gamma = 0$) if and only if:

$$A < A_2 \equiv \frac{\int_{\hat{q}}^{Q} qf(q)dq}{(1 - F(\hat{q}))}.$$

(Note that $\hat{q}$ does not depend on A.) In addition, in this region equation (A.6) gives λ:

$$\lambda = \frac{\beta(A - \hat{q})f(\hat{q})}{s^o\left[1 + \frac{\delta}{1-\delta}\hat{q}f(\hat{q})\right]}. \tag{A.10}$$

Hence, for $\gamma = 0$, λ defined by (A.10) is positive if and only if $\hat{q} < A$. This implies that the previous contract is a candidate only if $A > A_1 \equiv \hat{q}$. It is easy to verify that $A_1 < A_2$.

In order to translate the constraints is terms of the discount rate δ, note that (A.7) is an increasing function of δ. If δ goes to zero $\hat{q}$ goes to zero, and when δ goes to one $\hat{q}$ goes to Q. This implies that $\hat{q}$ is an increasing function of δ and takes values in the interval $[0, Q]$. The intersection of A and $\hat{q}$ implicitly defines δ_1: $\hat{q}(\delta_1) = A$. The threshold A_2 is also increasing in δ and takes values in the interval $[q^e, Q]$. The intersection of A and A_2 defines δ_2:

$$A_2 \equiv \frac{\int_{\hat{q}(\delta_2)}^{Q} qf(q)dq}{(1 - F(\hat{q}(\delta_2)))}.$$

Note that $\delta_2 < \delta_1$.

Summarizing, we have checked that $q^o = \hat{q}$ and s^o defined by (A.9) is an interior candidate for solution when $\delta \in (\delta_2, \delta_1)$.

2. If $\lambda = 0$ and $s^o > 0$ then q^o and s^o are determined by equation (A.6) (taking into account $\gamma = 0$, $\lambda = 0$ and $\mu = \beta$) and by condition (A.3) with equality, respectively:

$$q^o = A,$$
$$s^o = 1 - \frac{(1 - F(A))A}{\int_{A}^{Q} qf(q)dq}. \tag{A.11}$$

Note that s^o is always positive and lower than 1. Also $q^o \in [O, Q]$.

Therefore, the last Kuhn-Tucker condition to be checked to make sure that the previous (s^o, q^o) is indeed a candidate solution is (A.2), that is,

$$A \le \frac{\delta}{1-\delta}\int_A^Q qf(q)dq.$$

Given that $\hat{q}(= A_1)$ is the only value that satisfies the expression with equality, it is easy to check that the inequality holds if and only if $A \le A_1$, i.e., $\delta \ge \delta_1$. Hence, $q^o = A$ and s^o defined by (A.11) is a candidate solution when $\delta \ge \delta_1$.

3. Finally, consider the region where $s^o = 0$. Equation (A.2) holds. In this region, the Khun-Tucker conditions are:

$$(\beta-\mu)\int_{q^o}^Q qf(q)dq + \lambda\left(\frac{\delta}{1-\delta}\int_{q^o}^Q qf(q)dq - q^o\right) + \gamma \le 0,$$

$$\mu(A - q^o) = 0,$$

$$\mu(\int_{q^o}^Q qf(q)dq - (1-F(q^o))A) = 0, \text{and}$$

$$\int_{q^o}^Q qf(q)dq \ge (1-F(q^o))A.$$

First of all, we show that in this region $\mu = 0$. From $\mu(A - q^o) = 0$ we have that either $\mu = 0$ or $q^o = A$. But $q^o = A$ and

$$\mu(\int_{q^o}^Q qf(q)dq - (1-F(q^o))A) = 0$$

imply $\mu = 0$ (since $q^o = A < Q$).

