More Secrecy...More Knowledge Disclosure?

On Disclosure Outside of Patents*

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SEPTEMBER 2007

Abstract

It is an important concern that innovators by waiving their patent rights might obstruct the disclosure of knowledge and therefore retard progress. This paper explores this concern by using a simple model of two innovators who must decide *sequentially* whether to protect an innovation with *limited* patent rights. Two features are crucial to the disclosure decision. First: the second inventor may use his *valid* patent right to exclude the first inventor from using a secret invention. Second: when waiving her patent right, the first inventor may disclose her knowledge *outside* of a patent. Disclosure informs the Patent Office and courts that related inventions from later inventors may lack novelty and hence should not be protected by *valid* patent rights. This paper shows that when the first inventor chooses *not* to patent the innovation, the *amount* of disclosure is related to the intellectual property choices in a paradoxical way: the *amount* of disclosure will be 'large' ('small') when the second inventor chooses secrecy (patenting) to protect the innovation too.

KEYWORDS: Disclosure, Imitation, Duplication, Exclusion, Sequential Patent Rights.

I. Introduction

The disclosure of innovations is crucial to progress. The patent system confers rights on inventors in exchange for revealing their 'secrets'. Patents, however, are costly and limited property rights: by patenting, first inventors are exposed to the threat of *imitation*. These features of patents drive inventors to consider alternative intellectual property (IP) choices, mainly secrecy. Consistent with this description, empirical evidence (see Cohen, Nelson and Walsh [8] and Mansfield [19]) shows that, except in a small number of industries, patents are considered less effective than secrecy in protecting intellectual assets and that an important percentage of patentable inventions are not patented. Thus

*This paper was written while I was part of the Max Weber Programme at the European University Institute, Florence, Italy. I have benefited from numerous suggestions by Ramón Marimón, Massimo Motta and discussions with Joseph Ostroy. I thank useful comments from seminar participants at the Innovation and Competition Working Group.

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the essential concern is that by turning to secrecy, inventors might obstruct the disclosure of innovative knowledge.

But first inventors that waive their patent rights (secrecy) risk independent rediscovery by other researchers. If a second inventor obtains a *valid* patent right, at least in the U.S., he may exclude the first from using the secret innovation in the market.[1] Thus first inventors who choose not to patent their innovations are exposed to two kinds of overlapping threats: *duplication* and *exclusion.* Duplication occurs when a second inventor rediscovers the original innovation. Exclusion happens when duplication occurs *and* a second inventor obtains a *valid* patent right to exclude the first from using the secret innovation in the marketplace.

In this environment, the disclosure of enabling knowledge by first inventors plays a crucial role: it decreases the 'risk' of exclusion. The idea is simple: because patents are evaluated in the light of the prior art, first inventors, by disclosing, make it more difficult for second inventors to obtain *valid* patent rights on closely related innovations.[2] A concrete example of disclosure is that of Plantronics, a telephone headset manufacturer in California. The firm developed a new technology for reducing microphone noise and then posted a 'description' of it on a web site to establish the legal existence of the idea.[3] In this paper, I focus on this type of disclosure: the submission, by first inventors, of hard evidence to the Patent Office (PTO) and *courts* to indicate that innovations from later inventors may lack novelty and hence should not be protected by *valid* patent rights.

Using these observations as a point of departure, the paper pursues two main goals. First, it addresses the IP decisions (to patent or not) of research firms in the context of weak and costly patent rights. Second, it explores the concern that by not patenting their innovations, research firms might obstruct the disclosure of innovative knowledge. More precisely: the paper explores whether, and under what conditions, the use of disclosure may result in the widespread dissemination of innovative knowledge even when research firms choose not to patent their innovations.

To achieve these goals, I propose a model that captures the essential features of IP rights and disclosure. I consider a simple environment with two innovators who must *sequentially* decide whether to protect an innovation with patents. Two features are crucial to understanding the IP and disclosure decisions. First: the amount of the first inventor's disclosure not only reveals information to the PTO but it also transfers usable knowledge to the second inventor. I model this feature by assuming that at the time of disclosure the R&D outcome of the second inventor is still unknown. He could either

[1] In legal terms, first inventors who do not patent their innovations do not have prior user rights. See Denicolo and Franzoni [10] and Shapiro [24] for a discussion of the first inventor defense. Congress is considering legislation (H.R. 2795) that would create prior user rights in the U.S.

[2] Prior art is all the public knowledge either in previous patents, manuscripts, printed publications, etc. that existed prior to the filing of a patent application. In the United States, when an innovator discloses her invention, a one-year grace period ensures that the innovator's patent right is not immediately extinguished.

[3] See "Protecting Intellectual Property" The New York Times 02/18/2002, "Suddenly, 'Idea Wars' Take On a New Global Urgency" The New York Times 11/11/2002, and "On the Defensive About Invention" The Financial Times 09/19/2001. Johnson [12] is one of the few papers that provide data on disclosure. The author reports an increase of 200% in disclosure activity from 1995-1999 to 2000-2004: smaller firms are mostly responsible for that increment. Furthermore, companies like IP.com, in Rochester, and Research Disclosure Inc. provide disclosure services for research firms. More than 1,000 companies use Research Disclosure, which publishes about 400 disclosures a month. See also Baker, Lichtman and Mezzetti [4] for empirical evidence of disclosure.

succeed (innovative type) or fail (imitative type) in obtaining the innovation. Hence disclosure benefits imitative second inventors. I posit a simple link between disclosure and the imitative second inventor: the larger the level of disclosure, the higher the probability of duplication.

Second: the risk of exclusion depends on the IP decision of the second inventor. If he waives his patent right, the first inventor will not be exposed to exclusion. The IP decision of the second inventor is uniquely determined by the *value of patenting*: the difference between the expected return from using patenting versus secrecy to protect an intellectual asset. The value of patenting is in turn positively affected by the likelihood of obtaining a *valid* patent right and negatively affected by the (expected) patenting costs.[4] Thus, the *amount* of the first inventor's disclosure is critical to the IP decision of the second inventor: by increasing her disclosure level, the first inventor monotonically decreases the value of patenting and makes secrecy more attractive to the second inventor.[5]

Within this setup, the two central questions on which I focus are: (1) Why would a first inventor waive her patent right *and* disclose instead of patenting? (2) If a first inventor chooses not to patent her innovation, what should be the *amount* of knowledge disclosed outside of a patent? The answer to the first question is relatively simple. The first inventor will choose the IP strategy that maximizes her probability of obtaining the exclusive use of the innovation. More precisely: the first inventor will choose not to patent and disclose when the protection offered by this IP strategy is higher than the protection offered by a patent net of the patenting cost. The main ideas are easy to grasp. By patenting, the first inventor is exposed to imitation. By not patenting and disclosing, however, she optimally balances two 'risks': exclusion and duplication. By disclosing, she decreases the probability of being excluded at the cost of increasing the probability of being duplicated. I show that when patent protection is weak, the first inventor prefers to waive a patent right.

Two salient features of this result are worth stressing. First, I observe that even though the first inventor optimally waives a patent right, she discloses because she fears that the second inventor might want to obtain a patent. Why would a second inventor pursue a patent right when the first inventor did not find it attractive to use this IP option? The answer is direct but revealing. The first inventor may want to avoid patenting to conceal knowledge usable to imitative second inventors. The second inventor, however, when deciding his IP strategy, has no knowledge to conceal: he knows that the first inventor knows everything about the innovation. Second, I show that it is possible that the first inventor will waive a patent right and disclose even when there is a higher probability that her innovation will leak out under this IP strategy than under patenting. This outcome emerges because

[4] Patenting costs include not only the cost of obtaining a patent right but also the cost of monitoring a competitor, enforcing and defending a patent in court.

[5] My focus on the *amount* of disclosure as crucial in determining the duplication probability and IP choice of the second inventor can also be interpreted as the *precision* in the description of the innovation. Thus 'small' disclosure levels may be associated with poor descriptions of the innovation while 'large' disclosure levels with better descriptions of the invention. In this sense, it is usually said that in order to dilute the transfer of enabling knowledge to competitors *'...firms often publish anonymously, and they sometimes use vague language to describe an invention'.* Nevertheless the risks associated with this practice are that *'...if competitors are unable to understand an idea, there is a good chance that patent examiners will not either'.* See "Protecting Intellectual Property" The New York Times 02/18/2002.

the first inventor desires to avoid the costs involved in the patenting decision.

The answer to the second question is essential for understanding the importance of the disclosure decision. If the amount of disclosure outside of patents is ‘small’, inventors by waiving their patent rights might obstruct the dissemination of innovative knowledge. In this regard, the paper brings both good and bad news: the amount of disclosure, in the unique equilibrium, varies depending on the underlying economic environment. The good (bad) news is that the first inventor faces proper incentives to disclose a ‘large’ (‘small’) amount of knowledge when the intensity of product market competition is not too high (low) and when the threat of exclusion is relatively more (less) important than the threat of imitation.

I show that, in equilibrium, the amount of the first inventor’s disclosure is related to the IP choices in a paradoxical way: the amount of disclosure will be ‘large’ (‘small’) when the second inventor chooses secrecy (patenting) to protect the innovation too. Thus, from a social point of view, a subtle message may be conveyed: *one should not be too concerned about knowledge disclosure precisely when both inventors waive their patent rights and avoid the patent system.* Observe that when disclosure is ‘large’ both inventors avoid the patent system and its often lamented patenting and legal costs by resorting to secrecy. But the patent system plays a crucial ‘off the equilibrium path’ role to motivate a ‘large’ disclosure level: it is a vehicle used by second inventors to credibly threaten first inventors with exclusion.

The equilibrium which involves both inventors waiving their patent rights may appear, at first glance, the opposite of knowledge disclosure. Careful thought, however, clarifies the main idea. When the first inventor waives her patent right, she becomes exposed to the risk of exclusion unless the second inventor also waives his patent right. And the second inventor will waive his patent right when the first inventor’s disclosure level is sufficiently ‘large’ to make the value of patenting equal to zero. Put differently: by choosing a sufficiently ‘large’ disclosure level and inducing the second inventor to choose secrecy, the first inventor *fully* eliminates the risk of exclusion at the cost of a higher duplication probability. Summing up: when patent protection is weak and the intensity of product market competition is not too high, the unique equilibrium involves both inventors waiving their patent rights and the first inventor disclosing a ‘large’ amount of knowledge outside of the patent system.

