Patents, Trade Secrets and the Diffusion of Knowledge

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Abstract

This paper focuses on how to design patents that facilitate knowledge diffusion via licensing and compares patents and trade secrets along this dimension. Licensing takes place under the threat of imitation, which can be abated via the threat of free-riding. When the cost of imitation is low free-riding delays imitation, but not when it is high. For patents diffusion depends both on the cost of imitation and the type of innovator. For producer innovators this cost acts as a fence against imitation, leading to limited diffusion. For non-producer innovators when this cost is intermediate diffusion is comprehensive. Trade secrets allow for greater R&D incentives but for minimal diffusion.

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1 Introduction

One of the main roles of innovation policy is to incentivise R&D and promote its diffusion. These two goals are at odds. The public-good nature of an idea necessitates the restriction of its diffusion as to incentivise R&D (Arrow, 1962). Patents meet these two goals. In exchange for disclosure they turn non-rivalrous ideas into rivalrous goods by confining involuntary diffusion to 20 years. This limited time monopoly acts as an R&D incentive but, it burdens society with a dead weight loss (DWL), it can disincentivise innovation (Heller and Eisenberg, 1998; Williams, 2013; Galasso and Schankerman, 2014; Murray *et al.* 2016) and limit the exchange of tacit knowledge. Moreover, in our fast moving

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epoch, 20 years is often tantamount to perpetual protection. Licensing offers an attractive mechanism (Arora, Gambardella, 2010a,b) that voluntarily bridges R&D incentives with diffusion (Meurer and Scotchmer, 1992; Bessen, 2005) in a way that diminishes DWL while improving the prospects for subsequent sequential innovations (Bessen and Maskin 2009, Green and Scotchmer 1990). Economic theory has paid particular attention to licensing as a response to the threat of imitation (Galini, 1984; 1992), where the innovator is forced to license her idea to perspective imitators. Building on this literature we try to find how to design patents that promote licensing. As the relevant literature has mainly focused on either incentives to innovate or disclosure, to our knowledge we are the first to address this issue.

Specifically, starting with the seminal contribution of Nordhaus (1969), the literature has generally understood patents as R&D incentives and accordingly focused on how to calibrate their breadth and length in order to minimize DWL (Scotchmer, 2004 Ch4). The two main contributions that assume imitable patents, by Gallini (1992) and by Maurer and Scotchmer (2002), reach contradictory conclusions; the first argues for strong patents with minimal tenure, the second the opposite. Denicolò and Franzoni (2004) is the only paper working on imperfect patents that views patents as instruments of disclosure. They try to understand if patent can be fine-tuned as to promote socially valuable disclosure, and find that a positive patent life is required for this purpose. This trend is broadly followed by Bessen (2005) who does not focus on patent design but compares patents with imperfect trade secrets in terms of licensing, finding the latter as preferable.

In disentangling the role of intellectual property (IP) as an incentive to diffuse via licensing one is faced with two problems. Primarily, diffusion goes hand to hand with weak patents that face a small cost of imitation, in which case there is no reason for an innovator to patent. After all the *alter ego* of patents, trade secrets, present a popular way (Levin *et al.*, 1987; Arundel, 2001; Cohen *et al.*, 2000; Graham *et al.*, 2009; Png, 2017) of turning non-rivalrous ideas into rivalrous goods by masking the technology. True as it may be that patents and trade secrets are not directly comparable -because patents offer an array of R&D incentives that secrets lack (Panagopoulos and Park, 2018; Hall and Ziedonis, 2001), there cannot be a great inconsistency between the protection from imitation that patents and secrets offer. This argument implies that patents have to be at least relatively strong.

Furthermore, even under weak patents diffusion may not follow suit because there exist market forces that can protect an innovation from imitation even when the cost of imitation is small. For example Henry and Ponce (2011) argue that an innovator can use the threat of licensing a transferable contract in order to force imitators to wait than imitate; in which case there is no licensing. As in both occasions diffusion via licensing is minimal, at least superficially these arguments suggest that irrespectively of the strength of IP the result is the same, and licensing is instead driven only by strategic considerations (Katz and Shapiro, 1986, 2000). We contest this view.

