Signaling and the Ownership of Academic Patents[1]

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Abstract

Although in most countries, professors are legally obligated to disclose their inventions to their university's technology transfer office, the latter often does not have the real authority to enforce this rule. We here introduce a model that endogenizes a professor's decision of a form of transfer for her idea. If she does not disclose the idea to the transfer office, she still faces, on her own, both the difficulty of identifying a good match for her technology with a company and the incomplete information of the company on the quality of her idea. She can, however, signal that quality to the company at some cost, which decreases with quality. We find four types of pure strategy equilibria of this signaling game. Taking these four types of equilibria into account, the model predicts that the company ownership of academic patents is associated with higher patent quality, greater inventor experience in technology transfer, and lower technology transfer office experience. We estimate the model and confirm its predictions on an original sample of 1,260 patent-professor pairs drawn from British data. Specific care is taken to control for potential reverse causality effects, particularly, of applicant on patent quality.

Keywords: signaling game, academic patents, technology transfer.
JEL Codes: O31, O34.

1 Introduction

The basic rationale of the Bayh Dole reform in the US and similar university technology transfer reforms around the world consists of giving universities the right to retain property generated from government funded research because they are suspected to be the most efficient level at which to establish and manage the transfer of academic inventions to companies. Most research universities have now established their own technology transfer office (hereinafter *tto*), the main duty of which is to manage the transfer interface between the university and companies. Nowadays, the *tto*'s activity clearly constitutes a significant contribution to the technological leadership of developed nations. For instance, in the 2011 edition of the AUTM US Licensing Activity Survey, respondents reported up to 38,600 active licenses and options with nearly 4,900 new licenses executed that year.

Two problems facing transfer institutions have been identified and, for each one, there are arguments supporting the view that a university *tto* is indeed well suited to manage the transfer. The first problem is due to the fact that technology providers usually have much more information on the quality of their ideas than potential buyers. Several recent contributions have highlighted that an intermediary agency, such as the *tto*, may help to reduce the information asymmetry between inventors and investors by guaranteeing a minimum quality of the proposed inventions. Hoppe and Ozdenoren (2005), in a static model, and Macho-Stadler et al. (2007), in a dynamic context, show the advantage of a *tto* that pools inventions from several labs. Macho-Stadler et al, in particular, argue that a *tto* can build a reputation over time, which contributes to mitigating the information asymmetry problem between scientists and firms. Considering a repeated game with imperfect information (the *tto* observes the quality, while the firm does not), it is shown that the *tto* is indeed essential to the creation of a market for technology, especially in situations where the total innovative activity of the university is large enough but where each research laboratory is too small to build a reputation by itself. To build a reputation, the *tto* should put aside inventions of lower quality, as this will eventually reinforce firms' belief in the quality of academic inventions.

The second problem a transfer institution relates to the matching of technological innovations with specific industrial and commercial applications. In many domains, search costs are very high and selling these technologies on an auction basis may be complicated; thus efficient searches must often be performed by professionals. Academics usually do not know the real potential uses of their discoveries and, in turn, do not know which firms are potentially interested. Considerable time and effort must therefore be invested in identifying firms willing to acquire specific intellectual property rights from university inventions (Elfenbein, 2007). These search costs are likely to be mitigated by the *tto*, which incurs a lower cost of search, because of specialization and a lower opportunity cost of time. Hellmann (2007) specifically discusses the issue of matching inventors (scientists) and investors (firms) and theoretically shows that scientists have an incentive to delegate all search activities to the *tto*, with the assumption that the *tto* has superior knowledge in identifying which firms can make use of the scientists' discoveries.

Although these arguments are convincing in showing that university *tto*s are good at technology transfer, they are however not the only possible medium for technology transfer. As frequently highlighted, faculty members are not in an ivory tower and many professors build strong relationships with companies throughout their career, which may create the conditions for the emergence of a "gray market" for inventions (Shane, 2004, Link et al. 2007, Markman et al., 2008). Of course, in most universities and countries, including in the UK, scientists are legally obligated to disclose their inventions to the *tto*. However, scientists seem to have strong bargaining power over the *tto*. Anecdotal evidence shows that even though the *tto* often knows about the inventions that were commercialized through the "back door", they have little to no real power against established faculty members. Thus scientists may bypass their *tto* despite the fact they are formally obliged to disclose their inventions to it:[1] *tto* directors seem to have formal rather than real authority (Aghion and Tirole, 1994). As a matter of fact, the existence of

[1] See Kenney and Patton (2009) for an illuminating discussion on the inventor-*tto* relationship.

a "gray market" for inventions is now well documented empirically. Using a random sample of 54 US universities listed in the 1999-2000 edition of the Association of University Technology Managers (AUTM), Markman et al. (2008), found that 42% of 3,200 surveyed academic inventors bypassed their institution at least once. Similarly, Thursby et al. (2009) use a sample of 5,811 US academic patents and find that 26% of faculty patents are assigned directly to firms rather than to the faculty member's university. Lissoni et al. (2008) show that these figures are even higher in some Continental Europe countries where the majority of academic patents are owned by the business sector (61% in Sweden, 72% in France and 81% in Italy). In the present paper, we show that the UK, where almost 50% of all academic patents are company owned, is in this regard situated between the US and Continental Europe. These results highlight a third problem faced by *tto*, namely that of soliciting complete participation of academic inventors to the technology transfer process they manage. Though the *tto*s' institutional proximity with academics probably contributes significantly to minimize the share of inventions that are commercialized though the back door by their inventors, professors seem to be in the position to choose a different way of transferring their technologies.

In this paper we attempt to theoretically and empirically investigate the transfer of academic inventions (and their consequences) in this more complex context, that is in situations where *tto*s represent only one way of performing the transfer. Taking into account the empirical evidence, we develop a model that explicitly considers the possibility for academic scientists to sell their ideas directly to the market (thus bypassing the *tto*). However, in this situation, the faculty still faces, alone, the two technology transfer issues identified above: high search costs and asymmetric information about the quality of their ideas. We model search costs assuming that faculty members select one company among those they have had dealings with and propose their idea to that company. To mitigate asymmetric information about the quality her inventions vis-à-vis the sampled company, the faculty member is assumed to play first and to have the possibility of signaling the quality of her idea to that company. As in traditional signaling models, this signal is costly and the cost decreases with the quality of what is signaled: here it is assumed that it is easier to convince the potential investor, through private face to face meetings, of the high technological quality of the patent when it is of good quality. Once the signal is sent, the faculty makes a proposal to the company in the form of a fixed fee, which is assumed to be the only possible form of contract in this situation. If the company accepts the proposal, the intellectual property rights are granted to the company and the game ends with a patent assigned to the company. If it refuses the proposed deal, the professor then turns to the *tto*, the university retains the rights over the technology and sells an exclusive license through a Vickrey auction organized by the *tto*.

We find four types of Perfect Bayesian Equilibria of this game: two types of pooling equilibria and two types of separating equilibria. In the pooling equilibria, both the faculty member with the high quality idea and the one with the low quality idea go to the *tto*, or they both go to the company. In one type of separating equilibria, both faculty members make a deal with the company but only the faculty member with the high quality idea signals herself. In the other separating equilibrium, the (signaled) high quality idea is patented by the company and the low quality idea goes to the *tto*. The requirement that equilibria should respect the intuitive criterion (Cho and Kreps, 1987) partially rules out the multiplicity of equilibria, in such a way that the predictions of our model concerning the relation between the quality of ideas and patent ownership are completely clarified. Indeed, one of the most striking predictions of our theoretical model is that good ideas are more likely to bypass the *tto*. The model also predicts that the patentable ideas of the faculty members who can more easily find a good match on their own have a greater chance of being owned directly by firms. Finally, the model suggests that more experienced, and thus more efficient (Jensen et al., 2003) *tto*s attract more inventions. Variations of the theoretical model are also explored, which show that our predictions remain largely unchanged.

To estimate our model and its new predictions, we exploit a sample of 1,260 British patent-professor pairs corresponding to EPO patent applications made between 1990 and 2002. The baseline estimations of our theoretical model confirm that university ownership is associated with higher patent quality, greater inventor patenting experience and lower *tto* experience. Though we argue that the proxy we have chosen for technological patent quality (forward patent citations recorded in a three-year moving time window) is the most relevant, we also try various alternative proxies suggested in the literature (different lengths of the time window, composite indicator) that also support our main empirical result. We also develop specific empirical strategies to deal with the potential reverse causality of the type of ownership (company or university) on patent quality. Two specific reverse causality phenomena (further exploitation by the assignee and consulting activity) are taken into consideration by respectively excluding self-citations at the applicant level and by controlling for patent originality (as suggested by Thursby et al., 2009). In order to deal with other potential forms of reverse causality, we also develop an IV approach in which patent quality is instrumented by the quality of the previous patent invented by the same academic inventor, the average quality in the technological field, and the size of the inventor's team. Our results again confirm the robustness of our first estimations. The other predictions of the theoretical model are also confirmed: the ability of faculty members to find a good match, which we proxy with the patenting experience of the professor, increases the probability of company ownership, while more experienced *tto*s attract more inventions.

Our paper relates to a larger literature on the licensing of technologies and the licensing of university technologies in particular. Gallini and Wright (1990) and Macho-Stadler and Perez-Castrillo (1991) first explored the licensing of inventions in the presence of asymmetric information. Their main contributions concern the consequences of these asymmetries on the different types of licensing contracts (mainly royalties or fixed fee; exclusive or non exclusive licensing). The literature that specifically focuses on university inventions licensing has mostly focused on the necessity to involve faculty participation in the downstream development of inventions, given the fact that most university inventions are basic and thus require further development efforts from its inventors. Macho-Stadler and Perez-Castrillo (2010) provide a conceptual framework of the main contractual issues related to university technology transfer, in which they consider and compare licensing and spin-off creation as two different transfer paths. Dechenaux et al. (2009) develop a model in which the licensee company mainly faces a moral hazard problem stemming from the involvement of the faculty in the development stage because such involvement is not contractible at the initial licensing stage.[2] To our knowledge, there has, to date, been no examination of what happens before the invention reaches the *tto*; This is what we shall focus on in this paper. In previous work, the potential divergence of interests between the professors and the *tto* is only studied in the later development stage, whereas, in our approach, that divergence concerns the transfer path itself.

Focusing on what happens before the professors go to the *tto*, we are modeling a situation in which the property rights are not yet retained. At the first glance, this may suggest that professors face the standard appropriability problem of selling knowledge (Arrow, 1962; Anton and Yao, 1994, 2002). However, the fact that very shortly after meeting a company, professors can sollicitate the *tto*, provides them an implicit protection against the potential stealing of the invention by a company. Indeed, it sounds reasonnable to admit that professors can signal the quality of her ideas to companies, while still keeping secret for themselves a sufficient amount of information to be given to their *tto* if relevant, so that the latter can always be the first to file the patent.[3] Let's note that this leads to the apparent paradox that the presence of *tto*s in universities thus constitutes a substantial institutional support for professors to transfer theirs inventions directly to companies.