II. Background

A. *Disclosure and Limited Patent Rights*

This paper builds on the notion that patents are limited property rights. Moreover, the validity of the second inventor’s patent is affected by disclosure from the first inventor. Empirical evidence confirms this presumption. Allison and Lemley [1] have found that once a patent has been issued, the likelihood that a court will hold it valid is only slightly better than even. Besides, their study confirms that the majority of grounds for invalidity are rooted in prior art: in most cases, a printed publication accessible to the public is enough to invalidate a patent. The premise that patenting is costly in comparison with secrecy is also important. Lerner [17] confirms that less-established firms employ secrecy because the direct and indirect costs of patenting are too high. Furthermore, Bessen and Meurer [7] corroborate the fact that the legal costs faced by patentees in defending their rights through the courts are significant. Cohen, Nelson and Walsh [8] also present evidence suggesting that one of the most relevant reasons for not patenting is the cost of enforcement.[6]

B. *Related Literature*

This paper relates to two different categories of economics literature. On the one hand, it contributes to a growing literature aiming to understand IP choices. Horstmann, MacDonald and Slivinski [11] is the first paper to model the decision of whether to protect an innovation with a patent in a context of asymmetric information. Anton and Yao [2 and 3] study information disclosure when innovators select either patents or secrecy. The idea of these papers is that information is disclosed to signal strong capability in an environment of limited property rights. In this paper, however, disclosure is used to diminish the threat of exclusion from future inventors, an aspect not examined in these previous papers. My basic formulation that prior innovators may be hurt by subsequent inventors owes much to the work of Denicolo and Franzoni [10]. However, I examine an environment with weak property rights and disclosure outside of patents, aspects not discussed by them. In relation to the IP choice, Kultti, Takalo and Toikka [14] are close in some ideas to the present paper. They show that innovators prefer patenting rather than secrecy even when patents offer weaker protection. Reminiscent of their result, I show in the present paper that when it is almost sure that the second inventor has a competing innovation in hand, the first inventor should always opt for patenting. However, my focus and results are different to that of Kultti et. al.: I explore an environment where first inventors face incentives to keep their innovations secret and disclose outside of patents in order to eliminate exclusion, a situation not considered in their paper.[7]

On the other hand, this paper relates to a literature in law and economics which explores defensive publications in patent races. Parchomovsky [13] was the first to draw attention to the possibility that innovators may strategically change the state of prior art. Litchman, Baker and Kraus [12], building on Parchomovsky, offered a signalling model of defensive publication. Baker, Lichtman and Mezzetti [4] and Bar [5] construct models in which firms disclose in order to prolong the race, and this gives followers a chance to catch up. Because these papers consider a patent race, secrecy is not an option. Besides, disclosures are executed by laggards rather than by leaders (first inventors) as in the current paper.

[6] Also, if first inventors had prior user rights second inventors would not be able to exclude them. The paper does not elaborate on this case, but the main conjecture is that prior users relying on secrecy would encounter the same difficulties as first inventors who use secrecy *and* lack prior user rights: those of proving to the courts that they were prior users and not merely opportunistic imitators. To the extent that disclosure can be used to submit this credible evidence and separate true prior users from opportunistic imitators, this paper also includes the latter situation. Denicolo and Franzoni [10] document the fact that in some European countries the original inventor can deposit a sealed description of the invention as a proof of being first.

[7] Johnson [12] is another related paper that studies the choice of IP by an innovator including the possibility of defensive publishing. The papers however disagree in the questions they answer and in the framework they use. The main goal of Johnson's paper is to identify under which circumstances a defensive publication strategy (modelled as a transfer of profit) is preferred by an innovator to the alternative choices of secrecy and patenting. My goal is to examine the IP choices of a sequence of inventors and the amount of knowledge disclosed outside of a patent.

Section III of the paper describes the model, discusses its more important assumptions and prepares the conceptual stage for what follows. Section IV presents the main results of the paper. Section V concludes. Finally, proofs are presented in the Appendix.

III. The Model

Consider an industry composed of two firms, A and B. The firms have been involved in a race to discover an innovation that represents an improvement over the status quo. They are risk neutral and maximize expected profits. Firm A has been the first to obtain the innovation (*first inventor*). It must decide whether to protect its intellectual asset with a patent. Let $\mathcal{P}$ denote the choice of patenting and $\{\mathcal{S}, d\}$ for $d \in \mathcal{D} := [0, 1]$ the alternative of not patenting the innovation (secrecy) and disclosing innovative knowledge outside of a patent. When firm A decides between $\mathcal{P}$ and $\{\mathcal{S}, d\}$, the R&D outcome for firm B is still unknown. It could either succeed in obtaining the innovation (innovative type) or it could fail in his R&D attempt (imitative type). Firm A believes that firm B will be innovative with probability $\lambda \in (0, 1)$.

If firm A chooses patenting, the firms will continue interacting in a market competition stage. If firm A chooses $\{\mathcal{S}, d\}$, however, disclosure affects firm B through two different channels. First, if firm B has failed in its R&D activity (imitative type), he might try to rediscover the innovation. Disclosure will have the result of increasing its probability, $p \in (0, 1)$, of finding the innovation. Second, disclosure creates new prior art and thus it decreases the chance that firm B has of obtaining a 'secure' patent right. Thus any type of firm B with an innovation in hand must decide its IP action. Like firm A, it can choose either patenting, $\mathcal{P}$, or secrecy, $\mathcal{S}$.[8] Finally, after firm B has decided its IP, the interaction between the firms is reduced to market competition.

IP Protection and Market Payoffs

Concealing the innovation completely is 'risky' for firm A: if firm B discovers the innovation it could potentially exclude A from using it in the market. Patents, on the other hand, are limited and costly property rights. Filing a patent, monitoring the competitor and detecting imitation entail substantial costs. Moreover patent rights usually have uncertain validity and imitation is a common occurrence (see Lemley and Shapiro [16]). To capture these ideas I assume that patenting entails an economic cost equal to c and that a patent is only 'secure' or 'alive' with a certain probability.[9] More precisely, if firm A chooses patenting it will be able to exclude firm B from using the innovation with probability $\alpha \in (0, 1)$. Below (see: *IP choice of Firm B*) I specify the corresponding strength of the

[8] Firm B does not have the choice of disclosing. This is a convenient simplification because firm B has no (strict) incentives to disclose. Disclosure, as will become clear later on, occurs only with the purpose of strategically manipulating the IP choice of later inventors. Firm B, being the last, does not encounter this kind of problem.

[9] The cost c includes not only the direct costs of keeping the patent 'alive' but also the business cost of potential litigation: business is disrupted, managers allocate their time to legal effort, complementary investments are halted, etc. (for an excelent discussion, see Bessen and Meurer [7]).

patent for firm B.[10]

Concerning the market competition stage, I indicate the equilibrium profits of the firms in reduced form. If only firm j has a 'secure' patent right over the innovation (i.e., it is able to exclude its competitor from using the innovation) then firm j obtains a high profit, $\pi_{\mathbf{H}}$, and the other firm gets a low profit, $\pi_{\mathbf{L}}$. If either (a) one of the firms chooses patenting but it cannot exclude its competitor from using the innovation or (b) both firms choose secrecy, then A and B obtain a duopoly profit, $\pi_{\mathbf{D}}$. For simplicity, I normalize and order profits as follows: $\pi_{\mathbf{H}} \equiv 1 > \pi_{\mathbf{D}} \equiv \pi > \pi_{\mathbf{L}} \equiv 0$.[11] Note that this payoff structure implies that when A's patent is not 'alive', the imitative type of firm B will have access to the 'secret' of the innovation revealed by firm A in the patent. In section IV, I discuss how my results would be affected if my model included not only disclosure *outside* of patents but also the possibility of strategic disclosure *in* patents.

The extensive form of the game can be summarized as follows:

(i) Firm A decides its IP choice: $\{\mathcal{P}, \{\mathcal{S}, d\}\}$ for $d \in \mathcal{D}$.

(ii) Nature chooses the type of firm B. If firm A has chosen $\mathcal{P}$, A and B interact in a market competition stage. If firm A has chosen $\{\mathcal{S}, d\}$, then:

(iii) After observing d, the imitative type of firm B *again* seeks to obtain the innovation. He chooses an effort level, p, which is normalized to be the probability of obtaining the innovation: $p \in (0, 1)$.

(iv) Finally, any type of firm B with an innovation in hand decides its IP choice: $\{\mathcal{P}, \mathcal{S}\}$; and A and B interact in a market competition stage.

A pure strategy for firm A is an IP choice: $\{\mathcal{P}, \{\mathcal{S}, d\}\}$ for $d \in \mathcal{D}$. A behavior strategy for firm B is: $\{\psi_n, \{p, \psi_i\}\}$, where $\psi_n : \{\mathcal{S}, d\} \to [0, 1]$ is the probability that the innovative type of firm B chooses $\mathcal{P}$. Finally, $p : \{\mathcal{S}, d\} \to (0, 1)$ and conditional on success in duplication, $\psi_i : \{\mathcal{S}, d\} \to [0, 1]$. For clarity, I will simply write $\psi_n(d)$, $\psi_i(d)$ and $p(d)$. The solution concept is Subgame perfect Nash equilibrium (SPE).

A. *IP Choice of Firm B*

Disclosure decreases the probability that firm B (no matter its type) has of obtaining a secure or valid patent right.[12] The focus is then on the consequences that disclosure has on the attractiveness of patenting to B. For simplicity, I assume that when B is indifferent between patenting or secrecy, it chooses the latter. For any $d \in \mathcal{D}$, let $\gamma(d)$ denote the probability that B's patent is 'secure': the

[10] The parameter α may be given at least two interpretations: (a) it may be understood as the probability of the first patent being declared *valid*; or (b) the probability that the patent is *not* circumvented. In the first case, the patent might be challenged not only by firm B but also by an outsider to the industry. Bessen and Meurer [7] found that lawsuits usually take place between firms that operate in different industries. They conclude that an important burden of patent disputes falls on defending firms. For models of Patent Litigation, see Bessen and Meurer [6] and Crampes and Langinier [9].

[11] Because competition drives profits down: $\pi \in \left(0, \frac{1}{2}\right]$. Notice then that Bertrand's competition with homogeneous products is not included. I could start by including this case, and the result would be that, in equilibrium, the optimal disclosure level would be zero.

[12] From now on, I will sometimes use the term valid or validity to describe the strength of a second inventor patent.

probability that B will be able to exclude A from using the innovation. The main assumption about $\gamma(.)$ is:[13]

ASSUMPTION 1: (a) $\forall d \in \mathcal{D} : \gamma(d) \in (0,1)$.

(b) $\forall d \in \mathcal{D} : \gamma_d(d) < 0$ and $\gamma_{dd}(d) > 0$.

(c) At $d = 0$, $\gamma(0) \equiv \alpha \in (0,1)$.