Therefore,

$$\lambda\left(\frac{\delta}{1-\delta}\int_{q^o}^Q qf(q)dq - q^o\right) \le -\beta\int_{q^o}^Q qf(q) - \gamma.$$

We consider two sub-regions:

(3.i). $\gamma = 0$ and $q^o = Q$ (which implies that the previous condition is written as $\lambda(-Q) \leq 0$) and satisfies all constraints. Then the candidate in case (3.i) is $s^o = 0$ and $q^o = Q$ (no license is sold).

(3.ii). $\gamma > 0$ and/or $q^o < Q$ which imply $\lambda > 0$ and $q^o > \frac{\delta}{1-\delta}\int_{q^o}^{Q} qf(q)dq$. This last condition can be rewritten as

$$\frac{q^o}{\int_{q^o}^{Q} qf(q)dq} > \frac{\delta}{1-\delta},$$

where the left-hand side of the inequality is increasing in q^o. Also, given the definition of $\hat{q}, q^o > \frac{\delta}{1-\delta}\int_{q^o}^{Q} qf(q)dq$ if and only if $q^o > \hat{q}$.

The optimal q^o has also to fulfill the following condition:

$$\int_{q^o}^{Q} qf(q)dq \geq (1 - F(q^o))A.$$

Note that $\frac{1}{(1-F(q^o))}\int_{q^o}^{Q} qf(q)dq$ is increasing in q^o, and $A_2 \equiv \frac{1}{(1-F(\hat{q}))}\int_{\hat{q}}^{Q} qf(q)dq$. Hence, $q^o > \hat{q}$ implies $\frac{1}{(1-F(q^o))}\int_{q^o}^{Q} qf(q)dq > A_2$. Then, for every $A > A_2$ (that is, for every $\delta < \delta_2$) there is $\tilde{q} \in (\hat{q}, Q)$ satisfying $\int_{\tilde{q}}^{Q} qf(q)dq = (1 - F((\tilde{q}))A$. When A converges towards Q, then $\tilde{q}$ goes towards Q as well. The optimal contract in case (3.ii) is $s^o = 0$ and any $q^o \in [\tilde{q}, Q]$ with $\tilde{q}$ determined by

$$\frac{\int_{\tilde{q}}^{Q} qf(q)dq}{(1-F(\tilde{q}))} = A.$$

Note that these contracts give zero profits to the *TS*. We can summarize the candidates in the region $s^o = 0$ as the ones guaranteeing any $q^o \in [\tilde{q}, Q]$.

Finally, note that by assumption we are in the case $A > q^e$. Hence, we have to check under what conditions A_1 and A_2 are higher than q^e. It is easy to check that $A_2 > q^e$ for any combination of parameters. Now $A_1 > q^e \Leftrightarrow \hat{q} > q^e \Leftrightarrow \delta > \delta_1$ where δ_1 is defined by

$$\frac{\delta_1}{1-\delta_1}\int_{q^e}^{Q} qf(q)dq = q^e.$$

This completes the proof of the proposition, since the three candidates are unique in the region where they are candidates, and moreover they satisfy condition (A.1).

Proof of Corollary 2. The derivatives of q^o and s^o are immediate from the expressions in Proposition (1). We just compute here $\frac{\partial s^o}{\partial a}$ for $A \leq A_1$:

$$\frac{\partial s^o}{\partial a} = -\frac{(1-F(q^o))\int_{q^o}^{Q} qf(q)dq - Af(q^o)\left[\int_{q^o}^{Q} qf(q)dq - (1-F(q^o))q^o\right]}{(\int_{q^o}^{Q} qf(q)dq)^2}\frac{1}{\beta}$$

$$sign\left[\frac{\partial s^o}{\partial a}\right] = sign\left[-(1-F(q^o))\int_{q^o}^{Q} qf(q)dq + Af(q^o)\,(\int_{q^o}^{Q} qf(q)dq - q^o(1-F(q^o)))\right].$$

The first term is positive and the second one is negative because $\int_{q^o}^{Q} qf(q)dq > q^o(1-F(q^o))$. Hence, the sign is ambiguous.