The remainder of the paper is organized as follows. Section 2 lays out the

[2]The authors also insist on the adverse selection problem associated to the possibility that the company actually licenses the invention to shelve it. Dechenaux et al. (2011) further study empirically the relation between the different types of payments and the later faculty involvement in development through consulting contracts.

[3]It would not be a problem in the USPTO system given its "first to invent" rule.

theoretical model, studies pure strategy equilibria of the game, investigates the robustness of the results and proposes an empirical strategy. Section 3 presents the data and the variables. The econometric model and the results are exposed in Section 4. Section 5 concludes.

2 The signaling model

In this section we introduce the signaling model, present the equilibria of the game, explore variations of the model and propose an estimation strategy.

2.1 The ownership game

We model academic technology transfer as a game involving a professor (p), a sampled company (c) and the technology transfer office (tto). We assume first of all that the professor gets an idea she believes has a potential commercial application. She then has the choice between two technology transfer paths: i) to sell her idea directly to a company she knows (possibly from past experience), or ii) to disclose it to the tto and let it manage the transfer process. In the latter situation, the inventor discloses the invention to the university which is assumed to always retain the intellectual property rights and the game ends with a university-owned patent. In the former situation, the inventor hands over the property rights to the company and the game ends with a company-owned patent.

We assume that the expected commercial value ω of a patentable idea is a function of its intrinsic scientific and technological value$v$ (which can be seen as a probability of success) and the capacity q of the firm to convert the idea into marketable technology products with high returns. Of course, the two dimensions are complementary and we propose the following simple specification:

$$\omega = v \cdot q. \tag{1}$$

One of the basic premises of our model is that v is private information known only to the scientist. Here q is common knowledge; however this assumption could be relaxed without significantly changing the results. For the sake of simplicity, we will also assume that $v \in V \equiv \{v_h, v_l\}$, where $v_h > v_l \geq 0$. The objective prior probabilities common to all companies on the distribution of v are described by: $\Pr(v = v_l) = p = 1 - \Pr(v = v_h)$. The expected v is noted as $\langle v \rangle = pv_l + (1 - p)\, v_h$.

The academic scientist can exert a signaling effort e which produces a signal, noted s. It is not certifiable and is only observed by the sampled company (other companies cannot observe it). These efforts may consist of several meetings, including their preparation, that the faculty must hold to convince the company of the quality of her idea. A natural assumption is that it is easier to convince the company of the utility of an invention when it is of good quality. Of course, the signal has no effect on the intrinsic scientific value$v$ of the idea. Thus the effort needed to provide a certain signal s, is also a function of v: $e(s, v)$. The standard and natural assumptions are that the marginal cost of signaling decreases with the quality of the idea, increases with the signal, and the cross derivative is also negative: $e'_v < 0, e'_s > 0$ and $e''_{vs} < 0$. In practice here, we will use the following functional form for the signaling technology:

$$e(s, v) = s/v.$$

If an agreement is reached with the company, and assuming that effort and monetary income enter the utility function in a linear fashion, the net gain for the scientist is given by:

$$u_a(s, v) = F - e(s, v), \tag{2}$$

with F the fixed fee contract, which is assumed to be the only feasible type of contract. The company's expected payoffs, provided an agreement is reached, are:

$$\pi_a = \sum_{v \in V} v \cdot \mu\,(s, v) \cdot q - F, \tag{3}$$

where $\mu\,(s, v)$ denotes the posterior belief of the sampled company in the value of the idea v having observed signal s.

The other way to commercialize the idea is through the university's *tto*. Once the idea is disclosed to the *tto*, the latter retains the intellectual property rights and organizes a Vickrey auction for an exclusive license, and the expected returns to the scientist are given by:

$$u_{na}(s,v) = \alpha \langle v \rangle q_{tto} - e(s,v), \tag{4}$$

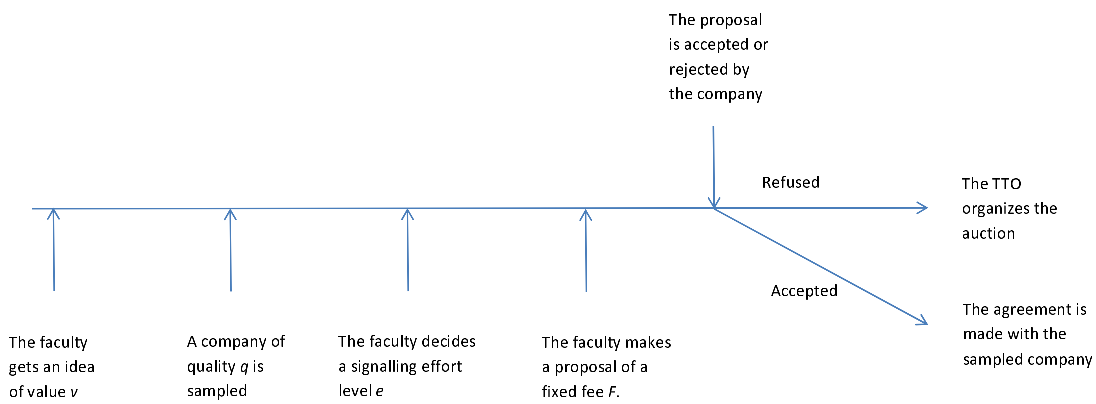
where α is the share of the sale price that goes to the scientist (with a share of $1-\alpha$ going to the institution). It may include a discount factor for the fact that going through the *tto* may take more time than making a deal with the sampled company. The quality of the second high-quality company that the *tto* is able to contact and convince of participating in the auction is q_{tto}. For the sake of simplicity, we assume here that the initial company is either never selected by the *tto*, or it never proposes the best offer. Therefore, the opportunity cost of accepting the offer is null: $\pi_{na} = 0$. Moreover, none of the bidders could observe signal s and evaluate the value of the idea at its mean $\langle v \rangle$. The highest bidder is the one that has the highest capacity $\bar{q} \geq q_{tto}$. He bids $\langle v \rangle \bar{q}$ and pays $\langle v \rangle q_{tto}$.

The timing of the game (summed up in Figure 1) is as follows:

- A faculty gets an idea and observes its quality $v \in \{v_H, v_L\}$.
- The faculty selects the most suitable company known and considers its quality q.
- Then, the faculty decides to exert a degree of personal effort e with the intention of convincing that company of the quality of her idea. The signal s produced is observed only by the company.
- The faculty proposes a fixed compensation F to be paid by the company in exchange for the property rights.
- The proposal is accepted or rejected by the company: $d \in \{1, 0\}$.
- If an agreement is reached, the fixed fee is paid, the company obtains the property rights to the idea and each party receives the payoffs associated with this result. Otherwise, the scientist goes to the *tto*, which retains the property rights, contacts several companies and organizes a Vickrey auction to provide an exclusive license (or even to sell such

property rights). Finally, it gives the scientist a share of the price paid (that was fixed before the game started).

Figure 1: Timing of the game.



2.2 Strategy profiles and equilibria

The game described above is a signaling game in which the informed agent typically plays first and has the opportunity to send a (costly) message (s) that may or may not reveal its type (v). Here, once this message is sent, the first player (the faculty) can again make a take-it-or-leave-it offer to the company in the form of a fixed fee F to be received in exchange for the property rights. The second player (the sampled company) merely accepts or rejects the offer $d \in \{1, 0\}$, after observing signal s and proposition F. A pure strategy profile of this game is thus: $((s, F) | v \,; d | (s, F))$. Mixed strategies are not allowed.

A system of beliefs of the uninformed agent is given by $(\mu(s, v))_{s \in \mathbb{R}^+, v \in V}$ with $\mu(s, v) \geq 0$ and $\sum_{v \in V} \mu(s, v) = 1, \forall s$. A weakly perfect Bayesian equilibrium of this game is characterized by a strategy profile and a system of beliefs $\left((s^*, F^*) | v \,; \; d^* | (s, F) ; \; (\mu(s, v))_{s \in \mathbb{R}^+, v \in \{v_H, v_L\}}\right)$ in which the two equilibrium strategies are the best responses to each other, also given the beliefs of the uninformed player, which are consistent with the equilibrium strategies of the informed player.

Depending on the values of the parameters, separating or pooling equilibria can arise. As shown below, for separating and pooling equilibria, two slightly different equilibria can arise.

2.2.1 Separating equilibria

Two forms of separating equilibria can occur, depending on whether the faculty with the low quality idea prefers to make a deal with the company or to go to the *tto*.

In the first type of separating equilibrium, both the faculty with the high quality idea and the faculty member with the low quality idea prefer to make a deal with the initial company rather than to hand over the intellectual property rights to the *tto*. This happens whenever the low quality scientist prefers to make a deal with the sampled company q rather than to hand over the property rights to the *tto*. Although the two agents make a deal with the company, the faculty with the high quality idea signals its quality, which enables her to make a better deal with the company. The faculty with the low quality idea sends no signal. The faculty with the high quality idea proposes to receive a fee $F^*(v_h) = v_h \cdot q$, while the faculty with the low quality idea proposes to receive a fee $F^*(v_l) = v_h \cdot q$. The company accepts the offer if $v_l q \leq F^* \leq v_h q$ and $s^* = qv_l(v_h - v_l)$ and when $F \leq v_l q$. The equilibrium strategies are formally described below.

Separating Equilibria 1.

- $s^*(v_h) = s^L \in [qv_l(v_h - v_l), qv_h(v_h - v_l)]\ ;\ s^*(v_l) = 0$
- $F^*(v_h) = qv_h\ ;\ F^*(v_l) = qv_l$
- $d^* = \begin{cases} 1 \text{ if } F \leq qv_h \text{ and } s = s^L \\ 1 \text{ if } F \leq qv_l \text{ and } s \neq s^L \\ 0 \text{ otherwise} \end{cases}$ (SE1)
- $\mu(s, v_h) = 1 - \mu(s, v_l) = \begin{cases} 1 \text{ if } s = s^L \\ 0 \text{ otherwise} \end{cases}$

The following lemma describes the conditions under which Separating Equilibria 1 hold.

Lemma 1 *Separating Equilibria 1 (SE1) hold if* $qv_l > \alpha q_{tto} \langle v \rangle$.

There is a second type of separating equilibria in which only the faculty with the high quality idea chooses to make a deal with the company rather than to hand over the intellectual property rights to the *tto*. The scientist with the low quality idea prefers to hand over the intellectual property to the *tto* as the maximum fixed fee that she would obtain from the company is lower than what she would get from the *tto*. According to the model, the scientist with the low quality idea will propose a high fixed fee to the sampled company, which the latter will reject.. The faculty with the high quality idea signals this quality, which enables her to make a better deal with the company. The faculty with the low quality idea sends no signal and hands over the intellectual property right to the *tto*. The equilibrium is given by:

Separating Equilibria 2.