The crucial part is (b): it holds that disclosure has a marginal decreasing effect on the probability of securing a valid patent. Part (c) is a consistency requirement: if firm A does not create prior art, the validity of the 'second' patent must be equal to the validity of the 'first' one.[14]

Because the payoffs associated with each IP choice are *independent* of the type of firm B, I will refer to the IP decision of firm B. By patenting, B obtains a payoff equal to: $\mathcal{P}(d,t) = \pi + \gamma(d)\,(1-\pi) - c$, where $t := (\pi, c, \lambda, \alpha)$ is one possible vector of parameters. If it opts for secrecy, it gets $\mathcal{S}(t) = \pi$. Thus: $\mathcal{P}(d,t) = \mathcal{S}(t) + [\gamma(d)\,(1-\pi) - c]$. Hence the IP decision of firm B is based on $\mathcal{Z}(d,t) \equiv [\gamma(d)\,(1-\pi) - c]$: the value of patenting. By pursuing a patent, B obtains a market payoff above (below) that of secrecy equal to the expected market premium, $\gamma(d)(1-\pi)$, minus the (expected) patenting costs, c. Thus, B's IP strategy is: $\psi(d) = \mathcal{S}\ \forall d$ s.t. $\mathcal{Z}(d,t) \leq 0$; and $\psi(d) = \mathcal{P}\ \forall d$ s.t. $\mathcal{Z}(d,t) > 0$.[15]

The value of patenting, $\mathcal{Z}(d,t)$, is a strictly decreasing function of disclosure: this fact expresses the idea that disclosure has a negative impact on the value of patenting for firm B.[16] By creating prior art, disclosure decreases the probability of obtaining a 'second' secure patent right and hence it diminishes the expected market premium. A consequence of this fact is that $\mathcal{Z}(d,t)$ achieves its maximum value when disclosure is zero, $\mathcal{Z}(0,t)$, and it assumes its minimum value when disclosure is one, $\mathcal{Z}(1,t)$. Note also that if $\mathcal{Z}(0,t) > 0$ and $\mathcal{Z}(1,t) < 0$, then there exists a disclosure level, denoted by $d_L(t) \in (0,1)$, such that $\mathcal{Z}(d_L(t),t) = 0$.[17] In this situation, A through disclosure affects the sign of $\mathcal{Z}(d,t)$ and hence the optimal IP choice of firm B. Using $\psi(d)$, $\mathcal{D}$ can be partitioned into two intervals: $\mathcal{D}_P := [0, d_L(t))$, the set of disclosure levels for which B chooses a patent, and $\mathcal{D}_S := [d_L(t), 1]$, the set of disclosure levels for which he chooses secrecy. In this case, firm B's IP strategy is: $\psi(d) = \mathcal{P}$ $\forall d \in \mathcal{D}_P$ and $\psi(d) = \mathcal{S}\ \forall d \in \mathcal{D}_S$. Finally, if $\mathcal{Z}(d,t)$ has the same sign for all disclosure levels, B has a dominant IP strategy: either patenting or secrecy.

B. *Duplication Activities of Firm B*

If firm B fails in its R&D activity and firm A chooses $\{\mathcal{S}, d\}$, then B might try *again* to make the innovation.[18] It chooses an effort level, p, to maximize its expected profits anticipating its optimal IP

[13] In general, derivatives will be denoted by subscripts.

[14] Part (a) implies that $\gamma(1) \equiv \beta > 0$.

[15] I have choosen to denote the behavior strategy of B by $\psi(d) = \mathcal{S}$ or $\psi(d) = \mathcal{P}$ rather than $\psi(d) = 0$ or $\psi(d) = 1$ to facilitate the exposition.

[16] $\mathcal{Z}(d)$ is differentiable and convex in d.

[17] Observe that $d_L(t) = \phi\left(\frac{c}{(1-\pi)}\right)$ where $\phi \equiv \gamma^{-1}(.)$.

[18] Massimo Motta made very useful suggestions to greatly simplify this part.

choice. Because I am interested in obtaining the duplication probability of firm B, I normalize p to be the probability of duplicating the innovation: $p \in (0, 1)$. For clarity I present here a version with an *exogenous* probability of duplication. However, all the results hold when p is obtained as the *best response* duplication probability of firm B. A simple model along these lines is presented in Appendix B. That model gives rise to a best response duplication probability that has the same features that I impose here on p. Let $p(d, \pi, c)$ be the duplication probability function. For short, I write $p(d, t)$. I make the following assumption about the duplication probability function.

ASSUMPTION 2: (a) $\forall d \in \mathcal{D} : p_d(d, t) > 0$.

(b) $\forall d \in \mathcal{D} : p_{dd}(d, t) > 0$.

(c) $\forall d \in \mathcal{D} : p_\pi(d, t) \geq 0$, and if patenting is chosen: $p_c(d, t) < 0$.

This specification of the duplication probability function captures the intuitive idea that disclosure reveals knowledge useful to duplicate the innovation. The (strict) convexity of $p(d, t)$ is assumed mainly to facilitate the analysis. Finally, part (c) represents the simple notion that when duopoly profits increase, firm B will put more effort into finding a more profitable innovation.

C. *Disclosure*

Here I turn my attention to those situations in which firm B does *not* have an IP dominant strategy. The opposite case in which firm B has a dominant IP strategy will be considered directly in section IV. The expected payoff for A when she chooses $\{\mathcal{S}, d\}$ is:

$$U_{\mathcal{S}}(d, t) \equiv \lambda\pi\left[1 - \gamma(d)\psi(d)\right] + (1 - \lambda)\{(1 - p(d, t)) + p(d, t)\left[1 - \gamma(d)\psi(d)\right]\pi\} \tag{1}$$

where $\psi(d) = 1\ \forall d \in \mathcal{D}_P$ and $\psi(d) = 0\ \forall d \in \mathcal{D}_S$. A's expected payoff is the sum of two terms. The first is the payoff it obtains when firm B is innovative. The magnitude of this term depends on d, because disclosure affects the probability of obtaining a 'secure' patent right, $\gamma(d)$, and the best IP response of firm B, $\psi(d)$. The second term is A's payoff when firm B is imitative. Disclosure affects the size of this term by influencing not only $\gamma(d)$ and $\psi(d)$ but also the duplication probability: $p(d, t)$.

On the one hand, when B chooses *secrecy*, A decides its optimal disclosure level, d^*, by maximizing $U_{\mathcal{S}}(d, t)$ subject to $d \in \mathcal{D}_S$. Thus, from (1), A maximizes $U_{\mathcal{S}|\mathcal{S}}(d, t) \equiv \lambda\pi + (1 - \lambda)\left[1 - p(d, t)(1 - \pi)\right]$ by choosing a disclosure level $d \in \mathcal{D}_S$. Because $U_{\mathcal{S}|\mathcal{S}}(d, t)$ is a strictly decreasing function of disclosure, the optimal disclosure level when B chooses $\mathcal{S}$ is $d^*(t) = d_L(t)$.

On the other hand, when B chooses *patenting*, A decides its optimal disclosure level by maximizing $U_{\mathcal{S}}(d, t)$ subject to $d \in \mathcal{D}_P$. Therefore, from (1), A maximizes $U_{\mathcal{S}|\mathcal{P}}(d, t) \equiv \lambda\pi\left[1 - \gamma(d)\right] + (1 - \lambda)\{(1 - p(d, t)) + p(d, t)\left[1 - \gamma(d)\right]\pi\}$ by selecting a disclosure level $d \in \mathcal{D}_P$. The first order condition for an interior solution is:

$$MB(d^*, t) \equiv -\gamma_d(d^*)\pi p_B(\lambda, d^*, t) = (1 - \lambda)p_d(d^*, t)\,\Pi(d^*, t) \equiv MC(d^*, t) \tag{2}$$

where $p_B(\lambda, d^*, t) \equiv \left[\lambda + (1 - \lambda)p(d^*, t)\right]$ is the aggregate probability of success for firm B and $\Pi(d^*, t) \equiv$

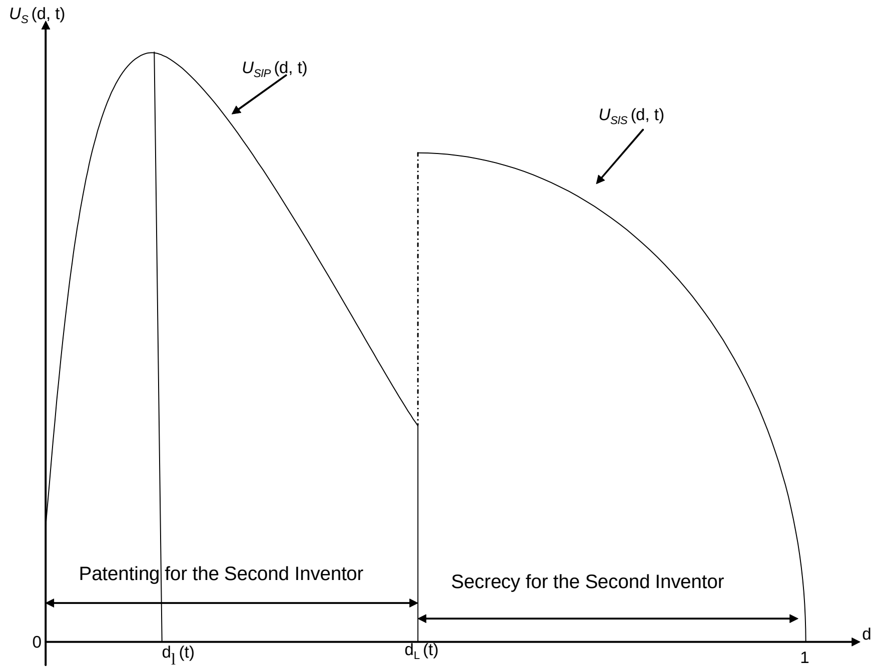

Figure 1: Existence of a Disclosure Level When B chooses Patenting

$[(1-\pi)+\gamma(d^*)\pi]$ is A's lost payoff due to B's success in duplication activities.[19] Note that $\{p_B(\lambda, d^*, t)\ \gamma(d^*)\}$ is the probability of *exclusion* suffered by firm A when it chooses $\{\mathcal{S}, d^*\}$. Thus $\{p_B(\lambda, d^*, t)\ \gamma(d^*)\}\pi$ is the expected loss due to the 'risk' of exclusion; and the marginal benefit of disclosing is just the marginal decrease in the expected loss due to exclusion. The marginal cost of disclosing is just the increase in the expected lost payoff due to the higher duplication probability associated with a higher disclosure level.