Proof of Proposition 3. The optimal contract solves the following program:

$$\underset{(s^o,q^o)}{Max}\{s^o\beta\int_{q^o}^{Q} qf(q)dq\}$$

$$\frac{\delta}{(1-\delta)}\left[s^o\int_{q^o}^{Q} qf(q)dq - (q^e - A)\right] \geq s^o q^o \tag{A.12}$$

$$(1-s^o)\int_{q^o}^{Q} qf(q)dq \geq (1-F(q^o))A \tag{A.13}$$

$$s^o \geq 0 \tag{A.14}$$

$$q^o \geq 0. \tag{A.15}$$

where we will forget the constraints $s^o \leq 1$, $q^o \leq Q$ and will check later that they hold in the proposed optimum.

Associating multipliers λ, μ, γ and η to the four constraints, the two FOCs of the previous program are:

$$\frac{\partial L}{\partial s^o} = \beta\int_{q^o}^{Q} qf(q)dq + \lambda\left(\frac{\delta}{1-\delta}\int_{q^o}^{Q} qf(q)dq - q^o\right) - \mu\int_{q^o}^{Q} qf(q)dq + \gamma = 0$$

and

$$\frac{\partial L}{\partial q^o} = -s^o\beta q^o f(q^o) - \lambda s^o\left[\frac{\delta}{1-\delta}q^o f(q^o) + 1\right] + \mu f(q^o)[A - (1-s^o)q^o] + \eta = 0.$$

1. Consider the region where $\lambda = 0$, $\eta = 0$ and $s^o > 0$ (then, $\gamma = 0$). Following the same steps as in 2 of the proof of Proposition (1) $\mu = \beta$, $q^o = A$, and:

$$s^o = 1 - \frac{(1-F(A))A}{\int_A^Q qf(q)dq}$$

with $s^o \in [0,1]$ and $q^o \in [0, Q]$. Hence, the last Kuhn-Tucker condition to be checked is (A.12), that is,

$$\left[1 - \frac{(1-F(A))A}{\int_A^Q qf(q)dq}\right]\left[\frac{\delta}{1-\delta}\int_A^Q qf(q)dq - A\right] - \frac{\delta}{1-\delta}(q^e - A) \geq 0.$$

Let us define

$$m(\delta) \equiv \frac{\delta}{1-\delta}\left(\left[1 - \frac{(1-F(A))A}{\int_A^Q qf(q)dq}\right]\int_A^Q qf(q)dq - (q^e - A)\right) - \left[1 - \frac{(1-F(A))A}{\int_A^Q qf(q)dq}\right]A.$$

Note that $m(0) < 0$. Also, $\int_A^Q qf(q)dq - (1-F(A))A - (q^e - A) > 0$, since $F(A)A - \int_0^A qf(q)dq > 0$. This implies that $m(\delta) > 0$ if δ is very close to 1 and that $m'(\delta) > 0$. Therefore, there exists a unique $\delta_3 \in (0,1)$, defined by $m(\delta_3) = 0$, such that $m(\delta) < (>) 0$ if and only if $\delta < (>) \delta_3$. Hence, if $\delta \geq \delta_3$, $q^o = A$ and the corresponding s^o is a candidate solution. Moreover, since this contract is the First Best contract, it will be the solution.

2. If $\eta > 0$, then $q^o = 0$. The FOC w.r.t. s^o is:

$$\frac{\partial L}{\partial s^o} = \left(\beta + \lambda \frac{\delta}{1-\delta} - \mu \right) q^e + \gamma = 0.$$

Therefore, $\mu > 0$ since $\beta > 0$. Then $s^o = 1 - \frac{A}{q^e} \in (0,1)$. Condition (A.12) is trivially satisfied.