- $s^* (v_h) = s^L \in [v_l (qv_h - \alpha q_{tto} \langle v \rangle), v_h (qv_h - \alpha q_{tto} \langle v \rangle)]$; $s^* (v_l) = 0$
- $F^* (v_h) = qv_h; F^* (v_l) > qv_l$
- $d^* = \begin{cases} 1 \text{ if } F \leq qv_h \text{ and } s = s^L \\ 1 \text{ if } F \leq qv_l \text{ and } s \neq s^L \\ 0 \text{ otherwise} \end{cases}$
- $\mu (s, v_h) = 1 - \mu (s, v_l) = \begin{cases} 1 \text{ if } s = s^L \\ 0 \text{ otherwise} \end{cases}$

(SE2)

The conditions under which Separating Equilibria 2 hold are given in Lemma 2.

Lemma 2 *Separating Equilibria 2 (SE2) hold if* $qv_l < \alpha q_{tto} \langle v \rangle \leq qv_h$.

2.2.2 Pooling equilibria

Two types of pooling equilibria exist according to the professor's expected returns from the *tto*. Along the path of the first type of pooling equilibria

(PE1), both types of ideas go to the company. Along the path of the second type of pooling equilibria (PE2), both types of ideas are handed over to the *tto*. Lemmas 3 and 4 tell us that at least one PE1 occurs when the professor's returns from the *tto* are low, while at least one PE2 occurs when these returns are high.

Pooling Equilibria 1.

$$\begin{array}{l} \bullet\ s^*(v_h) = s^*(v_l) = \hat{s} \in [0, v_l(\langle v \rangle - v_l)] \\ \bullet\ F^*(v_h) = F^*(v_l) = q\langle v \rangle \\ \bullet\ d^* = \begin{cases} 1 \text{ if } F \leq q\langle v \rangle \text{ and } s = \hat{s} \\ 0 \text{ otherwise} \end{cases} \\ \bullet\ \mu(s^*, v_h) = 1 - \mu(s^*, v_l) = \begin{cases} 1-p \text{ if } s = s^* \\ 0 \text{ otherwise} \end{cases} \end{array} \tag{PE1}$$

Lemma 3 *There exists at least one Pooling Equilibrium 1 (PE1) if* $\alpha q_{tto}\langle v \rangle \leq q\langle v \rangle$.

Pooling Equilibria 2.

$$\begin{array}{l} \bullet\ s^*(v_h) = s^*(v_l) = \bar{s} \in [0, qv_l(\alpha q_{tto}\langle v \rangle - v_l)] \\ \bullet\ F^*(v_h) > q\langle v \rangle\ ;\ F^*(v_l) > q\langle v \rangle \\ \bullet\ d^* = \begin{cases} 1 \text{ if } F \leq q\langle v \rangle \text{ and } s = \bar{s} \\ 0 \text{ otherwise} \end{cases} \\ \bullet\ \mu(s^*, v_h) = 1 - \mu(s^*, v_l) = \begin{cases} 1-p \text{ if } s = s^* \\ 0 \text{ otherwise} \end{cases} \end{array} \tag{PE2}$$

Lemma 4 *There exists at least one Pooling Equilibrium 2 (PE2) if* $\alpha q_{tto}\langle v \rangle \geq q\langle v \rangle$.

2.3 Synthesis and Empirical strategy

2.3.1 Multiplicity of equilibria

Let us write $\bar{\theta} = \alpha\langle v \rangle q_{tto}$, the returns expected by the faculty who goes through the *tto*-managed technology transfer process. Depending on $\bar{\theta}$, either one or two types of equilibria hold simultaneously:

- If $\bar{\theta} < qv_l$, then SE1 and PE1 hold. In these two types of equilibria, both faculties with the high and low quality ideas reach an agreement with the sampled company.

- If $qv_l < \bar{\theta} < q\langle v\rangle$, SE2 and PE1 hold. Then, the faculty with the high quality idea reaches an agreement with the company in both equilibria. The behavior of the faculty with the low quality idea varies from one type of equilibrium to the other: she goes with the company in PE1 but prefers to go with the *tto* in SE2.

- If $q\langle v\rangle < \bar{\theta} < qv_h$, SE2 and PE2 hold. Then, the behavior of the faculty with the low quality idea is invariant in both types of equilibria. Only the behavior of the faculty with the high quality idea differs: in SE2, she goes with the company while she prefers to go with the *tto* in PE2.

- If $qv_h < \bar{\theta}$, only PE2 holds in which both faculties choose the *tto* transfer process.

The conditions under which the four types of equilibria described above hold are synthesized in Table (1). It is apparent that we have two forms of multiplicity of equilibria: within types and between types. The first form is not really an issue for us since it does not modify ownership. The second, however, is more stringent when $qv_l < \bar{\theta} < qv_h$. In the following subsection, we will show that the intuitive criterion (Cho and Kreps, 1987) is sufficient to rule out such an undesirable multiplicity of equilibria.

Table 1: Weakly perfect Bayesian equilibria.

	$\bar{\theta} = \alpha\langle v\rangle q_{tto}$			
	qv_l	$q\langle v\rangle$	qv_h	
Equilibria	SE1 PE1	PE1 SE2	SE2 PE2	PE2
$v = v_h$	*cpy*	*cpy*	*cpy tto*	*tto*
$v = v_l$	*cpy*	*cpy tto*	*tto*	*tto*

2.3.2 The intuitive criterion

Weakly perfect Bayesian equilibria may rely on unreasonable beliefs off the equilibrium path. Cho and Kreps (1987) introduced a refinement, the intuitive criterion, which demands that off-equilibrium beliefs should interpret any deviation in terms of the signaling content it potentially embodies. The intuition behind the intuitive criterion is that following a sender's deviation (in this case, the professor), the receiver (the sampled company) should put a zero probability on the agent being of a type such that his equilibrium payoffs are greater than any payoff he could get from the deviation, provided the receiver plays his best response to the deviation (given his beliefs). Cho and Kreps (1987) show that the intuitive criterion rules out all pooling equilibria and keeps only the most efficient separating equilibrium in a single-crossing signaling model with two types. As a direct consequence, only the most efficient of Separating Equilibria 1 and Separating Equilibria 2 remain here. Pooling Equilibria 1 never survive and Pooling Equilibria 2 survive only when $\bar{\theta} > qv_h$. In this case, it is easy to see that no agent wants to deviate by signaling herself to the sampled company because the returns from the company cannot be greater than the expected returns of following the technology transfer process managed by the *tto*.

Table 2: Weakly perfect Bayesian equilibria that respect the intuitive criterion.

	$\bar{\theta} = \alpha \langle v \rangle q_{tto}$			
	qv_l	$q \langle v \rangle$	qv_h	
Equilibria	SE1	SE2	SE2	PE2
$v = v_h$	*cpy*	*cpy*	*cpy*	*tto*
$v = v_l$	*cpy*	*tto*	*tto*	*tto*

Table (2) presents the equilibria that still hold. It is clear here that the faculties with the high and low quality ideas adopt contrasted behaviors in the equilibrium paths when $qv_l < \bar{\theta} < qv_h$. This provides a key insight that will clarify the predictions of the model, in particular concerning the relation between the quality of ideas and patent ownership. This is the purpose of the last subsection.

2.3.3 Robustness of the theoretical results

In this subsection, we look at possible modifications or extensions of the model and examine if the results are affected. A first possible modification of the model would consist in allowing the professor to disclose her idea to the *tto* before considering making a separate deal with the sampled company. This would lead to the same payoffs than exerting no signaling effort and proposing a fee to the sampled company that would be rejected. Therefore, introducing this option in the model would not change the results at all. As a matter of fact, the only reason we have chosen to model a situation in which a prior agreement was made with the company is that to do the inverse - i.e. to approach the *tto* first - is likely to generate coordination costs, and it therefore always seems more judicious for the faculty member to approach the *tto* after discussing with the company if this proves right for her. One may also wonder if the assumed patent value technology (our specification of $\omega(v, q)$ impacts the results. It can easily be shown that for instance, an additive specification ($\omega = v + q$) rather than the multiplicative one we chose does change the results only very marginally and all conclusions remain unchanged.

Let us now consider more complex modifications of the model and discuss specifically to what extent the main prediction of the model (patent quality affects ownership) holds. Since this prediction relies on the existence of SE2 in which only the professors with high quality ideas choose the backdoor, in which high quality idea professors only prefer to take the back door, we will focus here on the robustness of this form of equilibria only.

Let us first consider that professors could later engage in a signaling process under the patronage of the *tto*. In a sense, it is a logical test: if the professor can engage in a signaling game with the sampled company, nothing prevents this from occurring in a situation where the transfer process is managed by the *tto*. If the professors could also signal the quality of their ideas later in the framework of a *tto* managed transfer process, they would still prefer to go with the initially sampled company if their returns are greater than the ones obtained by signaling later, under the patronage of the *tto*. The expected returns to signaling earlier would be unchanged ($u_a = qv_h - e(s^*(v_h), v_h)$) whereas the returns when signaling later would be given by $u_{na,s} \equiv \alpha v_h q_{tto} - e(s^*(v_h), v_h)$, assuming that the signaling technology is the same with or without the *tto*. Comparing these two expressions leads immediately to the conclusion that the high quality idea professor would signal the quality of her idea during the first stage when $q \geq \alpha\delta q_{tto}$, that is when $q \langle v \rangle \geq \bar{\theta}$. The differentiation in terms of transfer path depending on the quality of the idea is therefore sustained, although this differentiation is now valid for limited ranges of parameter values, that is to say when $qv_l < \bar{\theta} < q \langle v \rangle$.

Secondly, the high quality idea professor could propose a two-part tariff contract to the sampled company. Allowing a two-part tariff contract between the professor and the company would obviously extend the conditions for the existence of SE2: the high quality faculty, ceteris paribus, has the incentive to accept a small fixed amount, given that she expects larger returns thanks to the variable part. However, if two-part tariff licensing contracts are also possible between the *tto* and companies, then the conditions for the existence of SE2 would be reduced, in a similar fashion as above, when the faculty can also signal the quality of the idea through the *tto* transfer path. Therefore, the main conclusions as regard quality and ownership also remain here.

A third improvement of the model relates to the behavior of the companies participating in the *tto* auction, which could be modeled explicitly. If they were players in this game, one of the equilibrium conditions should be that their bids rationally take into account updated beliefs consistent with SE2. Companies participating in the auction would be able to guess that only the low quality ideas are proposed by the *tto* in this type of equilibria. Therefore they will make a bid, taking into account not $\langle v \rangle$ but v_l. A careful examination of the new incentives for professors with high or low quality ideas to deviate when the players reveal their private ideas, leads to a slight modification in the definition of the separating equilibrium itself. The only difference with the former definition of SE2 lies in the range of possible values for the limit signal from the professor with high quality ideas, which becomes $s^L \in [v_l (qv_h - \alpha q_{tto} v_l), v_h (qv_h - \alpha q_{tto} v_l)]$.[4] Therefore the main conclusions also apply in these circumstances.