Under some additional assumptions, $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is a strictly concave function of d. More precisely: a sufficient condition for $U_{\mathcal{S}|\mathcal{P}}(d,t)$ to be a strictly concave function of disclosure is for $U_{\mathcal{S}|\mathcal{P}}(d,t)$ to be strictly concave at a zero disclosure level. For simplicity, I assume here that $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is a strictly concave function of d and I provide the technical details in Appendix A. Thus for each value of t, there is a unique global maximum which is described by the previous first order condition. Figure 1 illustrates a possible solution to this problem, denoted by $d^*(t) \equiv d_\ell(t) < d_L(t)$. Figure 2, however, complements the analysis by pointing out a potential non-existence problem: for some parameter values, t', it may be that the solution to this problem, $d^*(t')$, is such that $d^*(t') \notin \mathcal{D}_P$.

In the following I summarize the preceding discussion.

LEMMA 1: (a) Suppose that firm B chooses secrecy. Then: there exists a unique optimal disclosure level for firm A, denoted by $d_L(t)$.

[19] A's expected payoff when B succeeds in duplication is: $\pi(1-\gamma(d))$. Similarly, when B fails in its duplication activity, A's payoff is 1. Thus, A's lost payoff due to B's success in duplication is: $\Pi(d,e) := 1 - \pi(1-\gamma(d)) = [(1-\pi)+\gamma(d)\pi]$.

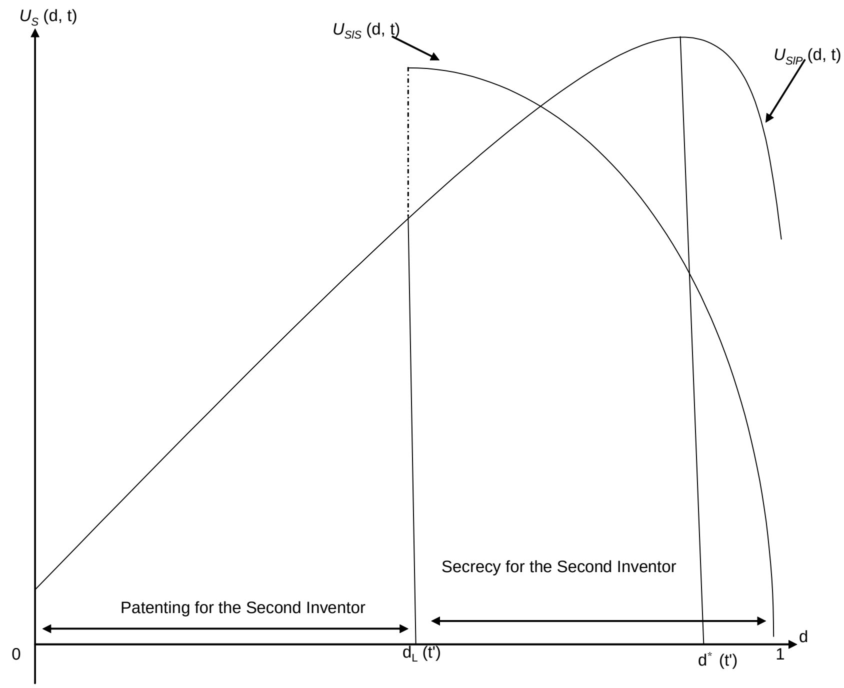

Figure 2: Non-Existence of a Disclosure Level When B chooses Patenting

(b) Suppose that firm B chooses patenting and that $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is a strictly concave function of disclosure. Then: the optimal disclosure level for firm A, when it exists, is uniquely determined by the first order condition (2) and denoted by $d_\ell(t) < d_L(t)$.

D. *IP Choice of Firm A*

Firm A must decide its IP strategy: $\{\mathcal{P}, \{\mathcal{S}, d\}\}$. If it chooses $\mathcal{P}$, it follows that firm A's maximum expected utility is: $U_{\mathcal{P}}(t) = \pi + \mathcal{Z}(0,t)$. By patenting, firm A is certain to obtain π. Moreover, if imitation does *not* occur, it will obtain the *maximum* value of patenting, $\mathcal{Z}(0,t)$: the value of the patent for firm A is always weakly *higher* than the value of the patent for firm B, because $\alpha \geq \gamma(d)$. If firm A chooses $\{\mathcal{S}, d\}$, it must select between $\{\mathcal{S}, d_\ell(t)\}$ and $\{\mathcal{S}, d_L(t)\}$. Simple rearrangements involving the use of $U_{\mathcal{S}|\mathcal{S}}(d,t)$ and $U_{\mathcal{S}|\mathcal{P}}(d,t)$ lead us to write the maximum expected utility of secrecy for firm A when she discloses $d_L(t)$ and $d_\ell(t)$ respectively as: $U_{\mathcal{S}|\mathcal{S}}(d_L(t),t) \equiv \pi + \upsilon_{\mathcal{S}|\mathcal{S}}(d_L(t),t)$ and $U_{\mathcal{S}|\mathcal{P}}(d_\ell(t),t) \equiv \pi + \upsilon_{\mathcal{S}|\mathcal{P}}(d_\ell(t),t)$, where:

$$\upsilon_{\mathcal{S}|\mathcal{S}}(d_L(t),t) \equiv (1-\lambda)\,[1 - p(d_L(t),t)]\,(1-\pi) \quad (3)$$

$$\upsilon_{\mathcal{S}|\mathcal{P}}(d_\ell(t),t) \equiv (1-\lambda)\,[1 - p(d_\ell(t),t)]\,(1-\pi) - p_B(\lambda, d_\ell(t), t)\gamma(d_\ell(t))\pi \quad (4)$$

Thus $\upsilon_{\mathcal{S}|\mathcal{S}}$ is the equilibrium value of secrecy for firm A when it discloses $d_L(t)$. Because firm B will choose secrecy, firm A is certain to obtain π. Besides, if it avoids duplication, it will obtain the market premium, $(1-\pi)$. This only happens when it faces the imitative type of firm B which is not successful in its duplication activity: an event that occurs with probability $(1-\lambda)\left[1-p(d_L(t),t)\right]$. Similarly, $\upsilon_{\mathcal{S}|\mathcal{P}}$ is the equilibrium value of secrecy for firm A when it discloses $d_\ell(t)$. The key difference to $\upsilon_{\mathcal{S}|\mathcal{S}}$ comes from the last term of $\upsilon_{\mathcal{S}|\mathcal{P}}$, $\{p_B(\lambda, d_\ell(t), t)\gamma(d_\ell(t))\}\pi$: the expected loss suffered by A due to the 'risk' of exclusion.

Thus A decides her IP by comparing $\mathcal{Z}(0,t)$, $\upsilon_{\mathcal{S}|\mathcal{S}}$ and $\upsilon_{\mathcal{S}|\mathcal{P}}$. The following observation is essential for what follows. By choosing $\mathcal{P}$, firm A is only exposed to imitation. By selecting $\{\mathcal{S}, d_\ell(t)\}$, it risks both duplication and exclusion. Finally, by choosing $\{\mathcal{S}, d_L(t)\}$, it is only concerned about duplication, because by disclosing $d_L(t)$, firm A fully eliminates the 'risk' of exclusion. The price it pays, however, is that of a higher duplication probability: $p(d_L(t),t) > p(d_\ell(t),t)$. Recall how firm B decided its IP strategy: just by looking at $\mathcal{Z}(d,t)$. This shows that firm A values secrecy differently to firm B. What distinguishes A from B is the order of moves and the belief of A that there is a positive probability of facing an imitative second inventor. The differential value of using secrecy for A, resides in concealing knowledge from imitative second inventors. Firm B when deciding its IP strategy has no knowledge to conceal: it knows that firm A knows everything about the innovation. I elaborate more on these points in the next section.

IV. Main Results

A. *The Benchmark Case: No Disclosure Outside of Patents*

To have a benchmark for comparison I provide here a couple of simple results whose main feature is the absence of disclosure outside of patents. In the following I consider an environment characterized by complete secrets.

PROPOSITION 1: Suppose $\mathcal{Z}(0,t) \leq 0$. Then: there is a unique SPE with strategies for A and B as follows:

$$\{\mathcal{S}, d^* = 0\} \text{ and } \psi(d)$$

PROOF. See Appendix A.

If the maximum value of patenting is negative, firm B will choose secrecy for all disclosure levels. Then, firm A will not only choose secrecy but it will also choose to conceal its innovation completely. In other words: it will disclose *zero*. The reasons are simple. Firm A, on the one hand, always values secrecy *weakly more* than firm B. B has nothing to conceal about the innovation, but A, however, does: it risks imitation in the case of patenting the innovation. Therefore, to avoid imitation it chooses secrecy. But, on the other hand, because B's dominant IP strategy is secrecy, firm A does not face the 'risk' of exclusion and therefore by disclosing it would only transfer useful knowledge to B.

Proposition 1 can be used to discuss some of the informal comments usually made about defensive publications. For example, it is often said that...'Many companies decide to publish inventions which are not worth the expense required to pursue patenting...'. Note that this is exactly the case under examination: $\mathcal{Z}(0,t) \leq 0$: not even for firm A it is worth patenting. My model, however, in which firms are symmetric in their patenting costs and market profits, transmits the opposite message: if patenting is not worthwhile, full secrecy should prevail.

Proposition 2 clarifies the relationship between λ and the IP choices of firms A and B. It conveys the opposite message of Proposition 1: if firm A believes that firm B is almost definitely innovative, it will patent the innovation. I interpret this proposition as suggesting that secrecy can only be used when firm A believes that the innovation is, in a certain sense, a *scarce* commodity. The proposition has a similar flavour to the result found by Kultti, Takalo and Toikka [9] that innovators prefer patenting to secrecy when there are many potential innovators of the same innovation.

PROPOSITION 2: Suppose there exists an interior level of disclosure, $d_L(t)$ such that $\mathcal{Z}(d_L(t), t) = 0$ and let $\lambda \to 1$. Then: there is a unique SPE with strategies for A and B as follows:

$$\{\mathcal{P}\} \text{ and } \psi(d)$$

PROOF. See Appendix A.

Proposition 2 implies that, at the *limit*, when the probability of facing the innovative type of firm B is almost one, firm A takes its IP decision in the same fashion as firm B: by looking only at the value of patenting. Why? Because, the order of moves in this situation does not matter any more. Secrecy has the *same* value for both A and B. Recall that the differential value of secrecy for firm A resides in the value of concealing information from the imitative type of firm B. But if the likelihood of encountering the imitative type of firm B is negligible, A places no additional value on secrecy in comparison to B. Viewing the result from a different perspective may also be worthwhile: A anticipates that if it chooses secrecy, it will be in its best interest to disclose $d_L(t)$ and therefore it will obtain a duopoly profit, π. Why? The likelihood of meeting the imitative type of firm B being practically zero, A knows that by choosing secrecy it will be almost definitely duplicated. Hence, A knows that it will obtain 0 if B obtains a *valid* patent right or that it will obtain π, the duopoly profit, if B chooses secrecy. Therefore, A will disclose $d_L(t)$ and it will 'persuade' B to choose secrecy. Put differently: the best disclosure level for A is the one that eliminates the 'risk' of exclusion, $d_L(t)$. By choosing a patent, however, it gets π for sure and because the maximum value of patenting is positive, $\mathcal{Z}(0, t) > 0$, it expects to obtain an extra positive gain.