2.1. When $A < q^e$, then $s^o > 0$ so $\gamma = 0$ and $\mu = \beta + \lambda \frac{\delta}{1-\delta}$. In this case,

$$\frac{\partial L}{\partial q^o} = \lambda \left(\frac{\delta}{1-\delta} f(0)A - \frac{q^e - A}{q^e} \right) + \beta f(0)A + \eta = 0.$$

This implies $\lambda > 0$ and $\frac{\delta}{1-\delta} f(0)A - \frac{q^e - A}{q^e} < 0$, which is equivalent to $\delta < \hat{\delta}_4$, where

$$\hat{\delta}_4 \equiv \frac{q^e - A}{q^e - A + q^e A f(0)}.$$

(Note that $\hat{\delta}_4 < \delta_3$ if and only if $m(\hat{\delta}_4) < 0$, which happens if and only if $f(0)$ is large enough.)

2.2. When $A = q^e$, then $s^o = 0$. In this case, $\frac{\partial L}{\partial q^o} = \mu f(0)A + \eta = 0$, which implies $\eta = 0$ and this is not possible in this region.

3. Consider now the region where $\lambda > 0, \eta = 0$ and $s^o > 0$. Then, $\gamma = 0$. Moreover,

$$\mu = \beta + \lambda \left(\frac{\delta}{1-\delta} - \frac{q^o}{\int_{q^o}^{Q} qf(q)dq} \right) \geq \beta + \lambda (q^e - A) > 0.$$

Substituting μ in the equation $\frac{\partial L}{\partial q^o} = 0$ gives λ as a function of the optimal q^o and s^o:

$$\beta(A - q^o) + \lambda \left[\frac{\delta}{1-\delta}(A - q^o) - \frac{s^o}{f(q^o)} - \frac{q^o}{\int_{q^o}^{Q} qf(q)dq}(A - (1-s^o)q^o) \right] = 0 \quad \text{(A.16)}$$

Finally, s^o and q^o are determined by constraints (A.12) and (A.13) with equality. That is $q^o = \bar{q}$, where $\bar{q}$ is implicitly defined by:

$$\left(1-\frac{(1-F(\bar{q}))}{\int_{\bar{q}}^{Q} qf(q)dq}A\right)\left(\frac{\delta}{1-\delta}\int_{\bar{q}}^{Q} qf(q)dq-\bar{q}\right)=\frac{\delta}{1-\delta}(q^e-A) \qquad \text{(A.17)}$$

and

$$s^o = 1-\frac{(1-F(\bar{q}))}{\int_{\bar{q}}^{Q} qf(q)dq}A.$$

Note that $0 < \bar{q} \leq \hat{q}$ and $s^o < 1$. In addition, in this region $s^o > 0$ iff $\frac{\int_{\bar{q}}^{Q} qf(q)dq}{(1-F(\bar{q}))} > A$. This always holds for every $\bar{q} > 0$ since $A \leq q^e$. Hence, the preceding contract $(\bar{q}, s^o)$ is a candidate in this region if and only if there is a solution to equation (A.17) for which the multiplier λ defined by (A.16) is positive. Notice that, in (A.16),

$$A-(1-s^o)q^o = A\left[1-\frac{(1-F(\bar{q}))}{\int_{\bar{q}}^{Q} qf(q)dq}\bar{q}\right]\geq 0.$$

Therefore, if $A - q^o \leq 0$, the expression that multiplies the parameter λ in equation (A.16) is strictly negative. Hence, the necessary and sufficient conditions for the multiplier λ to be positive are (substituting s^o by its value):

$$\bar{q} < A$$

and

$$\frac{\delta}{1-\delta}(A-\bar{q})<\frac{1}{f(\bar{q})}\left[1-\frac{(1-F(\bar{q}))}{\int_{\bar{q}}^{Q} qf(q)dq}A\right]+\frac{\bar{q}A}{\int_{\bar{q}}^{Q} qf(q)dq}\left[1-\frac{(1-F(\bar{q}))}{\int_{\bar{q}}^{Q} qf(q)dq}\bar{q}\right]. \qquad \text{(A.18)}$$

Let us now analyze equation (A.17). The point $\bar{q} = 0$ is a solution to (A.17). Since $0 < A$, the multiplier λ corresponding to $\bar{q} = 0$ is positive if and only if equation (A.18) holds for $\bar{q} = 0$. It is easy to check that this is the case if and only if $\delta < \hat{\delta}_4$. This gives the same candidate solution as the one obtained in case 2 before, except that $\bar{q} = 0$ is also a candidate when $A = q^e$.