2.3.4 Empirical strategy

Let us assume now that the returns from the auction organized by the *tto* are uncertain to the observer but known to the faculty, so the professor's expected returns from the auction are now given by $\theta = \bar{\theta} + \varepsilon$ where ε is normally distributed with zero mean. The dichotomic variable y that will be our dependent variable, takes value one if the property rights are handed over to the company, and zero otherwise. From the point of view of the observer, the probability that a given invention is sold to the company is now:

$$\Pr(y = 1|v) = \Pr\left(\bar{\theta} + \varepsilon < qv_l\right) + \Pr\left(qv_l < \bar{\theta} + \varepsilon < q\langle v\rangle\right) \times 1_{\{v=v_h\}} + \Pr\left(q\langle v\rangle < \bar{\theta} + \varepsilon < qv_h\right) \times 1_{\{v=v_h\}} \quad (5)$$

where $1_{\{\cdot\}}$ denotes the indicator function which equals one if the condition in brackets is met and zero otherwise. After some simple recombinations, the probability that an academic patent is owned by a company becomes:

$$\Pr(y = 1|v) = F\left(q\left(v_h - v_l\right) \cdot 1_{\{v=v_h\}} + qv_l - \bar{\theta}\right), \quad (6)$$

where F denotes the normal cumulative distribution function. The data presented below have the advantage of providing some proxies for each of the right hand variables. The quality of the idea (and the patent) can be measured ex post by using patent citations, the capacity q of the company can be also proxied by the scientist's patenting experience, assuming that the greater her patenting experience, the higher the number of companies

[4]Similar changes would also be obtained in SE1.

she knows and thus the higher the quality of the company she samples, and θ can also be proxied by the *tto*'s experience (essentially through q_{tto}), which has been highlighted as being of great importance in previous studies.

The immediate parametric analogue of equation (6) is given by :

$$\Pr(y = 1|v) = F\left(\alpha_1 q\,(v_h - v_l) \cdot 1_{\{v=v_h\}} + \alpha_2 q v_l - \alpha_3 \bar{\theta}\right). \tag{7}$$

At some point, we will be interested in separating the effects of the three variables that are interacted with, and we will also perform the following regression :

$$\Pr(y = 1|v) = F\left(\beta_1 q + \beta_2 1_{\{v=v_h\}} - \beta_3 \bar{\theta} + \beta_4 \mathbf{D}\right), \tag{8}$$

with **D,** a vector of covariates, including technological field dummies (capturing in particular $v_h - v_l$) and other control variables (including potentially university dummies).

3 Data description and variables

In this section, we focus on the description of the data and the construction of the variables used.

3.1 Sample and data collection

Data on British academic inventors have been collected using a methodology similar to the one described in Lissoni et al. (2008). Our database was obtained by merging the PATSTAT database containing all EPO applications filed between 1978 and 2002 and the Research Assessment Exercise (RAE) 2001 database containing data on 60,672 academic researchers employed by British universities and higher education institutions in 2001. Individual information only includes the name of university department (or research center) of affiliation, the discipline, surname and first name initials.

Academic inventors were identified in four stages. First, on the one hand, we only considered British inventors holding European patents and whose last patenting year was not before 1994 and not later than 2002.

On the other, we only considered the individual scientists included in the RAE database on Medicine, Biological Sciences, Pharmacy and Chemistry, Physics and Mathematics and Engineering Sciences and Electronics. Second, the two databases were merged into one by surname and first name initials. This procedure resulted in 9,009 potential British academic inventors. Third, web searches were performed to collect more detailed information in order to compare professors' full names with inventors' full names. After false matches were eliminated, we still had 5,005 potential UK academic inventors. Fourth, further web searches were performed to collect professors' email addresses, which resulted in a list of 2,588 professors' email addresses. These professors were then asked by email to confirm or infirm their inventor status using a web interface. Out of the 998 inventors who replied, 625 confirmed at least one invention. The comparison of respondents versus non-respondents showed no significant differences between disciplines.[5]

Altogether, these 998 inventors reported 1,376 academic patent applications filed at the European Patent Office (EPO) when they were working in a UK university. Table (3) breaks down these patents by the type of their first applicant(s).[6] Since our focus is on the allocation of ownership rights between universities and companies, we only consider the following categories: companies, universities, co-applications between universities and companies, and others.[7] Approximately 6% of academic patents were applied for by at

[5]Tests are not included is the paper due to space constraints but are available from the authors.

[6]It is possible that the applicant of the first filing may differ from the data we retrieved from the PATSTAT database, in case of a later change of ownership. In this case, there is the possibility that some patents that appear to be owned by companies were initially owned by public institutions or universities. To take into account this possibility, we individually checked all patents owned by companies according to the PATSTAT database. We found that 5% of these patents were originally owned by universities and for this reason we categorized them as being university owned.

[7]The patents in the last category include patents assigned to government institutions and PROs (Public Research Organizations), to physical persons, or to specific institutions such as the British Technology Group (BTG), which was a public organization operating as a brokerage agency in support of universities until its privatization in 1993. For robustness, all regressions were re-run after BTG patents are re-categorized as university owned

least two assignees of different types. Furthermore, most of the time, one university is listed as the co-applicants;In this case, and if in addition no company is involved, the patent is categorized as university owned in Table (3). Simultaneously, the patents assigned to companies in this table only involve company applicants. Despite this conservative rule, Table (3) shows that almost 50% of academic patents in the sample are owned only by firms. This figure puts the UK in between European continental countries - which usually report more than 70% of company owned academic patents (see Lissoni et al. 2008, Czarnitzki et al. 2012) - and the US in which only 25% of academic patents are assigned only to companies (Thursby et al. 2009). The high percentage of patents owned by firms in the UK may be surprising as scientists have been legally obligated to disclose their inventions to the *tto* since 1977.[8]

Table 3: Frequency and number of academic patents by type of ownership.

	%	Number
Company	48.1	662
University	38.1	524
Univ. and Company	3.5	48
Others	10.3	142
Total	100	1376

3.2 Variables

Since our aim is to explain why some academic patents are assigned to firms while others are assigned to universities, patents assigned to *Others* and co-applications are excluded from the analysis and the final dataset consists in $1,186$ patent applications,owned either by firms only or by at least one university but not co-owned by any company. The units of observation con-

patents whenever the priority year was before the privatization, and as company owned patents otherwise. All results remain the same (available upon request).

[8]For further discussion on university IPR regulations in Europe, see Geuna and Rossi (2011).

sist of patent-professor pairs, resulting in $1,260$ observations. Single patent applications may appear more than once if the invention was made by more than one academic inventor in the sample. The dichotomic dependent variable y_i indicates the type of the first patent applicant: zero for university and one for company only.

3.2.1 Patent value

In the theoretical model presented above, the total expected commercial value ω encompasses both the technical and scientific part captured by v and the ability of the company to translate it into commercial returns captured by q. What we intend to grasp behind the terms "patent value" is precisely. Bessen (2008) highlighted the importance of distinguishing the value of patent rents from the value of the underlying technology. If the former is generally linked to the quality of one or more products to be protected in the market, linked to the position of the company in the market, and thus correlated to the ability to generate profits, the latter is far away from the specificities of the market. A useful way of thinking of v here is that it should reflect the value of the patent *regardless of* the characteristics of the applicant. This remark leads to a more technical point: the proxy that should be used for v should not be prone to the potential endogeneity problem which arises to the extent that the quality of a patent is determined by the applicant itself.

In our view, the variable which best meets these requirements is the number of forward citations received by the patent. Since Trajtenberg (1990), forward patent citations have often been used as an indicator of patent value. It has been shown that patent citations are highly correlated with the perceived importance of the invention by the inventors themselves (Lanjouw and Schankerman, 2004; Harhoff et al. 1999; Harhoff and Reitzig 2004; Jaffe et al. 2000). In addition, forward citations are also highly positively correlated with the expected profits from the inventions (ω in the model, which increases with v) as well as various economic and financial indicators. For example, Hall et al. (2005), find a significant and positive relationship between the

Tobin's Q of firms and their stock of citation-weighted patents, and Hirschey and Richardson (2004), by measuring patent quality with the number of forward citations, find evidence that patent quality statistics help investors in predicting stock prices. Finally, Fischer and Leidinger (2014) find forward citations to be correlated with the patent economic value, which is inferred from the amount of money bidders are willing to pay in patent auctions.

Concerning the requirement that the chosen proxy for v should be independent from the characteristics of the company that exploits the patent, forward citations seem to be quite well suited, to the extent that some corrections can be made. The number of times a patent is cited is determined *after* the ownership decision has been made and it is not directly influenced by patent applicants and patent attorneys, and this should limit the problem related to the reverse causality between patent quality and ownership.[9] Other possible proxies such as the number of claims or the number of backward citations are more likely to be influenced by the characteristics of the applicant him/herself since they directly and at least partly result from decisions made by the applicant. However, a patent of a given quality may have a different number of citations due to the applicant's *exploitation*. Especially when originating from companies' R&D labs, patents may also be highly cited in other patent applications from the same company, which is likely to keep following this line of inquiry. To remove this bias, we do exclude all self-citations when computing patent quality.

More specifically, in the empirical analysis, the patent value is proxied by the number of forward citations to the focal patent, excluding self-citations at the applicant level (that is, those from down-the-line patents invented by the same applicant) in the first three years after the patent priority date ($PatQual_i$ where i refers to the patent-professor pair). We use a fixed moving time window to control for the fact that, because of truncation, older patents receive on average more citations than more recent patents. We consider a three-year window because early citations have been found to be highly correlated with the economic value of patents, while later citations are mostly seen as an indication for the science-basedness of patents (Lan-

[9]In Section 4.3 we explicitly discuss the endogeneity problem.

jouw and Schankerman, 2004; Sampat et al., 2003; Czarnitzki et al. 2012). However, to test for robustness, we consider different citation lags (results are discussed in Section 4.2).

Finally, since alternative measures of patent value could be also considered,[10] we also propose, in Section 4.2, a composite index of patent value based on a common factor model encompassing different proxies for patent quality that may be considered as acceptable, and show that replacing the forward citations with this measure does not change the results.

3.2.2 Other variables

The capacity of the company to exploit the professor's idea (q) is simply approximated by the patenting experience of the focal professor, assuming that the capacity to find a good match on one's own is enhanced by previous invention experiences. For each patent-professor pair i, the focal professor's patenting experience ($ProfExp_i$) is measured by the number of EPO patent applications she filed before the priority date of the focal patent.