This result captures the situation in which the innovations have been discovered almost simultaneously and independently by the two firms. A, having a small time advantage, decides to patent the innovation. Patents are used here as recipients of knowledge disclosure: competitive pressure from the second inventor is enough for the first to disclose its knowledge in a patent.

The previous arguments elucidate two important themes which will be the subject of the following discussion. First, they show that first inventors will disclose their knowledge only if they are credibly threatened with exclusion by second inventors. If the threat is not credible, $\mathcal{Z}(0, t) \leq 0$, the innovative environment would be characterized by complete secrecy. The most likely typical situation of a non-credible threat is when the first patent is believed to be sufficiently weak. Second, they reveal that if the threat of exclusion is credible, disclosure outside of patents may emerge only when first inventors believe that their innovations are, in a certain sense, relatively scarce.

B. *Equilibrium IP and Disclosure Outside of Patents*

In this section I explore the equilibrium IP choices for firms A and B. An important concern is understanding the equilibrium amount of knowledge disclosed outside of the patent system, if secrecy were chosen by firm A. I consider here the wide set of situations for which there exists an interior disclosure level such that $\mathcal{Z}(d_L(t), t) = 0$ and $\lambda \in (0, 1)$. Put differently, most real life innovations are likely to fall into this category: for some *low* disclosure levels it is profitable to use the patent system, and for *large* disclosure levels the best IP choice for the second inventor, firm B, is secrecy.

It is convenient to think of this problem in two stages. First if firm A chose secrecy, under what conditions would it disclose $d_\ell(t)$ or $d_L(t)$? Second, what is the best IP strategy for firm A?

To gain a clear understanding of the main results, I start by imposing a further restriction on the duplication probability function. I suppose that $\forall d \in \mathcal{D} : p_\pi(d, t) = 0$. This additional restriction greatly simplifies the analysis, but I show later that all the results of the paper hold when Assumption 2 part c) holds with strict inequality: $p_\pi(d, t) > 0$.

Stage 1

My goal is to determine under what parameter values, t, $\upsilon_{\mathcal{S}|\mathcal{S}}$ is greater or smaller than $\upsilon_{\mathcal{S}|\mathcal{P}}$. Before addressing the technical details, I will briefly summarize the main trade-offs faced by firm A when choosing between $d_\ell(t)$ and $d_L(t)$ from a conceptual angle. Firm A can either: (a) disclose a *'low'* amount of knowledge, $d_\ell(t)$, and make *patenting* the incentive-compatible IP choice for firm B; or (b) disclose a *'large'* amount of knowledge, $d_L(t)$, and make *secrecy* the incentive-compatible IP choice for firm B. The differences between these two strategies are as follows. By using the second (generous) disclosure strategy, firm A completely eliminates the 'risk' of exclusion. It is only exposed to being duplicated by the second inventor. By choosing the first (conservative) strategy, however, firm A risks not only duplication but also exclusion by the second inventor. The discount that it obtains from risking exclusion is a lower duplication probability.

To examine the conditions under which firm A chooses either the conservative or the generous disclosure strategy, I formally assume that that there exists one parameter point, denoted by $\widetilde{t}$, which belongs to the parameter set, T, such that, $\upsilon_{\mathcal{S}|\mathcal{S}} = \upsilon_{\mathcal{S}|\mathcal{P}}$.[20] Put differently: I devote my attention to exploring those innovative environments which are interesting from an economic point of view.

The main questions to be answered are:

(1) Will firm A choose to disclose $d_\ell(t)$ or $d_L(t)$ when the intensity of market competition, measured by π, decreases (increases), starting from $\widetilde{\pi}$?

[20] T is defined as: $T := \{t \in [0,1]^4 : 0 < \pi \leq \frac{1}{2}, \lambda \in (0,1), \alpha \in (0,1), \beta < c < \frac{\alpha}{2}\}$ and $c < \pi$, where the restrictions on the values of π and c come from: (a) $\alpha > \frac{c}{1-\pi}$ and $\max \pi = \frac{1}{2}$; and (b) $\beta < \frac{c}{1-\pi}$ and $\inf \pi = 0$.

(2) Will firm A choose to disclose $d_\ell(t)$ or $d_L(t)$ when λ increases (decreases), starting from $\widetilde{\lambda}$?[21]

1.A *Changes in the Intensity of Product Market Competition*

Now I write $p(d) \in (0,1)$ and I interpret $p(d)$ as the optimally determined 'spillover' rate under secrecy. In the following I show that when product market market competition is not too intense, firm A will use the generous disclosure strategy.

PROPOSITION 3: Suppose that $p_\pi(d,t) = 0$. Then: a higher (lower) π leads firm A to disclose $d_L(t)\,\{d_\ell(t)\}$, and firm B to choose secrecy (patenting).

PROOF. See Appendix A.

Proposition 3 implies that when firm A waives its patent right the parameter space can be partitioned, along the profit dimension, into two subsets: (a) $(\pi_{\mathbf{L}}, \widetilde{\pi})$, the set of profit levels for which firm A will disclose $d_\ell(t)$ and therefore firm B will choose patenting; and (b) $\left[\widetilde{\pi}, \frac{1}{2}\right]$ the set of profit levels for which firm A will disclose $d_L(t)$ and hence firm B will opt for secrecy. A main lesson may therefore be extracted: when the intensity of product market competition is not too high, $\pi \in \left[\widetilde{\pi}, \frac{1}{2}\right]$, firm A will choose the generous disclosure strategy. However, when the returns for being the technological leader are significant, firm A will shift to the conservative disclosure strategy. Conditional on waiving their patent rights, first inventors will face incentives to disclose a *'large'* amount of knowledge only if product market competition is not too intense.

The central question is then: why does less intense product market competition guide firm A to use the generous disclosure strategy? A detailed answer will lead us directly to the proof. The *main* intuition, however, is easy to grasp. Start by assuming that firm A is indifferent between the two disclosure strategies. Then, if product market competition becomes less intense, the generous disclosure strategy becomes more attractive because: (a) the expected loss due to exclusion, $\{p_B(\lambda, d_\ell(t), t)\gamma(d_\ell(t))\}\pi$, increases; and (b) the relative gain from avoiding duplication, $(1-\pi)$, the crucial advantage of the conservative disclosure strategy, decreases.

But is this result still valid if one insists on imposing the more realistic condition $p_\pi(d,t) > 0$? The answer is yes but at the cost of imposing the following mild additional assumption on the duplication technology:

ASSUMPTION 3: $\frac{\partial p(d_\ell(t),t)}{\partial \pi} \geq \frac{\partial p(d_L(t),t)}{\partial \pi}$

Assumption 3 says that, when π rises, the duplication probability should increase at least as much when disclosure is low as when disclosure is large. More precisely, it says that the duplication probability function exhibits substitutability between disclosure and duopoly profits.[22] Assumption 3 simplifies

[21] I answer these questions by using the Envelope Theorems and computing the change in the optimal values of $v_{\mathcal{S}|\mathcal{S}}$ and $v_{\mathcal{S}|\mathcal{P}}$. Because the usual 'regularity' conditions for the Implicit Function Theorem to work are satisfied *everywhere* in the interior of the domain of T, the results obtained using the Envelope Theorems are valid not only locally (around $\widetilde{t}$) but also at every point t in the interior of T. See Milgrom and Roberts [21] for an excellent discussion of monotone comparative statics methods.

[22] Keeping λ and c fixed, Assumption 3 is equivalent to saying that the duplication probability function exhibits decreasing differences: $\forall \pi' > \pi$ $p(\pi', d_L(t), t) - p(\pi, d_L(t), t) \leq p(\pi', d_\ell(t), t) - p(\pi, d_\ell(t), t)$

the presentation of the results. Corollary 1 below remains valid, under certain additional conditions, even if I allow the duplication probability function to exhibit a certain degree of complementarity between disclosure and duopoly profits: $\frac{\partial p(d_L(t),t)}{\partial \pi} > \frac{\partial p(d_\ell(t),t)}{\partial \pi}$. However, in that case the presentation of the results and the notation becomes cumbersome.

COROLLARY 1: Suppose that $p_\pi(d,t) > 0$ and Assumption 3 hold. Then: a higher (lower) π leads firm A to disclose $d_L(t)$ $\{d_\ell(t)\}$, and firm B to choose secrecy (patenting).

PROOF. See Appendix A.

The economic intuition behind the result of Corollary 1 is almost the same as that of Proposition 3.

1.B *Changes in the Intensity of Competition in the Innovation Market*

Next, I establish a couple of intermediate results which characterize the optimal response of firm A to changes in λ.

LEMMA 2: Suppose there exists an interior disclosure level, $d_L(t)$ such that $\mathcal{Z}(d_L(t),t) = 0$. Then: the optimal disclosure level which is incentive-compatible with firm B choosing patenting, $d_\ell(t)$, is monotonically increasing in λ.

PROOF. See Appendix A.

Lemma 2 has a simple implication: there must exist a $\lambda_1(t) \in (0,1)$ such that: $d_\ell((\pi,c,\alpha), \lambda_1(t)) = d_L(t)$. Although the formal argument behind this conclusion is simple, I present this implication as a formal corollary and I relegate its proof to the Appendix.

COROLLARY 2: Suppose there exists an interior disclosure level, $d_L(t)$ such that $\mathcal{Z}(d_L(t),t) = 0$. Then: if $\lambda \in (\lambda_1(t), 1)$ an optimal disclosure level which is incentive-compatible with firm B choosing patenting does *not* exist.

PROOF. See Appendix A.

Corollary 2 points to the existence problem described in Figure 2. It basically says that if $\lambda \in (\lambda_1(t), 1)$ and firm A chooses not to patent the innovation, the optimal disclosure level will be $d_L(t)$. The idea is simple: if firm A believes that firm B is innovative with a sufficiently high probability, then the expected loss due to exclusion becomes sufficiently high and therefore firm A opts for eliminating it by disclosing $d_L(t)$. Hence, according to Corollary 2, an optimal disclosure level which is incentive-compatible with firm B choosing patenting exists if and only if $\lambda \in (0, \lambda_1(t))$.

In the following I provide a *first* description of the relationship between disclosure and λ.

PROPOSITION 4: Suppose that $\lambda \in (0, \lambda_1(t))$. Then: a higher (lower) λ leads firm A to disclose to disclose $d_L(t)$ $\{d_\ell(t)\}$, and firm B to choose secrecy (patenting).