In arguing our case in a way that incorporates both of the above arguments we built an infinite horizon framework in the spirit of Henry and Ponce (2011) –henceforth HP. Within an n-firm Cournot oligopoly an innovator faces multiple identical downstream producers who can imitate by incurring a commonly known fixed cost of imitation. The innovator can choose between a patent and a trade secret. Our policy variable is the cost of imitation and the only difference between patents and secrets is that for patents this cost is determined by the regulator and for secrets by the innovator. We vary this cost, which is often considered as a proxy of the strength of IP (Gallini, 1992), from naught up to monopoly profits and study how it affects licensing.

In this setting, forced by the prospect of imitation the innovator can license or sell the technology, with the additional license leading to lower prices, dissipating profits (Maurer and Scotchmer, 2002). Equally, if an imitator copies the technology she can also license/sell it to other downstream producers. In view of this, the innovator's only defense is the threat of free riding, as in Anton and Yao (1994). In particular, upon imitation the two parties will compete in offering licenses to all other producers. Such Bertrand competition allows non-imitators to obtain the technology for free.

Though we extend HP by accounting for: i) both the licensing and the sale of innovations; ii) producers and non-producer innovators; iii) patents and trade secrets; iv) an array of imitation costs, our principal addition to HP is v) that instead of a transferable contract we resort to the "traditional" threat of free riding (Anton and Yao, 1994) as a method for abating imitation. This diversion from HP is for two reasons. A transferable contract serves the purpose of stopping licensing. Therefore, even though its use makes sense for producer innovators who aim to protect their monopoly, such a contract is counterintuitive for non-producer innovators that rely on licensing for their profits. Primarily though, under a transferable contract, irrespectively of the IP strength set by the regulator, in equilibrium the innovator would set a licensing price that is equal to the low imitation cost that imitable trade secrets face. Thereby, contrary to what we aim to study, patents and trade secrets are indistinguishable and licensing is always minimal.

Against this backdrop we find that the cost of imitation acts as a switch that can reverse the main HP result when it stops being small, allowing for licensing to ensue. Specifically, similar to HP, when the cost of imitation is small (i.e. all can imitate) in equilibrium imitators randomize their entry time in such a way that entering and waiting are equivalent until the first entry, *à la* a war of attrition. This strategy is optimal for the innovator even though she foregoes the revenue from the transferable contract, available in the HP setting above, as this is a relatively small amount. The expected length of delay until the first entry allows the inventor to recoup the entire monopoly profits. Thus, as the innovator can fully abate imitation, there is no licensing.

By contrast, when this cost is greater so that few firms are able to imitate, imitation would stop after a certain number of downstream producers have imitated due to price dissipation as in Galini (1992). In such an occasion, since a producer innovator may stop short of spreading the knowledge to all firms, randomization is no longer possible because by delaying an imitator is no longer certain to get a license if someone else imitates first. Hence, there is licensing, albeit its agent-specific.

For non-producer innovators we show that under reasonable conditions an intermediate cost of imitation facilitates the comprehensive and socially optimal diffusion of ideas. However, when this cost is high there is a negative relationship between this cost and diffusion, resulting in limited licensing. When the innovator is a producer, for both an intermediate and a high imitation cost, there is a negative relationship between this cost and diffusion.

To summarize, for a regulator who is interested in fine-tuning patents as to promote licensing, IP protection of intermediate strength can lead to comprehensive diffusion of knowledge. For a profit maximizing innovator who needs to decide on how strong secrecy should be, both a strong and a weak level of secrecy can preclude imitation and allow for monopoly profits; the first by making imitation impossible, the second by forcing imitators to wait than imitate. Therefore, as long as the cost of keeping a secret is non-negligible the innovator would choose a small imitation cost for her technology; a cost that is comparable to the one offered by patents of intermediate strength.

The paper proceeds as follows. In section two we explain how this theme links to the literature. In section three we outline the assumptions. In sections four-five we solve the model assuming a low and then higher costs of imitation respectively. In section six we offer a discussion on the issue and outline the evidence in support of our theory, and conclude in section seven.

2 Literature review

The role of trade secrets as instruments of innovation policy is clear. Their purpose is to mask an idea, making it a private good. This is not so for patents. The purpose of patents is debated and the actual interpretation we attach to them matters because it will be employed by courts. Assuming that a patent is not a right *per se*, it is then viewed as a "privilege" bestowed to the innovator by society in a *quid pro quo* that is understood through two different theoretical strands.