The expected returns to the faculty using the technology transfer process managed by the *tto* ($\bar{\theta}$) is approximated by the *tto* patenting experience. The idea is that the higher the number of patents managed by the university *tto*, the higher its efficiency and its ability to make profits (Curi et al. 2012). For each patent, we consider the number of patents applied for by each university in which the academic inventor was working at the time of application. In order to retrieve this information, we relied on curriculum vitae and affiliations from publications. The variable $UnivExp_i$ is the cumulative number of EPO patents owned by the university (at the time of the focal patent invention) where the focal professor was employed at the time she filed the focal patent. In addition or alternatively to this measure we also use university dummies - one for each professors' university - to control for the university technology transfer policies and efficacy, and control for non observable characteristics. Interestingly, great heterogeneity in the

[10]See Squicciarini, Dernis, Criscuolo (2013) for a recent discussion on definitions and measurements of patent quality.

ownership of faculty's inventions appears from the data.

Finally, we also consider the idea that making a good match with a company may also depend on the local demand side. The patenting experience of the private sector in the professor's technological sector and local environment may increase the probability that she will leave the intellectual property to a company. We thus build a control for the number of patents applied by companies in the same technological field as the focal patent and in the same county as that of the professor's the patent application year. However, this variable is never significant and does not affect estimates of other variables, which might suggest that the local market for technology is not the main target of the academic inventions. For this reason we prefer not to display the results on the models built using this control.

3.3 Descriptive statistics evidence

Table (4) presents summary statistics for the previously described explanatory variables and reports them separately for 568 academic patent-professor pairs assigned to universities and 692 assigned to companies. The two samples show statistically significant differences for all variables considered. In particular, a simple t test for the comparison of means reveals that the two groups are significantly different in terms of patent value ($PatQual_i$) as measured by forward citations (t-value = -3.23): patent-professors pairs assigned to companies have on average 50% citations more than those assigned to universities. In terms of patenting experience ($ProfExp_i$), more experienced professors are on average associated to the company assigned patents category and this difference is statistically significant (t-value = -3.19). Finally, academic patents assigned to universities are associated with higher *tto* experience, as measured by the number of patents owned by the professor's university ($UnivExp_i$). In particular, the universities of professors who decided to hand over the IPR to the *tto* have already filed approximately 50 patent applications on average by the time they file the focal patent application have on average around 50 patents applied at the time of the patent, while universities of inventors who preferred the bypass option have previously filed about 38 patent applications. This difference is highly statistically significant (t-value = 4.76).

Table 4: Summary statistics on the sample of academic patent-professor pairs.

	University assigned					Company assigned					T - test	
	obs.	mean	sd	min	max	obs.	mean	sd	min	max	diff.	t-value
$PatQual_i$	568	1.08	2.28	0	28	692	1.63	3.49	0	44	-.55	-3.23
$ProfExp_i$	568	3.50	5.20	0	29	692	4.49	5.69	0	29	-.99	-3.19
$UnivExp_i$	568	50.76	48.59	0	274	692	37.82	47.59	0	288	12.94	4.76

4 Estimation issues and results

4.1 Baseline estimations

According to the theoretical model, we regress patent, professor and university characteristics on a binary assignment variable which equals one if the patent is initially assigned to a firm and zero if it is assigned to a university. Since the observations in the model consist of patent-professor pairs, and academic inventors may appear multiple times in the data, we used clustered standard errors to control for potential dependence among the error terms. The error terms are assumed to be normally distributed and thus we use probit models.

Probit coefficient estimates and their level of significance are presented in Table 4. In each model, we include year dummies, which control for the influence of the year during which a patent was applied for at the EPO. In some models we also consider technological dummies (according to the OST (2008) classification in 30 classes) which account for the fact that academic patents in some fields, due to their intrinsic characteristics, are more likely to be assigned to one or the other type of organization. We also introduce at some point university dummies to control for the (invariant) specificities of the professors' university as regard technology transfer. All explanatory variables are expressed as their logarithm plus one in order to avoid the nuisance of a null value.

Column (I) presents the estimated coefficients of equations derived from model (7). Low (v_l) and high (v_h) patent quality are approximated by the 25^{th} and 75^{th} percentiles in the population of all UK patents in the year and technological field of the focal patent: $PatQual_i^{25^{th}}$ and $PatQual_i^{75^{th}}$. As the quality is proxied by forward citations up to 3 years after the filing year and the distribution of citations is highly skewed, the 25^{th} percentile of the distribution in each year and sector is zero, that is $v_l = 0$. Hence, technological field impacts are captured only by v_h that is now $PatQual_i^{75^{th}}$. The patent quality indicator function $1_{\{v=v_h\}}$ in Equation (7) is replaced by the patent quality v itself approximated by the number of forward citations($PatQual_i$) since in real life patent quality is more continuous. When we also replace each parameter with its empirical counterpart and index for patent-professor pair i, Equation (7) becomes:

$$\Pr(y_i = 1) = F\left(\alpha_1 \cdot PatQual_i \cdot ProfExp_i \cdot PatQual_i^{75^{th}} - \alpha_3 \cdot UnivExp_i\right). \tag{9}$$

Column (II) presents the estimated coefficients of the equation with the addition of technological field dummies. Column (III), (IV) and (V) show the estimated coefficients of Equation (8) when we break up the interaction effect in order to separate the effect of patent quality from the effect of inventor's patenting experience, that is relying on an equation of the form:

$$\Pr(y_i = 1) = F\left(\beta_1 \cdot PatQual_i + \beta_2 \cdot ProfExp_i - \beta_3 \cdot UnivExp_i + \beta_4 \mathbf{D}\right). \tag{10}$$

The vector of controls $\mathbf{D}$ in column (IV) and (V) includes field effects that are captured by 29 technological dummies, in column (V) university-dummies[11] which control for all non observable characteristics at the university level.

In each probit model the signs of the coefficient estimates are in line with the theoretical discussion and significantly different from zero. In particular, when we consider the interaction term of patent quality, the inventor's patenting experience and the technological field impact captured by v_h as

[11] We lose 87 observations because in some cases we don't observe variability in the patent assignement for some universities.

explanatory variable the effect is positive and significant at 99% confident level. At the same time the influence of $UnivExp_i$ is as expected: the higher the *tto* experience, the smaller the chance that a patent is assigned to a company. In terms of marginal effect,[12] this means that a 1% increase in the *tto*'s patenting experience reduces by 0.07% the probability of bypassing.

Models (III)-(V) continue to support the view that patent ownership is a rational decision by academic inventors who consider the costs and benefits of bypassing the *tto*. First of all, according to the parameter estimates higher quality ideas are more likely to go directly to firms. In particular, when only technological dummies are taken into account (Column IV), the effect of patent quality is substantial and significant at the 99% confidence level. The associated probit coefficient is 0.16 which, in terms of marginal effect, means that a 1% increase in the number of citations implies a 0.06% increase in the probability that the patent is owned by a firm. In line with the prediction of the model, we find that the higher the professor's patenting experience, the greater the probability that the academic patent is owned by a company. In marginal effects, it means that a 1% increase in $ProfExp_i$ increases this probabilty by 0.06%. As expected again, more experienced *tto*s are more likely to attract inventions. However, university patenting experience ($UnivExp_i$) isn't significant anymore when we control for university dummies (Column V). This suggests that our measure of *tto* experience captures more variation between universities than within university.

[12] All marginal effects are calculated at mean values of the explanatory variables and are available from the authors.

Table 5: Baseline models

	I	II	III	IV	V
	Probit	Probit	Probit	Probit	Probit
$PatQual_i \cdot ProfExp_i \cdot PatQual_i^{75^{th}}$	0.149***	0.143***			
	(0.0419)	(0.0405)			
$ProfExp_i$			0.172***	0.167***	0.166**
			(0.0658)	(0.0635)	(0.0654)
$UnivExp_i$	-0.181***	-0.163***	-0.186***	-0.170***	0.0879
	(0.0499)	(0.0476)	(0.0503)	(0.0476)	(0.176)
$PatQual_i$			0.162***	0.160***	0.208***
			(0.0561)	(0.0556)	(0.0570)
Tech. dummies	No	Yes	No	Yes	Yes
Univ. dummies	No	No	No	No	Yes
Pseudo R^2	1260	1260	1260	1260	1173
Observations	0.053	0.085	0.060	0.091	0.170

Clustered standard errors in parentheses.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Year dummies are included in all models. The dependent variable is equal to one if the patent applicant is a company, and zero if it is a university. Patents applied for by individuals, BTG and PROs are not considered. $PatQual_i$ is the number of forward citations excluding self-citations at the company level, within the first three years after the patent priority date. In column V we lose 87 observations because of the perfect correlation between university dummies and patent assignment. All explanatory variables are taken in logs plus one.

4.2 Alternative measures of patent quality

In this Section we control for the robustness of the results by considering different citation lags for the computation of the patent quality and a composite indicator which encompasses alternative proxies for patent quality.

As mentioned in Section 3.1 we have chosen to consider primarily a three year window because citations are found to be more correlated with the economic value of patents in the short term than in the long term (Lanjouw and Schankerman, 2004; Sampat et al., 2003; Czarnitzki et al. 2012). By considering different citation lag (displayed in Table 6) we show that measures for patent value computed considering citations made during the first four years following the priority date are always significant and positively correlated with corporate patent ownership. Moreover the associated coefficient decreases over time and eventually disappears when considering citations in a longer period of time. Moreover, the other coefficients in the regression are not affected by the choice of citation lag.

If the forward citations are extensively used as a proxy for patent value, the literature shows however that alternative measures of patent value could also be considered. This is the case, for example, of the number of backward citations listed in the patent application ($Back - citations_i$) and the number of 8-digit IPC technology fields (Ipc_i). A higher number of backward citations may indicate a higher potential profitability of the domain of the patent (Lanjouw and Schankerman (2001), Harhoff et al. (2003)). The number of IPC technology fields should reflect the diversity and the scope of the patented invention (Lerner, 1994) and should be, for this reason, positively correlated to the value of the invention.

In order to check for the robustness of the empirical results we follow Lanjouw and Schankerman (2004)[13] and, along with forward citations, the two[14] alternative patent quality indicators were combined into a composite index of patent 'quality' derived from a common factor model. The methodology is briefly presented in Appendix 7.2. Results are shown in the last column of Table 6: as for the patent quality based on the 3-year forward citations, academic patents with an higher value of the $CompositeIndex_i$ have a higher probability of being assigned to the private sector.

[13]A composite patent quality indicators is also used later by Mariani and Romanelli (2006) and Hall et al. (2007).

[14]We also consider the number of claims in the patent application (Tong and Davidson, 1994) as component of the quality index instead of the number of IPC classes. Results do not change - although the problem of weak instruments is more pronounced - and are available by the authors.