PROOF. See Appendix A.

Proposition 4 says that the parameter space, along the 'belief' dimension, can be partitioned into two subsets: (a) $(0, \tilde{\lambda})$ the subset for which firm A discloses $d_\ell(t)$ and therefore firm B chooses patenting; and (b) $[\tilde{\lambda}, \lambda_1(t))$ the subset of beliefs for which firm A discloses $d_L(t)$ and therefore firm B opts for secrecy. Opposite to Proposition 3, firm A will use the generous disclosure strategy when it believes that there exists at least a *minimum* of competitive pressure in the 'innovation market'. Alternatively put: first inventors will never use the generous disclosure strategy if they believe that there do not exist substitute second inventors who can exclude them from using secret innovations.

The intuition behind the result is simple. As with the previous proposition, assume that, initially, firm A is indifferent between the conservative and the generous disclosure strategy. An increase in λ leads firm A to choose the generous disclosure strategy, mainly because the probability of exclusion increases and therefore the expected loss due to exclusion also becomes larger. Besides, when λ increases, the threat of duplication also rises: a force that, in relative terms, operates against the conservative disclosure strategy.[23]

Stage 2

Here I compare the maximum value of secrecy, $\mathcal{V}_{\mathcal{S}}(t) \equiv \max(\upsilon_{\mathcal{S}|\mathcal{S}}, \upsilon_{\mathcal{S}|\mathcal{P}})$, with the maximum value of patenting, $\mathcal{Z}(0,t)$, to determine firm A's optimal IP choice. I discuss outcomes that may arise in two different situations. First, I consider those values of π and λ for which firm A chooses $\{\mathcal{S}, d_L(t)\}$. Formally: keeping constant the patenting cost, I consider those vectors $(\pi, \lambda) \in \left[\tilde{\pi}, \frac{1}{2}\right] \times \left[\tilde{\lambda}, \lambda_1(t)\right]$ such that $\mathcal{V}_{\mathcal{S}}(t) = \upsilon_{\mathcal{S}|\mathcal{S}}$.

In this situation, a necessary and sufficient condition for firm A to choose $\{\mathcal{S}, d_L(t)\}$ is:

$$\upsilon_{\mathcal{S}|\mathcal{S}}\left(d_L(\pi,\lambda,\tilde{c}),(\pi,\lambda,\tilde{c})\right) \geq \mathcal{Z}(0,(\pi,\lambda,\tilde{c})) \iff \alpha_{\mathcal{S}|\mathcal{S}} \geq \alpha - \frac{\tilde{c}}{(1-\pi)} > 0 \tag{5}$$

where: $\alpha_{\mathcal{S}|\mathcal{S}} \equiv (1-\lambda)\left[1 - p(d_L(t),t)\right]$.

Observe first that $[1 - p(d_L(t),t)]$ is a measure of the strength of the protection under secrecy when firm A chooses to disclose $d_L(t)$ *and* firm B is imitative. But then $\alpha_{\mathcal{S}|\mathcal{S}}$, the *protection* offered by secrecy, takes into account the fact that firm B is imitative with probability $(1-\lambda)$. Equation (5) then suggests a nice intuition: firm A will choose $\{\mathcal{S}, d_L(t)\}$ when the protection offered by secrecy, $\alpha_{\mathcal{S}|\mathcal{S}}$, is higher than the protection offered by patents net of the patenting cost in terms of the market premium. It might well be that $\alpha_{\mathcal{S}|\mathcal{S}} < \alpha$: secrecy offers less protection than patenting but still firm A avoids patenting and chooses $\{\mathcal{S}, d_L(t)\}$. The outcome will depend on the environment under study. That is, it will depend on the nature of the duplication technology, the strength of patent protection, α, and the expected patenting costs. Two features behind this 'simple' IP rule are worth stressing. First, and remarkably, because firm A chooses the generous disclosure strategy, in equilibrium

[23] Obtaining monotone comparative statics results with respect to the patenting cost is difficult. One needs to impose stronger assumptions and, even in that case, little can be said about the disclosure strategy that will be chosen by the first inventor when c varies.

exclusion does not play any role in deciding between secrecy and patenting. The risk of exclusion is completely eliminated and firm A only considers duplication and imitation when choosing between its IP alternatives. Secondly, and obviously, for relatively 'low' values of α, or weak patent protection, firm A chooses $\{\mathcal{S}, d_L(t)\}$ and, for 'high' values of α, or more secure patent rights, patenting will be its preferred option.

Second I also consider those vectors $(\pi', \lambda') \in \left[\pi_{\mathbf{L}}, \widetilde{\pi}\right] \times \left[0, \widetilde{\lambda}\right]$ such that $\mathcal{V}_{\mathcal{S}}(t) = \upsilon_{\mathcal{S}|\mathcal{P}}$. Then firm A will select $\{\mathcal{S}, d_\ell(t)\}$ if and only if:

$$\upsilon_{\mathcal{S}|\mathcal{P}}\left(d_\ell(\pi', \lambda', \widetilde{c}), (\pi', \lambda', \widetilde{c})\right) \geq \mathcal{Z}(0, (\pi', \lambda', \widetilde{c})) \iff \alpha_{\mathcal{S}|\mathcal{P}} \geq \alpha - \frac{\widetilde{c}}{(1-\pi')} > 0 \tag{6}$$

where $\alpha_{\mathcal{S}|\mathcal{P}} \equiv (1-\lambda^{'})\left[1 - p(d_L(t), t)\right] - \frac{p_B(\lambda, d_\ell(t), t)\gamma(d_\ell(t))\pi'}{(1-\pi')}$.

The main difference between (5) and (6) is that when firm A chooses between $\{\mathcal{S}, d_\ell(t)\}$ and $\mathcal{P}$, it must consider not only imitation and duplication but also the risk of exclusion: by disclosing $d_\ell(t)$, firm A finds it optimal to keep the probability of exclusion positive. The following summarizes this discussion.

PROPOSITION 5: Suppose there exists a parameter point $\widetilde{t} \in T$ such that $\upsilon_{\mathcal{S}|\mathcal{S}}(\widetilde{t}) = \upsilon_{\mathcal{S}|\mathcal{P}}(\widetilde{t})$. Then:

(i) Suppose $\mathcal{V}_{\mathcal{S}}(t) = \upsilon_{\mathcal{S}|\mathcal{S}}(t)$. Then: if and only if $\alpha_{\mathcal{S}|\mathcal{S}} \geq \alpha - \frac{\widetilde{c}}{(1-\pi)}$ there is a unique SPE in which firm A chooses $\{\mathcal{S}, d_L(t)\}$ and firm B also chooses $\mathcal{S}$. Otherwise, firm A selects $\mathcal{P}$.

(ii) Suppose $\mathcal{V}_{\mathcal{S}}(t) = \upsilon_{\mathcal{S}|\mathcal{P}}(t)$. Then: if and only if $\alpha_{\mathcal{S}|\mathcal{P}} \geq \alpha - \frac{\widetilde{c}}{(1-\pi')}$ there is a unique SPE in which firm A chooses $\{\mathcal{S}, d_\ell(t)\}$ and firm B chooses $\mathcal{P}$. Otherwise, firm A chooses $\mathcal{P}$.

To sum up, Proposition 5 underscores a remarkable message: the prevalence of secrecy may be associated with a substantial amount of innovative knowledge disclosed outside of patents. The main idea is that first inventors, in equilibrium, optimally eliminate the 'risk' of exclusion by disclosing a large amount of knowledge outside of patents. For this type of equilibrium to arise, duopoly profits must be above a certain threshold and the likelihood of meeting an unsuccessful second inventor must be below a critical level. The message is therefore that even if first inventors rely on secrecy, the disclosure of innovations will not be excessively restricted if the intensity of product market competition is not too high and simultaneously some competitive pressure is exerted in the 'innovation market'.

I close this section with a final proposition. Basically in this proposition I compare secrecy with patenting when the optimal disclosure level which is incentive-compatible with firm B pursuing a patent does not exists.

PROPOSITION 6: Suppose that the set $\Delta(t) := (\lambda_1(t), \lambda_2(t))$, for $\lambda_2(t) = \frac{[1-p(d_L(t),t)-\alpha](1-\pi)+c}{[1-p(d_L(t),t)](1-\pi)}$, is different from the empty set. Then if $\lambda \in \Delta(t)$ there is a unique SPE with strategies for A and B as follows:

$$\{\mathcal{S}, d_L(t)\} \text{ and } \psi(d)$$

PROOF. It follows trivially from Corollary 2, and by comparing $\upsilon_{\mathcal{S}|\mathcal{S}}(t)$ and $\mathcal{Z}(0,t)$. $\square$

The value of Proposition 6 resides in the fact that it basically shows that, when $\Delta(t)$ is non-empty and $\lambda \in \Delta(t)$, there is a unique perfect equilibrium in which both firms choose secrecy to protect their innovations. But in addition, the first inventor, firm A, fearing the credible threat of firm B using the patent system, discloses a substantial amount of knowledge *outside* of a patent. Both firms avoid the patent system and its often lamented patenting and legal costs by resorting to secrecy. But the informational costs usually associated with secrecy are considerably ameliorated because of the knowledge disclosed by the first inventor *outside* of a patent.

It is worth observing the differences and similarities between Proposition 2 and Proposition 6. The main similarity is the following: in both environments λ is sufficiently high such that it leads firm A to disclose $d_L(t)$ when choosing secrecy. In other words: in both situations, if firm A chose secrecy it would prefer to eliminate the 'risk' of exclusion by persuading firm B to choose secrecy too. The main difference is that in the environment described by Proposition 2, firm A knows that, if she chose secrecy, it would be duplicated with probability almost one, because it is almost sure that firm B is innovative. In the environment delineated in this proposition, however, firm A knows that, if it chose secrecy, it would be duplicated with high probability *but less* than one. By decreasing the risk of duplication the nature of the equilibrium changes radically: both inventors choose secrecy and the first discloses a substantial amount of knowledge *outside* of a patent.