To continue the analysis of equation (A.17), we denote:

$$j(q^o) \equiv \frac{\delta}{1-\delta}\left[\int_{q^o}^{Q} qf(q)dq + F(q^o)A - q^e\right] - \left(1 - \frac{(1-F(q^o))}{\int_{q^o}^{Q} qf(q)dq}A\right)q^o.$$

The value(s) $\bar{q}$ is (are) implicitly defined by $j(\bar{q}) = 0$.

Taking derivatives of the function $j(.)$:

$$j'(q^o) = \frac{\delta}{1-\delta} f(q^o)(A-q^o) - \left(1 - \frac{(1-F(q^o))}{\int_{q^o}^{Q} qf(q)dq}A\right) + \frac{f(q^o)Aq^o}{\int_{q^o}^{Q} qf(q)dq}\left[1 - \frac{(1-F(q^o))}{\int_{q^o}^{Q} qf(q)dq}q^o\right].$$

Therefore, a point $\bar{q}$ satisfying $j(\bar{q}) = 0$ has a positive associate multiplier λ (hence, it is a candidate solution) if and only if $\bar{q} < A$ and $j'(\bar{q}) < 0$.

The function $j(.)$ also satisfies the following properties: (i) it is continuous in all its arguments; (ii) $j'(0) > 0$ if and only if $\delta > \hat{\delta}_4$; (iii) $j(A) = m(\delta)$; and (iv) $j(q^o)$ is increasing in δ for all the values of q^o for which $j(q^o)$ is non-negative.

Given all the previous characteristics, we can assert the following two properties for the situation where $\delta < \delta_3$ (i.e., $j(A) < 0$) (the first best can be achieved in the other region). First, if $\delta > \hat{\delta}_4$ (i.e., $j'(0) > 0$), then it is necessarily the case that at least one candidate $\bar{q}$ exists. Second, whenever a candidate exists for a certain δ, a candidate exists for every other δ' larger than δ (and smaller than δ_3). Hence, there exists a threshold value $\delta_4 \leq \hat{\delta}_4$ from which on we can find a candidate $\bar{q}$. Moreover, locally, a candidate $\bar{q}$ increasing in δ exists.

Next, we check that, if there exists $\bar{q} > 0$ satisfying $j(\bar{q}) = 0$, then the profits at this point are larger than with a contract involving $q^o = 0$. Indeed, using that $j(\bar{q}) = 0$:

$$\beta s^o(\bar{q})\int_{\bar{q}}^{Q} qf(q)dq = \beta(q^e - A) + \beta\frac{1-\delta}{\delta}s^o(\bar{q})\bar{q} > \beta(q^e - A) = \beta s^o(0)\int_0^{Q} qf(q)dq$$

where the last equality holds since $j(0) = 0$. Finally, note that the larger the candidate $\bar{q}$ (among those values with $j(\bar{q}) = 0$) the larger the profits. Indeed, as shown in the previous equation, the difference in profits among the candidate $\bar{q}$s is driven by the term $s^o(\bar{q})\bar{q}$. Since $s^o(\bar{q})$ is increasing in $\bar{q}$ so are the profits. This property, together with the properties of the function $j(\cdot)$ previously highlighted, imply that the best $\bar{q}$ is increasing in δ (although, for particular distribution functions $j(.)$, the best $\bar{q}$ may not be a continuous function of δ).

4. The region where $s^o = 0$ and $\eta = 0$ is only possible when $A = q^e$. Indeed, $s^o = 0$ and (A.12) imply $q^e \leq A$. The solution with s^o is equivalent in terms of profits to the situation when $q^o = 0$ and $s^o = 0$ which comes out when $A = q^e$ in case 2.