Table 6: Alternative measures of patent quality

	I	II	III	IV	V	VI	VII
	Probit	Probit	Probit	Probit	Probit	Probit	Probit
$ProfExp_i$	0.168***	0.167***	0.167***	0.167***	0.170***	0.173***	0.167***
	(0.0633)	(0.0634)	(0.0635)	(0.0636)	(0.0636)	(0.0638)	(0.0639)
$UnivExp_i$	-0.172***	-0.171***	-0.170***	-0.170***	-0.170***	-0.171***	-0.171***
	(0.0477)	(0.0475)	(0.0476)	(0.0477)	(0.0477)	(0.0475)	(0.0478)
$PatQual_i$ (1 year)	0.199**						
	(0.0986)						
$PatQual_i$ (2 years)		0.193***					
		(0.0670)					
$PatQual_i$ (3 years)			0.160***				
			(0.0556)				
$PatQual_i$ (4 years)				0.0919*			
				(0.0491)			
$PatQual_i$ (5 years)					0.0464		
					(0.0453)		
$PatQual_i$ (after 5 years)						0.000880	
						(0.00488)	
$CompositeIndex_i$							0.586**
							(0.245)
Tech. dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Univ. dummies	No	No	No	No	No	No	No
Observations	1260	1260	1260	1260	1260	1260	1260
Pseudo R^2	0.088	0.091	0.091	0.088	0.087	0.086	0.090

Clustered standard errors in parentheses.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Year dummies are included in all models. The dependent variable is equal to one if the patent applicant is a company, and zero if it is a university. Patents applied for by individuals, BTG and PROs are not considered. $PatQual_i$is the number of forward citations excluding self-citations at the company level, computed for different citation lags. $CompositeIndex_i$ is the Composite index of patent quality is based on the number of forward citations (3 years citation lag), backward citations and 9-digit IPC technological classes. All explanatory variables are taken in logs plus one but the composite index which is normalized.

4.3 Endogeneity of patent quality

The main result of our baseline models indicates that patents of higher value are more likely to be assigned to companies. Nevertheless, we are concerned that the estimates presented in the previous section might be biased due to a reverse causality issue. On the one hand, patent ownership can depend on patent quality as the theoretical model describes, but, on the other hand, patent quality can also be due to the type of applicant. This could be the case when the number of patent citations is influenced to some extent by the applicant's characteristics.

We propose two complementary methods to address this issue. The first one, presented in the next subsection, relates to a specific view on the way reverse causality arises (professors' consulting activities) and offer practical and simple solutions. The second one relies on an instrumental variable approach that is presented in the second subsection. All results are presented in a third subsection.

4.3.1 A specific reverse causality phenomena: consulting

When a company has an important problem to address but does not have all the necessary competencies to deal with it, it may be interested in contacting academic professors. There is the obvious possibility that the inventive idea does not originate from the university laboratory, but that the company moves first and then selects professors and employs them in a *consulting* activity and retains ownership. This could also occur in the context of a research contract between the company and the laboratory for instance. In this case, by moving first and bringing the problem in, the company may be more likely to retain the assignment of any potential resulting intellectual property. Thursby et al. (2009) suggest that patents derived from consulting activities should be less basic than those assigned to universities and propose to add a variable capturing the originality of the scientific idea. As they suggest, we rely on the patent originality measure developed by Trajtenberg et al. (1997), a Herfindhal based index reflecting the dispersion of citations made by the patent across patent classes, which is calculated as follows:

$$Originality_i = 1 - \sum_j s_{ij}^2, \tag{11}$$

where s_{ij} is the share of i's backward citations classified in the technological class $j = 1, ..., 30$ (which we measure by the OST 30 classes).[15] A score of 0 indicates that all backward citations fall into one technological class, while a score close to one indicates citations that can be classified in many classes. In this light, a patent is considered more original when it cites prior art from many different technological classes. We therefore expect a negative sign.

4.3.2 The instrumental variable approach

Although we control for the consulting effect, it is still possible that patent quality might to some extent be determined by the type of ownership. On the one hand, we might expect that companies, because they have more resources than universities do, are able to produce more valuable patents from the same invention. In other words, given the professor's scientific quality idea, the value of the associated patent would be higher when developed in an company than in an university, simply because the company has more possibilities and competencies than the university to exploit the technological idea. In this case a positive bias of the estimates is expected. On the other hand, a patented idea might spill over more easily if it is developed in a university rather than in a company. Through scientific conferences and publications, researchers in academia gain reputation by disseminating their discoveries and, for this reason, knowledge embedded in university patents appear to be disseminated more rapidly (Henderson et., 1998; Montobbio and Bachiocchi, 2009). Since forward patent citations measure the patent quality and indicate knowledge flows (Jaffe et al., 1993), a patent developed in a university could be associated to more citations. In this case a negative bias of the patent quality estimates is expected.

[15] For patents without backward citations in the search report, Originality would be unspecified. We adopted the following stratagem: whenever a patent does not cite any patent, we consider that patent cites itself.

To control for generic causes of reverse causality, we thus propose an instrumental variable approach. As an exogenous source of variation in patent quality we use three instruments. The first one is the quality of the previous patented invention by the same academic inventor. Our idea is that the previous patent quality is likely to not be correlated with the ownership of the actual patent, and rather to be correlated with the quality of the actual patent, since both originate at least partly from the same mind. The issue that remains unresolved her is whether the exogeneity condition really holds, as one could argue that if personal contacts are important in the ownership decision and do not change quickly over time, the ownership of the focus patent might in the end be correlated with the quality of the previous patent (because the ownership and the quality of the previous patent would be also correlated). In order to improve the estimation precision, we also consider two additional instruments: the average patent quality in the same technological class of the focal patent (we here rely on the broader OST classification in seven categories), and the size of the patent inventor's team. It is known that the number of inventors listed in the patent is related to patent quality whereas it does not seem to be related to the ownership of academic patents. Sapsalis et al. (2006), in a sample of 400 biotech Belgian patents, found that the average size of the inventor's team was the same (about 3.3) for university and company owned patents. Our data show a slightly higher number of inventors for company patents (3.5 versus 3.2). Our identification assumptions are that our instruments are related to patent quality but not to patent ownership. If this is the case, they turn out to be valid and satisfy the orthogonal assumption. A probit model on patent ownership that incorporates the instrumented patent quality as an explanatory variable is estimated in the second stage.

Since the first instrument is based on the characteristics of the previous patent applied for by the same academic inventor we lose 527 patent-professor pairs.[16]

[16]In fact i) 314 academic inventors who only have one patented invention are excluded and ii) the observations related to the first patent for those with more than one patent are dropped.

4.3.3 Results

The results are exposed in Table 7. Models in columns (I) and (II) are similar to the models of columns (IV) and (V) of Table 5 with the inclusion of the variable $Originality_i$ as a control for inventions which presumably originate from the company. In columns (III) to (VI), we show the results of the different specifications of the two step IV-probit for the restricted sample of patent-professor pairs.

According to models (I) and (II), even when we control for $Originality_i$, quality and the professor's patenting experience are still positively and significantly correlated with the company ownership. Interestingly, with the inclusion of $Originality_i$ the effect of patent quality is slightly more pronounced than before, which might reveal a negative bias in the parameter estimates in the baseline model.[17] In terms of marginal effects, it means that a 1% increase in the number of citations increases the probability that the patent is owned by a company by around 0.07%. As expected, $Originality_i$ is found to be negatively correlated with the company ownership (although it turns out to be significant only when we control for university dummies), a result which is consistent with the consulting hypothesis (Thursby et al. 2009).

The IV-estimates are displayed in columns (III) to (VI). In columns (III), (IV), and (V) patent quality (the instrumented variable) is measured as the number of forward citations with respectively 3, 4 and 5-year citation windows, while in column (VI) patent quality is proxied by the composite index discussed in Section 4.2. The Amemiya's generalized Least Squares (AGLS) probit estimation[18] (Newey, 1987) that we use amounts to estimating OLS on patent quality and then using the predicted values in the ownership probit model. The AGLS estimator produces a consistent estimation of the standard errors and may perform better than MLE with a smaller sample when instruments are weak (Adkins, 2010). However, the IV Probit estimation

[17] The correlation between $PatQual_i$ and $Originality_i$ is in fact positive and significant.

[18] We use the 'ivprobit, twostep' routine in Stata.

Table 7: Endogeneity issues.

	Probit	Probit	IV probit	IV probit	IV probit	IV probit
	I	II	III	IV	V	VI
$ProfExp_i$	0.174***	0.173***	0.149**	0.134*	0.135**	0.120*
	(0.0638)	(0.0654)	(0.0727)	(0.0687)	(0.0663)	(0.0646)
$UnivExp_i$	-0.166***	0.0900	-0.210***	-0.207***	-0.213***	-0.199***
	(0.0478)	(0.179)	(0.0493)	(0.0465)	(0.0449)	(0.0433)
$Originality_i$	-0.266	-0.392**				
	(0.165)	(0.181)				
$PatQual_i$(3 years)	0.173***	0.225***	1.369***			
	(0.0557)	(0.0569)	(0.493)			
$PatQual_i$ (4 years)				0.914**		
				(0.367)		
$PatQual_i$ (5 years)					0.666**	
					(0.295)	
$CompositeIndex_1$						2.957**
						(1.401)
Tech. dummies	Yes	Yes	No	No	No	No
Univ. dummies	No	Yes	No	No	No	No
Observations	1260	1173	733	733	733	733
Wald (p-value)			0.003	0.007	0.013	0.067
Amemiya-Lee-Newey (p-value)			0.702	0.466	0.272	0.185
Weak instr. F-test			7.27	8.92	10.60	11.63
Pseudo R^2	0.093	0.173				

Clustered (at professor level) standard errors in parentheses in columns I-II. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Year dummies are included in all models. The dependent variable is equal to one if the patent applicant is a company, and zero if it is a university. Patents applied for by individuals, BTG and PROs are not considered. $PatQual_i$ is the number of forward citations excluding self-citations at the company level, computed in the first three years after the priority date. $CompositeIndex_i$ is the Composite index of patent quality is based on the number of forward citations, backward citations and 9-digit IPC technological classes. The instruments for patent quality are the number of patent inventors, the patent quality of the previous patent invented by the same professor, and the average patent quality All explanatory variables are taken in logs plus one but the composite index which is normalized. Note that in the second step of the IV procedure technological dummies are omitted because of collinearity with the average value of patent quality which is calculated at technological level.

with clustered standard errors is not feasible in this case.[19]

To test whether patent quality is endogenous to the ownership regression, the Wald test of endogeneity (Wooldridge, 2001) was performed. The null hypothesis corresponds to the exogeneity case of the regressor under scrutiny. The Wald test computations (bottom of Table 7) lead us to reject the null hypothesis of exogeneity of the regressor and therefore justify the use of IV-estimations. Then, in order to test whether the three instruments are valid, the Amemiya-Lee-Newey test was used. The null hypothesis is that the instruments are jointly valid, that is, they are uncorrelated with the error term in the structural equation and the instruments are correctly excluded from the estimated equation. With the three aforementioned instruments for patent quality, Table 7 shows that the Amemiya-Lee-Newey minimum chi square p-values are between 0.185 and 0.702[20], which leads to the non-rejection of the null hypothesis. Finally, regarding the performance of our instruments, the F-test for weak instruments approximates the threshold of 10 and it might be an indicator of potential weak instruments problem. However, the first-stage results (not displayed here to save space but available from the authors) indicate a significant partial correlation of our instruments with patent quality.