The intuition behind the IP choice of firm A is extremely simple. Firm A must balance three forces: exclusion, duplication and imitation. If it chooses $\{\mathcal{S}, d_L(t)\}$ it persuades firm B to choose secrecy too. Therefore by selecting secrecy $\{\mathcal{S}, d_L(t)\}$, firm A, in equilibrium, optimally eliminates the 'risk' of exclusion. Thus, it results that it must decide its IP choice by considering that: (a) by patenting, a costly activity, it 'risks' imitation with probability $1-\alpha$; and that (b) by choosing $\{\mathcal{S}, d_L(t)\}$, it 'risks' duplication with probability $(1-\lambda)\,[1-p(d_L(t),t)]$. What the proposition shows is that when $\lambda \in \Delta(t)$, the first inventor finds $\{\mathcal{S}, d_L(t)\}$ the best IP choice. The heart of this argument can be reinforced by observing that a *necessary* condition for this equilibrium to exist is $\lambda_2(t) > 0$, or alternatively: $[1-p(d_L(t),t)]\,(1-\pi) > \mathcal{Z}(0,t)$. This simple expression reveals a clear message: if firm B were imitative, $\{\mathcal{S}, d_L(t)\}$ should dominate patenting. Furthermore, note that it may well be the case that patenting offers better 'protection' than $\{\mathcal{S}, d_L(t)\}$, that is: $\alpha > [1-p(d_L(t),t)]$. Nevertheless, when A accounts for its patenting costs, it chooses not to patent.[24]

Finally, compare the outcomes of Proposition 1, 5 (i) and 6. An outside observer reading the IP choices of the inventors (secrecy for A and secrecy for B) might conclude that both equilibria are economically equivalent. Nothing is more misleading than this casual observation. Secrecy is chosen by second inventors, for completely different reasons in these equilibria. In the equilibrium described in Proposition 1, secrecy is chosen by second inventors because it is *exogenously* profitable to do so. In the equilibrium shown in Propositions 5(i) and 6 secrecy is selected by second inventors because they

[24] The proposition does not guarantee existence. In a model like mine with very general functional forms it is impossible to assure that $\lambda_2(t) > \lambda_1(t)$.

have been *endogenously* persuaded by first inventors.

V. Discussion and Concluding Remarks

An important policy concern is that self-interested innovators by choosing secrecy might obstruct the disclosure of technical knowledge and therefore halt further technological progress. To explore this concern, this paper provides a simple model of IP choice and disclosure outside of patents. Paradoxically, the paper makes the novel and remarkable contribution that the higher the use of secrecy, the larger the amount of knowledge disclosed *outside* of patents. Put differently: the paper points out that the choice of secrecy may be signalling a sufficiently large amount of disclosure in the public domain.

Moreover, the paper identifies conditions under which the prevalence of secrecy is strongly associated with disclosure outside of patents. The structure of incentives which is needed to support a generous disclosure strategy, if secrecy is selected, can be summarized as follows. The nature of competition in the product market between first and second inventors must not be too tough and first inventors must hold expectations that, at least, with some probability, second inventors may independently obtain closely-related inventions. Under these circumstances, the reported use of secrecy to protect intellectual assets should not concern us 'too much' from a social point of view: market forces jointly with institutional details lead first inventors to disclose a generous amount of innovative knowledge outside of patents.

Institutional 'details' are important in sustaining disclosure outside of patents. This paper also contributes to the recent debate about the convenience or not of granting prior user rights (see Denicolo and Franzoni [10], Kultti, Takalo and Toikka [13], Maurer and Scotchmer [20] and Shapiro [24]). My model shows that a *necessary* condition for inventors to *strategically* disclose outside of patents is the absence of an independent invention defense. Moreover, this paper underscores, and in this respect complements and strengthens others (see Kultti, Takalo and Toikka [14]), by highlighting the idea that disclosure outside of patents may emerge only when first inventors believe that their innovations are, in a certain sense, relatively scarce.

Finally, the analysis of this paper focuses on the simple case in which innovators disclose all of their knowledge when choosing patenting. This is a rather strong assumption; but I use it because it substantially simplifies the model and it does not interfere with my main aim: understanding disclosure *outside* of patents and whether first inventors should pursue patenting or secrecy. Anton and Yao [2 and 3] build models in which innovators have discretion with respect to the *extent* of the information disclosed *in* a patent. This limitation might be addressed as follows. I might assume that the first inventor may retain knowledge when patenting her innovation. However, failure to include the best mode of exploiting an invention usually results in the invalidation of the resulting patent. Thus partial disclosure may help the second inventor and also invalidate the 'first' patent. My conjecture is that by complicating the model and adding one more avenue of disclosure (*in* the patent) the main conclusions of the paper would still remain valid. However, an analysis of such a model is left for future research.

Appendix A

Strict Concavity of $U_{\mathcal{S}|\mathcal{P}}(d,t)$

Recall that when B chooses *patenting*, A decides her optimal disclosure level by maximizing $U_{\mathcal{S}}(d,t)$ subject to $d \in \mathcal{D}_P$. Therefore, A maximizes $U_{\mathcal{S}|\mathcal{P}}(d,t) \equiv \lambda\left[(1-\gamma(d))\right]\pi + (1-\lambda)\{(1-p(d,t)) + p(d,t)\left[(1-\gamma(d))\right]\pi\}$ by selecting a disclosure level $d \in \mathcal{D}_P$. I assume:

ASSUMPTION A4: (a) $\forall d, \forall t : p_{ddd}(d,t) = 0$

(b) $\forall d : \gamma_{ddd}(d) = 0$

(c) $|\gamma_d(0)| < g(0)$

where $g(d) \equiv (2p_d(d,t))^{-1}\left\{\gamma_{dd}(d)p(d,t) + p_{dd}(d,t)\left[\frac{(1-\pi)}{\pi} + \alpha\right]\right\}$

LEMMA A1: Suppose that Assumption A4 holds. Then: $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is a strictly concave function of disclosure.

PROOF. For $U_{\mathcal{S}|\mathcal{P}}(d,t)$ to be a strictly concave function of disclosure it must be that $\forall d \in \mathcal{D} := [0,1]$:

$$\frac{\partial^2 U_{\mathcal{S}|\mathcal{P}}(d,t)}{\partial d^2} = -\gamma_{dd}(d)\pi p_B(\lambda,d,t) - (1-\lambda)p_{dd}(d,t)\,\Pi(d,t) - 2\gamma_d(d)\pi(1-\lambda)p_d(d,t) < 0$$

where $p_B(\lambda,d,t) \equiv [\lambda + (1-\lambda)p(d,t)]$ and $\Pi(d,t) \equiv [(1-\pi)+\gamma(d)\pi]$. If A4 holds then part (c) implies:

$$(2\pi p_d(0,t))^{-1}\frac{\partial^2 U_{\mathcal{S}|\mathcal{P}}(0,t)}{\partial d^2} = -\left[\gamma_{dd}(0)p(0,t) + p_{dd}(0,t)\left(\frac{(1-\pi)}{\pi} + \alpha\right)\right] - \gamma_d(0) < 0$$

because: $p_B(0,0,t) = p(0,t)$. Hence A4 (c) implies that $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is strictly concave at $d=0$. But because $\forall d \in \mathcal{D} : |\gamma_d(0)| > |\gamma_d(d)|$ and because by A4 parts (a) and (b): $\forall d \in \mathcal{D} : g(0) = g(d)$, it follows that strict concavity at $d=0$ plus A4 parts a) and b) is sufficient for global concavity. □

Proofs

PROOF OF PROPOSITION 1. Given that $\mathcal{Z}(0,t) \leq 0$, it follows that firm B will choose secrecy for all disclosure levels and firm A will choose $\{\mathcal{S},0\}$ The proof of this last statement is as follows. A's expected utility for any disclosure level is: $\lambda\pi + (1-\lambda)\left[(1-p(d(t),t)) + p(d(t),t)\pi\right]$. At $d=0$, firm A can only deviate by increasing the level of disclosure to say $d_1 > 0$. By Assumption 2, the new level of disclosure will result in a rise in the duplication probability chosen by the imitative type of firm B, $p(d(t),t)$. This in turn implies that for firm A, the probability distribution over its market payoffs changes by shifting mass away from 1 (the best payoff) and increasing mass on π (the duopoly payoff). This decreases the expected utility of firm A. Hence, upward deviations are not profitable. Thus $d=0$ is an optimal disclosure strategy. To prove uniqueness, suppose that initially disclosure is higher than zero, $d \in (0,1]$. Then, using a reverse argument to the one above, given that firm B is choosing secrets $\forall d \in [0,1]$, by diminishing d to d_1 and reducing the duplication probability, $p(d(t),t)$, firm A increases $(1-p(d(t),t))$ and thus it also raises its expected payoff. And, because $\mathcal{Z}(d,t)$ is a strictly decreasing function of disclosures, this ensues that $d \in (0,1]$ cannot be an optimal disclosure level. Now if firm A chooses patenting, its equilibrium value will be $\mathcal{Z}(0,t) \leq 0$. However by choosing secrecy, A's equilibrium value is $\upsilon_{\mathcal{S}|\mathcal{S}}(t) = (1-\lambda)\left[1-p(0,t)\right](1-\pi) > 0$, because $p(0,t) \in (0,1)$. □

PROOF OF PROPOSITION 2. Firm A must decide whether to disclose $d_L(t)$ or $d_\ell(t)$. First, using the first order condition (2): $\forall d \in \mathcal{D} : \lim_{\lambda\to 1}\left\{-\gamma_d(d)\pi\left[\lambda+(1-\lambda)p(d,t)\right]\right\} = \lim_{\lambda\to 1} MB(d,t) = -\gamma_d(d)\pi$. Second, again using equation (2): $\forall d \in \mathcal{D} : \lim_{\lambda\to 1} MC(d,t) = \lim_{\lambda\to 1}\left\{(1-\lambda)p_d(d,t)\Pi(d,t)\right\} = 0$. Third, due to assumption 1.b), it follows that: $\forall d \in \mathcal{D} : -\gamma_d(d)\pi > 0$. Thus the optimal disclosure level is $d^* = 1$. But $d^* = 1 \notin \mathcal{D}_P$, and because $\mathcal{D}_P$ is not closed, there does not exist an optimal disclosure level, d^*, which is incentive-compatible with B choosing a patent. Hence, the optimal disclosure level would be the one which makes it incentive-compatible for B to choose secrecy: $d_L(t)$. Fourth, if firm A chose secrecy its equilibrium value would be $\lim_{\lambda\to 1}\upsilon_{\mathcal{S}|\mathcal{S}}(t) = \lim_{\lambda\to 1}\left\{(1-\lambda)\left[1-p(d_L(t),t)\right](1-\pi)\right\} = 0$. By choosing patenting, however, its equilibrium value would be: $\mathcal{Z}(0,t) > 0 : \forall\lambda \in (0,1)$. □

PROOF OF PROPOSITION 3. I proceed in three steps. In the first two, I apply the envelope theorem for constrained problems to the optimal value of the objective functions of firm A when firm B chooses patenting and secrecy respectively. In the third step, I compare the difference in the change of the objective functions of these programs.