Proof of Corollary 4. Most derivatives of q^o and s^o are immediate from the expressions in Proposition (3). The only difficult analysis concerns region 2, where $\delta \in (\delta_4, \delta_3)$. Here, the optimum $\bar{q}$ is determined by the equation $j(\bar{q}) = 0$, where we also know that $j'(\bar{q}) < 0$. It is also easy to check that the derivative of the function $j(\cdot)$ with respect to the parameter A is increasing, hence the optimum $\bar{q}$ is increasing in A and so is the share s^o.

Proof of proposition 5. The best *PBE* consisting of strategies characterized by a "contract" (s^o, q^o) is the solution to:

$$Max\left[s^o G((1-s^o)E(q/q \geq q^o))\int_{q^o}^{Q} qf(q)dq\right] \text{s.t. (6)}, s^o \geq 0 \text{ and } q^o \geq 0$$

(Note that at the optimum, $s^o \leq 1$ and $q^o < Q$, otherwise the *TS* does not sell). We denote the Lagrange multipliers by λ, γ and η respectively. Denoting by $E \equiv E(q\ /\ q \geq q^o)$ and $E' \equiv \dfrac{\partial E(q/q \geq q^o)}{\partial q^o}$, the FOCs of the program can be written as:

$$\frac{\partial L}{\partial s^o} = \left(1+\lambda\frac{\delta}{1-\delta}\right)\left[G((1-s^o)E) - s^o E g((1-s^o)E)\right]\int_{q^o}^{Q} qf(q)dq - \lambda q^o + \gamma = 0 \quad \text{(A.19)}$$

$$\frac{\partial L}{\partial q^o} = \left(1+\lambda\frac{\delta}{1-\delta}\right)\left[g((1-s^o)E(1-s^o)E'\int_{q^o}^{Q} qf(q)dq - G((1-s^o)Eq^o f(q^o)\right] \quad \text{(A.20)}$$

$$s^o - \lambda s^o + \eta = 0.$$

We will consider different regions.

a) $\lambda > 0, \eta = 0$ and $s^o > 0$. In this case $\gamma = 0$. In the uniform case, after some computations, we can write equations (A.19), (A.20) and (5.1) respectively as follows:

$$\left(1+\lambda\frac{\delta}{1-\delta}\right)(1-2s^o)\frac{(Q+q^o)^2(Q-q^o)}{4Q^2}-\lambda q^o=0 \qquad \text{(A.21)}$$

$$\left(1+\lambda\frac{\delta}{1-\delta}\right)(1-s^o)\frac{(Q+q^o)^2(Q-3q^o)}{4Q^2}-\lambda=0 \qquad \text{(A.22)}$$

$$\frac{\delta}{1-\delta}\left[s^o(1-s^o)\frac{(Q+q^o)^2(Q-q^o)}{4Q^2}-\frac{Q}{16}\right]=s^oq^o. \qquad \text{(A.23)}$$

From equations (A.21) and (A.22) we obtain:

$$s^o=\frac{Q^2+2q^{o2}-q^oQ}{2Q^2+2q^{o2}-q^oQ}$$

which satisfies $s^o \le s^D = \frac{1}{2}$ iff $q^o \le q^* = \frac{Q}{3}$. The function $s^o(q^o)$ has U form in the interval $q \in \left(0, \frac{Q}{3}\right)$ and takes the value $\frac{1}{2}$ in the extremes of the interval.

Replacing s^o in equation (A.22) we can obtain the multiplier λ as a function of q^o. After some computation, one can check that $\lambda \ge 0$ if and only if $q^o \le \frac{Q}{3}$ and

$$\delta \ge \frac{1}{1+\dfrac{(Q^2-q^{o2})(Q+q^o)(Q-3q^o)}{4Q^2(2Q^2-q^oQ+q^{o2})}}$$

where the right-hand side of the inequality is an increasing function of q^o taking values from $\delta = \frac{8}{9}$ for $q^o = 0$ until $\delta = \frac{72}{75}$ for $q^o = \frac{Q}{3}$.