The IV estimates of patent quality coefficients are significant and much higher than the ones observed in the baseline model displayed in Table 5. In column (V), which is the IV estimate less prone to the problem of weak instruments, the coefficient of patent quality is more than ten times the coefficient of the same measure of patent quality when not instrumented (Table 6, column V). This suggests again that the baseline probit coefficients of patent quality are downward biased. Interestingly, the coefficient of professor patenting experience decreases when controlling for endogeneity and this might suggest that part of the effect of patent quality was previously

[19] A possible solution is to use the clustered bootstrap method, which creates resamples of the observed data by dyads (patent-inventor) and then estimates by IV Probit method. Unfortunately this method does not give us reliable estimates since one or more parameters cannot be estimated in too many replications.

[20] Calculated using the iv-probit and overid modules for Stata.

captured by professor experience. In the model without university dummies, university patenting experience still has an effect on the patent ownership.

5 Conclusions

While many scholars in the fields of law, sociology, and economics explore which entities should and could optimally own inventions that arise from federally funded academic research (Kenney and Patton 2009, 2011), we, in this article, highlight the strategic behaviour of academic inventors in the commercialization of their invention even when by law they are required to assign ownership to their university. More specifically, we theoretically and empirically investigate the transfer of academic inventions by considering the *tto*s as facilities representing only one way of commercializing university inventions. In this perspective, university researchers may try to commercialize their inventions on their own, thus bypassing the *tto*, and then directly face the problems of asymmetric information in invention quality and that related to the matching of inventions with a specific industrial and commercial use. In order to address the first problem we argue that they may signal the quality of their idea to a sampled company. Regarding the second problem, we hypothesize that professors can rely on their previous patenting experience. The structure of the pure strategy equilibria of the signaling model leads to a positive relation between patent quality and company ownership.

Our empirical analysis relies on a sample of more than twelve hundred pairs of professors in British universities and patents (they invented) applied for between 1990 and 2001 at the European Patent Office. Simple statistics show that almost 50% of them were assigned to a company. Probit estimates show that company ownership is indeed associated with higher patent quality. Moreover, as predicted by the model, greater inventor patenting experience and lower *tto* experience are also associated with company ownership. Results are robust to the inclusion of various controls (such as the technological class or university dummies) and to the use of various proxies of patent quality (different citation windows for recording forward citations and the use of a composite indicator). Finally, potential reverse causality problems are taken into consideration. We find that the removal of self-citations at the applicant level (controlling for further development of the technology by the owner) and controlling for patent originality (reflecting a potential consulting phenomena) do not change the results. In addition, an IV approach in which patent quality is instrumented by the quality of the previous patent invented by the same academic inventor, the average quality in the technology field, and the size of the patent inventors team demonstrates the robustness of our results.

These findings may be of interest for technology policy designers and technology transfer managers. They support the idea that the *tto*s only represent one of the possible means of technology transfer from which university professors can choose. Though scholars do not enjoy the so called "professors privilege" in the UK (the right to retain intellectual property on their research results), they seem to behave as such, and thus the legal debate does not seem to be essential, at least when these inventions are not pure gold mines, a situation which unfortunately is extremely rare. This also suggests that the CEOs of the *tto*s should develop specific contractual strategies to prevent professors from bypassing their facility, in particular when their inventions are suspected of being of higher quality, a line of investigation that is directly suggested by our results: late entrant universities in technology transfer could inflate royalty shares to inventors as a means of compensating for their lack of experience in technology commercialisation; professors with high levels of experience in patenting could be offered higher shares as well (or an improved service), and *tto* should let personal financial returns decrease less strongly with the total income generated by the invention.

Our analysis is not without limitations. It would be interesting to bring our basic model of ownership decision closer to reality by putting it in a broader perspective, for example by considering at which stage of the academic R&D process firms and professors contact each other, or by empirically analysing the role played by royalty and license fees proposed by their *tto* on the strategic behaviour of academic scientists.

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7 Appendix

7.1 Proofs

7.1.1 Proof of Lemma 1 (Separating Equilibria 1)

The proof of Lemma 1 is organized in three steps: first, it examines the incentives of the faculty member with the high quality idea to deviate from her equilibrium strategy (i), before turning to the case of the faculty with the low quality idea (ii) and finally to the sampled company (iii).

(i) Let us first consider the case of the faculty with the high quality idea.

In SE1, she incurs a signaling cost $e(s^*(v_h), v_h)$ that fully reveals her quality v_h. In this equilibrium, the company's expected payoffs, observing such a signal, are $\pi_a = v_h q - F^*(v_h)$, since its (fully consistent) posterior beliefs lead to $\mu\left(s^*(v_h), v_h\right) = 1$, and $\mu\left(s^*(v_l), v_l\right) = 0$. Therefore, the faculty with the high quality idea proposes an agreement to the company that saturates its participation constraint $F = qv_h$, and her utility becomes:

$$u_a\left(s^*(v_h), v_h\right) = qv_h - e(s^*(v_h), v_h). \tag{12}$$

Provided the signal is not less than $qv_l\left(v_h - v_l\right)$ (to prevent the faculty with the low quality idea from also signaling), the faculty sets it no greater than $qv_h\left(v_h - v_l\right)$ and her utility is such that:

$$u_a\left(s^*(v_h), v_h\right) \geqslant qv_l. \tag{13}$$

The scientist could deviate by simultaneously modifying the signaling efforts and the agreement proposal made to the sampled company. It is trivial to see that a higher signal would lead to a lower utility, as increasing signaling efforts would be costly and would not enable the scientist to obtain a better deal. A lower signal $s < s^*(v_h)$, would lead to be considered as not signaling, and obviously, in this case, her utility would simply be the same as that of the faculty with the low quality idea in this equilibrium, since she then has no incentive to make any signaling effort at all. The faculty's payoffs become equal to either the payoffs obtained with the *tto*-managed technology transfer process if she does not modify her proposition to the sampled company, that is $\alpha q_{tto} \langle v \rangle$, or qv_l if she formulates a proposal that saturates the sampled company's participation constraint. Here, as stated in Lemma 1, we have $qv_l > \alpha q_{tto} \langle v \rangle$, and thus the faculty with the high quality idea would simultaneously modify her proposal to the company to obtain an agreement. Therefore, the scientist with the high quality idea would not have any incentive to deviate by reducing her signaling costs whenever $u_a\left(v_h, s^*(v_h)\right) \geqslant qv_l$, which, as equation (13) states, is always verified.

(ii) Let us now consider the incentives to deviate that the faculty with the low quality idea may have.

In the equilibrium path, sustaining a null signaling cost $e(0, v_l) = 0$ and proposing an agreement that saturates the participation constraint of the sampled company, provides her with a utility of:

$$u_a\left(0, v_l\right) = qv_l. \tag{14}$$

The faculty could deviate by choosing a signal that would mimic the scientist with the high quality idea. Then, her signal would be: $s(v_l) = s^*(v_h) = s^L \geq qv_l\left(v_h - v_l\right)$. The efforts associated with such a signal for the scientist with the low quality idea are $e(s^L, v_l) \geq q\left(v_h - v_l\right)$. While also proposing the same agreement to the company as that proposed to the faculty with a high quality idea, her utility is such that:

$$u_a\left(s^*(v_h), v_l\right) \leq qv_l. \tag{15}$$

Thus, the scientist with the low quality idea will never have an incentive to deviate. The scientist with the low quality idea could also deviate from the equilibrium strategy by charging a different fee to the sample company. A lower fee would trivially bring less and a higher fee would lead to a refusal from the company in this equilibrium, which would push the faculty to disclose the idea to the *tto* and obtain $u_{na} = \alpha q_{tto} \langle v \rangle$, which is lower than qv_h (let us remember that the assumption here is that $\alpha q_{tto} \langle v \rangle < qv_l$ and that by assumption $v_l < v_h$).

(iii) Finally, let us consider the case of the sampled company.

The company could deviate from the equilibrium strategy by accepting the offer either when $s < s^L$ and $F \leq v_h q$, when $s \geq s^L$ and $F > v_h q$, or even when $F > qv_l$ and $s < s^L$, or when $F \leq qv_l$ and $s \geq s^L$. It is trivial to see that it would not be better off in any of these cases.

7.1.2 Proof of Lemma 2 (Separating Equilibria 2)

In the equilibrium path of any SE2, only the faculty with the high quality idea prefers to make a deal with the sampled company rather than to disclose her idea to the *tto*. Lemma 2 shows that these equilibria stand whenever $qv_l < \alpha q_{tto} \langle v \rangle < qv_h$.

The proof of Lemma 1 is organized in three steps: first, it examines the incentives of the faculty with the high quality idea to deviate from her equilibrium strategy (i), before turning to the case of the faculty with the low quality idea (ii) and lastly to the sampled company (iii).

(i) Let us first consider the case of the faculty with the high quality idea.

In SE1, she incurs a signaling cost $e(s^*(v_h), v_h)$ that fully reveals her quality v_h. In this equilibrium, the company's expected payoffs, observing such a signal, are $\pi_a = v_h q - F^*(v_h)$, since its (fully consistent) posterior beliefs are such that $\mu\left(s^*(v_h), v_h\right) = 1$, and $\mu\left(s^*(v_l), v_l\right) = 0$. Therefore, the faculty with the high quality idea proposes an agreement to the company that saturates its participation constraint $F = qv_h$, and her utility becomes:

$$u_a\left(s^*(v_h), v_h\right) = qv_h - e(s^*(v_h), v_h). \tag{16}$$

In any of these equilibria, the faculty with a high quality idea sets a signal no greater than $qv_h\left(qv_h - \alpha q_{tto} \langle v \rangle\right)$ and her utility is then such that:

$$u_a\left(s^*(v_h), v_h\right) \geqslant \alpha q_{tto} \langle v \rangle\,. \tag{17}$$

[2]The faculty with the high quality idea could deviate by simultaneously modifying the signaling efforts and the agreement proposal made to the sampled company. It is trivial to see that a higher signal would lead to a lower utility since increasing signaling efforts would be costly and would not

enable the scientist to obtain a better deal. A lower signal $s < s^*(v_h)$, would lead to the faculty not signaling her type, and obviously, in this case, her utility would simply be the same as that of the faculty in this equilibrium, since she then has no incentive to provide any signaling effort at all. The faculty's payoffs become equal to either the payoffs obtained through a *tto*-managed technology transfer process if she does not modify her proposition to the sampled company, that is $\alpha q_{tto} \langle v \rangle$, or qv_l if she formulates a proposal that saturates the sampled company's participation constraint. Here, as stated in Lemma 2, we have $qv_l < \alpha q_{tto} \langle v \rangle$, and thus the faculty with the high quality idea would simultaneously modify her proposal to hand over the IP to the TTO. Hence, the scientist with the high quality idea would not have any incentive to deviate by reducing her signaling costs whenever $u_a (s^*(v_h), v_h) \geqslant \alpha q_{tto} \langle v \rangle$, which is always verified (as stated in Equation 17).