The first one, the "rewards" theory, asserts patents as a limited time monopoly society offers to innovators to compensate *ex-post* (Arrow, 1962) or *ex-ante* investments (Kirtch, 1977). Though the intuitiveness of this view stands at odds with existing empirical evidence (Levin *et al.*, 1987; Arundel, 2001; Cohen *et al.*, 2000 , Graham *et al.* 2009) it offers the most popular understanding of patents. Under this narrative, in exchange for the afforded R&D incentives, society is willing to self inflict itself by barring the burden of the relevant dead weight loss (DWL).

Starting with Nordhouse (1969), this *quid pro quo* was examined from the view point of patent races (Denicolo, 1996) and licensing (Gallini and Scotchmer, 2002). The first model to address the issue in terms of licensing under imperfect IP rights was Gallini (1992) who finds that social surplus is maximized when patents are broad (no imitation) and patent life is adjusted to achieve the desired patent reward. Maurer and Scotchmer (2002) reach the opposite conclusion by making the point that since in equilibrium no imitation takes place patents should be of infinite length, with breadth adjusted so as to provide a pre-specified reward to the patentee, as in Gilbert and Shapiro (1990).

The second theoretical strand, the "contract" theory, understands patents as a social contract: "*the result of a bargain between society and inventor, a contract in which the inventor agreed to disclose his secret and the state agreed, in exchange, to protect the inventor for a number of years*" (Machlup and Penrose, 1950, pg 26). Patents are instruments that can induce firms to disclose their innovation (Denicolò and Franzoni, 2004; Bessen, 2005), rather than tools necessary to foster R&D. We have turned our attention to this understanding of patents and argued that for IP of intermediate strength it is both possible to minimize DWL via non-exclusive licensing and maximize consumer surplus.

The call for moderate IP rights is not new (Bessen and Maskin, 2009; Fershtman and Markovich, 2010). In facilitating the comparison of patents with trade secrets the notion of weak IP rights as an incentive to innovate has been recently revived by Panagopoulos and Park (2018), in a dynamic bargaining model where patents prevail of over secrets because they act as transferable bargaining chips. This comparison has only recently attracted much attention in the economic literature, mainly by Horstmann *et al.* (1985), Anton and Yao (2004), Denicolo and Franzoni (2004), Kultti *et al.* (2006, 2007), Kwon (2012). These papers emphasize secrecy as an R&D incentive, contrasting the present approach that focuses on diffusion where trade secrets fail to diffuse because the same market forces that protect them from imitation equally restrict their diffusion.

In terms of these market forces, the innovator can threaten copycats with free riding (Anton and Yao, 1994); the sharing of the secret with rivals. In such an occasion the imitator is faced with a dilemma because by successfully imitating she incurs the re-innovation cost for something that everyone else will get to use for free. Therefore, it is best to wait until someone imitates first (Henry and Ponce, 2011). Equally, since imitation allows more people to use the secret, it also diminishes an imitator's incentives to protect the secret from further imitation, in which case it is again best to wait for someone else to imitate first (Henry and Ruiz-Aliseda, 2016). In this paper we argue that free riding and the ensuing diffusion depends on the cost of imitation, which acts like a switch that can turn the protection of free riding on or off.

The cost of imitation, which is a central element of the patent race literature, is generally considered as socially wasteful (Fundeberg *et al.*, 1983). In our model this cost is not wasteful because (unlike patent races) it is never sunk in equilibrium, yet its magnitude can induce licensing and in doing so affect market structure. By affecting downstream competition it is of relevance to endogenous growth theory (Grossman and Helpman, 1991; Aghion and Howitt, 1992), which assumes an upstream monopoly and a downstream competitive environment.

3 Assumptions

We consider an infinite horizon model in which an agent, denoted by i, has developed an innovation. This innovator can either be a producer or a non-producer innovator (NPI). For NPIs licensing decisions are driven by necessity, thereby NPIs have no choice but to license. Prominent examples of NPIs are universities, research organizations, as well as most startup firms. The innovation can be protected by a patent or a trade secret (TS) and i faces a finite number of identical downstream producers with the capacity to imitate.