The candidate q^o is found by substituting s^o (as a function of q^o) in equation (A.23). The candidate is $q^o = \tilde{q}Q$, where $\tilde{q}$ is the solution to:

$\delta(36 - 57\tilde{q} + 106\tilde{q}^2 - 53\tilde{q}^3 + 16\tilde{q}^4 + 4\tilde{q}^5 + 8\tilde{q}^6) = 32 - 48\tilde{q} + 96\tilde{q}^2 -$
$- 48\tilde{q}^3 + 32\tilde{q}^4$.

The previous equation always has a unique solution $\tilde{q}$, as a function of δ, for every $\delta \in \left(\frac{8}{9}, \frac{72}{77}\right)$. Moreover, the function is increasing in δ.

b) $\lambda = 0, \eta = 0$ and $s^o > 0$. In this case $\gamma = 0$. From (A.19) and (A.20) in the uniform case we obtain:

$$(1-2s^o)\frac{(Q+q^o)^2(Q-q^o)}{4Q^2} = 0$$

$$(1-s^o)\frac{(Q+q^o)(Q-3q^o)}{4Q^2} = 0$$

which imply $s^o = \frac{1}{2}$ and $q^o = \frac{Q}{3}$. The ICC (5.1) is only satisfied if $\delta \geq \frac{72}{77}$.

c) $\eta > 0$ (hence $q^o = 0$) and $s^o > 0$ ($\gamma = 0$). From (A.19) with the uniform distributions we obtain $s^o = \frac{1}{2}$. Also, (5.1) is easily satisfied. Moreover, (26) is only satisfied with $\lambda \geq 0$ for $\delta \leq \frac{8}{9}$.

d) Finally, the case $s^o = 0$ is never a solution.

ABOUT THE AUTHORS*

INÉS MACHO-STADLER ** is Professor of Economics at the Autonomous University of Barcelona. She obtained her PhD in Economics from the Ecole des Hautes Etudes en Sciences Sociales, in Paris. Her research interests are in Economics of Information, Industrial Organization, Public Economics, and Game Theory. She was co-editor of the *Spanish Economic Review* from 1997 to 2001, and took over as president of the Asociación Española de Economía in December 2004.

DAVID PÉREZ-CASTRILLO *** is Professor of Economics at the Autonomous University of Barcelona. He graduated in Economics from the Ecole des Hautes Etudes en Sciences Sociales, in Paris. His research interests include Game Theory, Research and Development, Economics of Information, and Public Economics. He received a Young Researcher Award (2001) from the Catalan Government. From October 2000 to March 2004, he held the post of Managing Editor of *Investigaciones Económicas*. He has been on the Executive Committee of EARIE since 2000.

REINHILDE VEUGELERS **** has been since 1985 with the Catholic University of Louvain, Belgium, where she obtained her PhD in Economics in 1990. Since then she has been a professor in the Department of Applied Economics. Her research focuses on the fields of Industrial Organisation, International Economics and Strategy. She is a member of the editorial board of the *International Journal of Industrial Organisation* and member of the Executive Committee of EARIE. Currently, she is Economic Advisor to the European Commission, DG ECFIN.

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** Universitat Autònoma de Barcelona; Dept. of Economics and CODE; 08193 Bellaterra, Spain. e-mail: Ines.Macho@uab.es

*** Universitat Autònoma de Barcelona; Dept. of Economics and CODE; 08193 Bellaterra, Spain. e-mail: David.Perez@uab.es

**** Katholieke Universiteit Leuven; Dept. of Applied Economics; Naamsestraat 69; 3000 Leuven, Belgium and CEPR, London. e-mail: Reinhilde.Veugelers@econ.kuleuven.ac.be

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Fundación BBVA

Gran Vía, 12
48001 Bilbao
Tel.: 94 487 52 52
Fax: 94 424 46 21

Paseo de Recoletos, 10
28001 Madrid
Tel.: 91 374 54 00
Fax: 91 374 85 22

informacion@fbbva.es
www.fbbva.es