(*ii*) Let us now consider the incentives of the faculty with the low quality idea to deviate.

In the equilibrium path, sustaining a null signaling cost $e(0, v_l) = 0$, and proposing an agreement greater than the participation constraint of the sampled company ($F^*(v_l) > qv_l$) in order to hand over the IP to the TTO, provides her with a utility of:

$$u_{na} (0, v_l) = \alpha q_{tto} \langle v \rangle . \tag{18}$$

The faculty could deviate by choosing a signal that would mimic the scientist with the high quality idea. Then, her signal would be: $s(v_l) = s^*(v_h) = s^L \geq v_l (qv_h - \alpha q_{tto} \langle v \rangle)$. The efforts associated with such a signal for the scientist with the low quality idea are such that $e(s^L, v_l) \geq (qv_h - \alpha q_{tto} \langle v \rangle)$. While also proposing the same agreement to the company as that proposed to the faculty with a high quality idea, her utility (by deviating from the equilibrium strategy) becomes:

$$u_a (s^*(v_h), v_l) \leq \alpha q_{tto} \langle v \rangle . \tag{19}$$

Thus, the scientist with the low quality idea would not have the incentive to deviate. The scientist with the low quality idea could also deviate from the equilibrium strategy by charging a different fee to the sample company. A fee lower than the firm participation constraint in the low quality inventor case would trivially bring less (the company would accept the offer and in that case the scientists would obtain $v_l q < \alpha q_{tto} \langle v \rangle$, and a higher fee would lead to the same outcome of the equilibrium (as the company would not accept the proposal and the scientist would end up with the TTO outcome).

(iii) Finally, let us consider the case of the sampled company.

The company could deviate from the equilibrium strategy by accepting the offer either when $s < s^L$ and $F \leq v_h q$, when $s \geq s^L$ and $F > v_h q$, or even when $F > qv_l$ and $s < s^L$, or when $F \leq qv_l$ and $s \geq s^L$. It is trivial to see that it would not be better off in any of these cases.

7.1.3 Proof of Lemma 3 (Pooling Equilibria 1)

In the equilibrium path of any pooling equilibrium 1, both scientists with the high quality and low quality ideas prefer to make a deal with the sampled company rather than disclosing their idea to the *tto*.

The proof of Lemma 3 is organized in in three steps: first, it examines the incentives of the faculty with the high quality idea to deviate from her equilibrium strategy (i), before turning to the case of the faculty with the low quality idea (ii) and finally to the sampled company (iii).

(i) Let us first consider the case of the faculty with the high quality idea.

In PE1, she incurs a signaling cost $e(s^*(v_h), v_h) = \frac{\hat{s}}{v_h} \leq \frac{v_l}{v_h} (\langle v \rangle - v_l)$. In this equilibrium, the company's expected payoffs, observing such a signal, are $\pi_a = \langle v \rangle q - F^*(v_h)$, since its posterior beliefs remain unchanged: $\mu(s^*(v_h), v_h) = 1 - p$, and $\mu(s^*(v_l), v_l) = p$. Therefore, the faculty with the high quality idea proposes an agreement to the company that saturates its participation constraint $F = \langle v \rangle q$, and her utility becomes such that:

$$u_a(s^*(v_h), v_h) = \langle v \rangle q - e(s^*(v_h), v_h) \geq \langle v \rangle q - \frac{v_l}{v_h} (\langle v \rangle - v_l) \qquad (20)$$

The scientist with the high quality idea could deviate by simultaneously modifying the signaling efforts and the agreement proposal made to the sampled company. It is trivial to see that a higher signal would always lead to a lower utility, as increasing signaling efforts would be costly and would not enable the scientist to obtain a better deal. It is also trivial to see that by asking for a lower fee, the scientist will end up with a payoff that is lower than the equilibrium. On the other side, by asking for a higher fee ($F^d > \langle v \rangle q$), the scientist will end up with the *tto* outcome, as the sampled company would reject the offer in equilibrium: in this case, the associated gross payoff would be $\alpha\delta q_{tto} \langle v \rangle$ instead of $\langle v \rangle q$. Thus, she would not have the incentive to deviate to the extent that $\langle v \rangle q \geq \alpha q_{tto} \langle v \rangle$. If the low quality idea professor deviates by reducing efforts, then the optimal deviation is to provide no effort and the net payoffs become null. Thus the professors do not deviates this way if $\langle v \rangle q \geq \frac{\hat{s}}{v_h}$.

(*ii*) Let us now consider the incentives of the faculty with the low quality idea to deviate.

The above reasoning applies to the faculty with the low quality idea. In the equilibrium path, sustaining a signaling cost $e(s^*(v_l), v_l) = \frac{\hat{s}}{v_l}$, and proposing an agreement that saturates its participation constraint $F = \langle v \rangle q$, her utility becomes:

$$u_a(0, v_l) = \langle v \rangle q - e(s^*(v_l), v_l) = \langle v \rangle q - \frac{\hat{s}}{v_l} \tag{21}$$

It is trivial to see that the scientist will not have the incentive to deviate to the extent that $\langle v \rangle q \geq \alpha q_{tto} \langle v \rangle$ (as stated in Lemma 3) and $\langle v \rangle q \geq \frac{\hat{s}}{v_l}$.

(*iii*) Finally, let us consider the case of the sampled company.

The company could deviate from the equilibrium strategy by accepting the offer when $F > \langle v \rangle q$. It is trivial to see that, in this case, it would not be better off as the expected profit would be negative.

Compiling (*i*) and (*ii*) and (*iii*), we see that there is always at least one Pooling Equilibrium 1 when $\langle v \rangle q \geq \alpha q_{tto} \langle v \rangle$, the one of which the on-the-equilibrium path signal is $\hat{s} = 0$. This completes the proof of Lemma 3.

7.1.4 Proof of Lemma 4 (Pooling Equilibria 2)

In the equilibrium path of all second pooling equilibria, both the scientists with the high quality and low quality ideas prefer to disclose their idea to the *tto* rather than make a deal with the sampled company.

(i) Let us first consider the case of the faculty with the high quality idea.

In PE2, she does incur a signaling cost $e(s^*(v_h), v_h) = \frac{\bar{s}}{v_h}$. In this equilibrium, the company's expected payoffs, observing such a signal are $\pi_a = \langle v \rangle q - F^*(v_h)$, since its (fully consistent) posterior beliefs lead to $\mu(s^*(v_h), v_h) = 1 - p$, and $\mu(s^*(v_l), v_l) = p$. In the equilibrium, the faculty with the high quality idea proposes an agreement to the company that is greater than its participation constraint $F^*(v_h) > \langle v \rangle q$ and her utility becomes:

$$u_{na}(\bar{s}, v_h) = \alpha q_{tto} \langle v \rangle - e(s^*(v_h), v_h) = \alpha q_{tto} \langle v \rangle - \frac{\bar{s}}{v_h} \tag{22}$$

The scientist with the high quality idea could deviate by simultaneously modifying the signaling efforts and the agreement proposal made to the sampled company. It is trivial to see that a higher signal would lead to a lower utility, as increasing signaling efforts would be costly and would not enable the scientist to get a better deal. It is also trivial to see that by asking for a fee that is not greater than the company's participation constraint, the scientist will end up with the associated payoff of $\langle v \rangle q$ instead of $\alpha q_{tto} \langle v \rangle$. Thus, she will not have the incentive to deviate to the extent that $\alpha q_{tto} \langle v \rangle > \langle v \rangle q$. If the low quality idea professor deviates by reducing efforts, then the optimal deviation is to provide no effort and the net payoffs become null. Thus the professors do not deviate this way if $\langle v \rangle q \geq \frac{\bar{s}}{v_h}$.

(ii) Let us now consider the incentives of the faculty with the low quality idea to deviate.

The same reasoning above applies to the faculty with the low quality idea. In the equilibrium path, sustaining a signaling cost $e(s^*(v_l), v_l) = \frac{\bar{s}}{v_l}$ and proposing an agreement to the company that is greater than its participation constraint $F^*(v_h) > \langle v \rangle q$, her utility becomes:

$$u_{na}(\bar{s}, v = v_l) = \alpha q_{tto} \langle v \rangle - \frac{\bar{s}}{v_l} \tag{23}$$

It is trivial to see that the scientist will not have the incentive to deviate to the extent that $\langle v\rangle q \geq \alpha q_{tto} \langle v\rangle$ and $\langle v\rangle q \geq \frac{\bar{s}}{v_l}$.

(iii) Finally, let us consider the case of the sampled company.

The company could deviate from the equilibrium strategy by accepting the offer when $F > \langle v\rangle q$. It is trivial to see that, in this case, it would not be better off as the expected profit would be negative.

Compiling (i) and (ii) and (iii), we see that there is always at least one Pooling Equilibrium 2 as soon as $q \geq \alpha q_{tto}$, the one where the equilibrium path signal $\hat{s} = 0$ (as stated in Lemma 4).

7.2 A composite patent quality index

Following the approach suggested by Lanjouw and Schankerman (2004), we use a multiple indicator model with an unobserved common factor:

$$x_{i,n} = \gamma_i s_i + e_{i,n} \tag{24}$$

where $x_{i,n}$ is the value of the i-th patent indicator for the n-th patent observation (in logs); s_i is the common factor with factor loading γ_i and normally distributed.

The common factor is the unobserved characteristic of a patent that positively influences three 'quality' indicators:

1. $PatQual_i$: the number of forward citations that a patent receives in the first three years following the priority date, excluding self citations at the applicant level.

2. $Back - citations_i$: the number of backward citations listed in the patent application.

3. Ipc_i: the number of 9-digit IPC technology fields.

The analysis is based on the total number of EPO patent applications between 1990 and 2002 with at least one inventor residing in the UK (60,680 observations).

We estimated s_i following a two-step procedure. We first regress the three observed patent quality indicators against two observable patent characteristics, the priority year and the technological class of the patent according to the OST30 classification. The residuals of such equations are the indicator values that are not explained by observable characteristics. In the second step we use the residuals from the first step as determined by the common factor. From the matrix of variance-covariance of error terms of the three equations we derive the parameter estimates of the common factor model.[21]

The table below shows the parameter estimates of the indicators that set up the composite quality index.

Table 8: Parameter estimates of the Common Factor Model.

$PatQual_i$	0.47***
	(0.023)
$Back-citations_i$	0.14***
	(0.008)
Ipc_i	0.33***
	(0.017)
Observations	60680

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parenthesis.
The explanatory variables are the standardized residuals of regressions
of the threethree patent quality indicators against year and technological field dummies.

[21]We use the 'SEM' routine in Stata.