Step 1. It is well known from the envelope theorem that:

$$\frac{dU_{\mathcal{S}|\mathcal{P}}(t)}{d\pi} = \frac{\partial\mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)}{\partial\pi} = \lambda\left[1-\gamma(d_\ell(t))\right] + (1-\lambda)\left\{p\left(d_\ell(t),t\right)\left[1-\gamma(d_\ell(t))\right] - p_\pi\left(d_\ell(t),t\right)\Pi(d_\ell(t),t)\right\}$$

where $\mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)$ is the natural Lagrangian for the problem: $\max_{d\in\mathcal{D}_P} U_{\mathcal{S}|\mathcal{P}}(d,t)$ and $\Pi(d_\ell(t),t) \equiv \{\,(1-\pi) +\gamma(d_\ell(t))\pi\}$. Notice that no Lagrange multiplier appears in the expression because all of them are optimally equal to zero.

Step 2. By the envelope theorem:

$$\frac{dU_{\mathcal{S}|\mathcal{S}}(t)}{d\pi} = \frac{\partial\mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)}{\partial\pi} = \lambda + (1-\lambda)p\left(d_L(t),t\right) - (1-\lambda)p_\pi\left(d_L(t),t\right)\left[1-\pi\right] - \mu\frac{\partial d_L(t)}{\partial\pi}$$

where $\mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)$ is the natural Lagrangian for the problem: $\max_{d\in\mathcal{D}_S} U_{\mathcal{S}|\mathcal{S}}(d,t)$, $\mu > 0$ is the Lagrange multiplier of the binding constraint $d \geq d_L(t)$; and:

$$\frac{\partial d_L(t)}{\partial\pi} = \frac{c}{\gamma_d(d_L(t))(1-\pi)^2} < 0$$

Step 3. Define $\Delta U \equiv \frac{\partial\mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)}{\partial\pi} - \frac{\partial\mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)}{\partial\pi}$. Simple algebra leads to:

$$\Delta U = \lambda\gamma(d_\ell(t)) + (1-\lambda)\left\{\Delta p + \left[p\left(d_\ell(t),t\right) + p_\pi\left(d_\ell(t),t\right)\right]\gamma(d_\ell(t))\right\} + (1-\lambda)\left[1-\pi\right]\left(\nabla p_\pi\right) - \mu\frac{\partial d_L(t)}{\partial\pi} > 0$$

because $\Delta p := p\left(d_L(t),t\right) - p\left(d_\ell(t),t\right) > 0$, and $\nabla p_\pi := p_\pi\left(d_\ell(t),t\right) - p_\pi\left(d_L(t),t\right) = 0$, because both $p_\pi\left(d_\ell(t),t\right) = 0$ and $p_\pi\left(d_L(t),t\right) = 0$. □

PROOF OF COROLLARY 1. It follows immediately from Proposition 3 because by Assumption 3 $\nabla p_{\pi} \geq 0$.

PROOF OF LEMMA 2. Using equation (2) and differentiating $MB^{*}(d(t),t)$ and $MC^{*}(d(t),t)$ with respect to λ, one obtains: (a) $\frac{\partial MB^{*}}{\partial \lambda} = -\gamma_{d}(d_{\ell}(t))\pi\left[1-p(d_{\ell}(t),t)\right] > 0$; and (b)$\frac{\partial MC^{*}}{\partial \lambda} = -\{(1-\pi)+\gamma(d_{\ell}(t))\pi\}\frac{\partial p(d_{\ell}(t),t)}{\partial d} < 0$. By the Implicit Function Theorem: $\frac{\partial d_{\ell}(t)}{\partial \lambda} = \{\frac{\partial MB^{*}}{\partial \lambda} - \frac{\partial MC^{*}}{\partial \lambda}\}\frac{1}{H} > 0$ where $H \equiv \left(\frac{\partial MC^{*}}{\partial d} - \frac{\partial MB^{*}}{\partial d}\right) > 0$ because by Lemma A.1 $U_{\mathcal{S}|\mathcal{P}}(d,t)$ is strictly concave. Thus, $d_{\ell}(t)$ increases monotonically with λ. □

PROOF OF COROLLARY 2. The argument has two parts. First, it is a fact that $d_{\ell}(t)$ is a continuous increasing function and that $d_{L}(t) < 1$. Second, it is known by Proposition 2 that when $\lambda \to 1$, the marginal cost of disclosing goes to zero and the marginal benefit of disclosing remains positive. Hence: $\lim_{\lambda \to 1} d_{\ell}(t) = 1$. Therefore by the continuity of $d_{\ell}(t)$, there must exist a critical value for λ, denoted by $\lambda_{1}(t) \in (0,1)$, such that $d_{\ell}(t,\lambda_{1}(t)) = d_{L}(t,\lambda_{1}(t))$. □

PROOF OF PROPOSITION 4. As with Proposition 3, I proceed in three steps.

Step 1. From the envelope theorem:

$$\frac{dU_{\mathcal{S}|\mathcal{P}}(t)}{d\lambda} = \frac{\partial \mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)}{\partial \lambda} = -\left[1-p\left(d_{\ell}(t),t\right)\right]\Pi(d_{\ell}(t),t)$$

where $\mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)$ is the Lagrangian for the problem: $\max_{d\in\mathcal{D}_{P}} U_{\mathcal{S}|\mathcal{P}}(d,t)$ and $\Pi(d_{\ell}(t),t) \equiv \{(1-\pi)+\gamma(d_{\ell}(t))\pi\}$.

Step 2. By the envelope theorem:

$$\frac{dU_{\mathcal{S}|\mathcal{S}}(t)}{d\lambda} = \frac{\partial \mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)}{\partial \lambda} = -\left[1-p\left(d_{L}(t),t\right)\right](1-\pi)$$

where $\mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)$ is the Lagrangian for the problem: $\max_{d\in\mathcal{D}_{S}} U_{\mathcal{S}|\mathcal{S}}(d,t)$.

Step 3. Define $\Delta U := \frac{\partial \mathcal{L}_{\mathcal{S}|\mathcal{S}}(t)}{\partial \lambda} - \frac{\partial \mathcal{L}_{\mathcal{S}|\mathcal{P}}(t)}{\partial \lambda}$. Simple algebra leads to:

$$\Delta U = (1-\pi)\left[p\left(d_{L}(t),t\right) - p\left(d_{\ell}(t),t\right)\right] + \left[1-p\left(d_{\ell}(t),t\right)\right]\gamma(d_{\ell}(t))\pi > 0$$

because $p\left(d_{L}(t),t\right) - p\left(d_{\ell}(t),t\right) > 0$. □

Appendix B: Duplication Activities for Firm B

The imitative type of firm B chooses p after observing d. $C(p,d)$ is B's cost of achieving p, given d. $C(p,d)$ satisfies: $C_{p}(p,d) \geq 0, C_{pp}(p,d) > 0$. Also $\forall d \in [0,1] : C(0,d) = 0$ and $C_{p}(0,d) = 0$. Moreover:

ASSUMPTION B1: $\forall (p,d) \in [0,1]\times[0,1] : C_{pd}(p,d) < 0$.

Assumption B1 says that a higher disclosure level diminishes the marginal cost of duplication. It implies that $C_{d}(p,d) < 0$. Firm B chooses p to maximize its expected payoff. With probability $(1-p)$ duplication is a failure and profits are zero. With probability, p, duplication is a success. In this case, firm B obtains some payoff depending on its optimal IP choice. Its maximum value function is therefore: $\mathbb{V}(d,t) = \max\left\{\mathcal{P}\left(d,t\right),\mathcal{S}\left(t\right)\right\}$. Hence firm B's problem is: $\max_{p\in[0,1]}\left\{p\mathbb{V}(d,t) - C\left(p,d\right)\right\}$. To avoid corner solutions at both $p=0$ and $p=1$, I assume:

ASSUMPTION B2: $c < \pi$ and $C_p(1,1) \geq 1 \equiv \pi_{\mathbf{H}}$.

The first order necessary (and sufficient) condition is: $\mathbb{V}(d,t) = C_p(p,d)$. Lemma B1 below shows the existence of firm B's best response.

LEMMA B1: (a) Under any IP choice, firm B's best response exists and it is a C^1 function:

$$p^*(d,t) := \begin{cases} p(d,e) & \text{if } \mathbb{V}(d,t) = \mathcal{P}(d,t) \\ p^s(d,t) & \text{if } \mathbb{V}(d,t) = \mathcal{S}(t) \end{cases}$$

(b) Firm B's best response under patenting, $p(d,e)$, and under secrecy, $p^s(d,e)$, are such that:

$$p_d(d,t) = \frac{\mathcal{Z}_d(d,t) - C_{pd}(p,d)}{C_{pp}(p,d)} \lesseqgtr 0; \; p^s_d(d,t) = \frac{-C_{pd}(p,d)}{C_{pp}(p,d)} > 0$$

PROOF. Part (a) follows from the satisfaction of the conditions for the implicit function theorem: $\forall(p,d) \in [0,1] \times [0,1] : C_{pp}(p,d) \neq 0$. Part (b) follows from the characterization of comparative static effects of d on p^* using the first order condition. □

If firm B chooses $\mathcal{S}$, disclosure always increases its duplication probability: this is a restatement of Assumption B1. However, if B opts for patenting, disclosure could either lead to a higher or a lower level of p. This follows from the combination of Assumption B1 and the negative effect of disclosure on $\mathcal{Z}(d,t)$. If the negative effect of disclosure is large relative to its positive role, higher disclosure decreases firm B's best response. Given that conditional on success, $\gamma(d)$ also decreases with d, it follows that the optimal disclosure strategy would be $d^* = 1$. For all cases of practical interest, I focus on the situation in which the positive role of disclosure dominates its negative effect. Thus:

ASSUMPTION B3: $\forall(p,d) \in [0,1] \times [0,1] : \mathcal{Z}_d(d,t) - C_{pd}(p,d) > 0$.

There are also two technical issues to be dealt with. One is that for different disclosure levels the slope of the marginal cost, C_{pp}, might change. It is difficult to predict in which direction this effect might go. But the key matter is that the results of the paper are independent of this issue. Second, note also that the *complementarity* between disclosure and the duplication probability, C_{pd}, might change with the level of disclosure. This is a rather more important. But still the main concern is that Assumption B1 holds at all disclosure levels. Hence, I impose:

ASSUMPTION B4: $\forall(p,d) \in [0,1] \times [0,1] : C_{ppd}(p,d) = 0$ and $C_{pdd}(p,d) \leq 0$.

The reader can verify that under Assumptions B3 and B4 the following Lemma holds.

LEMMA B2: (a) Under Assumption B3, firm B's best response under patenting, $p(d,e)$, is a monotonically increasing function of disclosure.

(b) Under Assumptions B3 and B4, firm B's best response under patenting, $p(d,e)$, is a twice continuously differentiable strictly convex function of disclosure.

Finally, it can easily be checked that both under patenting and secrecy, $p^*_\pi(d,t) > 0$, and that under patenting $p_c(d,t) < 0$.

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