We model the downstream market as an n-Cournot oligopoly. Similar to Denicolò and Franzoni (2004) demand is linear and takes the form $p(Q) = 1 - aQ$. We assume that the downstream producers cannot collude. Perspective imitators are indexed by $j = 1, 2, \cdots, n$. They may "adopt" the innovation by either (i) buying the knowledge from i or (ii) employing costly imitation (henceforth, imitating). The innovation is introduced into the product market at time period $t = 0$. For notational ease the profits of the downstream producers are normalized to zero if they do not use the innovation.

When an imitator adopts the innovation at time period t, we say that she "enters" the market, irrespective of the mode of her entry. Upon entry the innovator and all imitators obtain the same equilibrium profits. We use π_m to denote the per-period equilibrium profit received by each firm operating in the product market using the innovation when a total of m firms operate as such. All parties are risk neutral and maximize the sum of their expected discounted payoffs (profits plus potential contract payments). They discount the future exponentially with a per-period discount factor equal to $\delta := e^{r\Delta}$, where $r > 0$ is the discount rate and Δ is the length of each time period. We use $\Pi_m := \pi_m/r$ to denote the equilibrium discounted value of market profits per firm when m firms operate (employing the innovation) in the product market.

When the innovation is kept secret an imitator can obtain a facsimile of $i's$ innovation at any time t, by spending a commonly known fixed amount of resources that we view as a one-time sunk cost of imitation. This cost must be incurred to reverse-engineer the innovation. We assume that there exist prior user rights i.e. if an imitator succeeds in reverse-engineering she cannot get a patent.

Equally, when the innovation is patented an imitator can create a perfect non-infringing substitute of $i's$ innovation (i.e. a variant technology), or a differentiated product with a symmetric demand at any time t, by spending a commonly known one-time sunk cost to legally bypass $i's$ innovation. We assume that both the original innovation and its variant are protected by commonly assumed valid patents. Plus, the original innovation is not protected by a standard and essential patent, nor is it part of a patent pool. Furthermore, the variant is not liable to pay licensing fees to i.

In this setting the only difference between patents and secrets is that for TS i decides on the imitation cost, while for patents it is the regulator who makes this choice. This means that for TS the innovator will choose its optimal level of secrecy by acting as a profits maximizer, while the innovator will act having diffusion in mind. It should be noted that perfect secrecy is costly because TS must not be known to the public and their owner must have taken steps to conceal their particulars. Such steps include the careful monitoring of employees, contractors and consultants, strict use of restrictive covenants in employment contracts and vigilant observance of non-disclosure agreements. Additionally, upon licensing concealment requires supervision of similar practices by all users.

Imitation is not the only way to enter the market. An alternative to imitation is to buy the knowledge through contracting. There are two kinds of contracts: licensing and sale. However, upon contracting there is a risk the licensee will refuse to honor her commitments after the TS's details have been revealed (Arora, Fosfuri, and Gambardella, 2001). As Anton and Yao (1994) have explained, the threat of free riding can diminish such moral hazard, because if the licensee refuses to pay the TS is freely shared. Therefore, in this setting refusal to abide with the contract is tantamount to imitation.

At time t, licensing grants a licensee j a perpetual right to use the technology for a one-off up-front fee f_j^t, but not the right to transfer the knowledge in any manner. Unlike licensing, at time t the sale of knowledge transfers full ownership to a buyer j for a one-off up-front price p_j^t. From that subsequent period onwards the seller has no rights to the knowledge i.e. the seller becomes an imitator who has not entered. Finally, we assume that if an imitator enters by imitating, she can also sell or license knowledge.

We embed these elements within the following extensive form game. Consider any time period t in which no imitator has entered yet. The timing of the game is then as follows: (i) The innovator announces, on a take-it-or-leave-it basis, a pair of contracts $(f_j^t, p_j^t) \in \mathbb{R}^2$ for each imitator j. (ii) The imitators simultaneously decide whether to enter the market—by imitating, licensing, or buying knowledge—or not to enter. The game continues in this manner until there is an entry. If at time period t all imitators have entered, the game ends and all parties collect a profit π_M from that period onward, where M is the number of firms operating. Note that $M = n$ if the innovator is an NPI and $M = n + 1$ if the innovator is a producer. However, if $m < M$ firms operate prior to t, the game continues as follows: (i) The buyers of knowledge from the innovator (possibly through a sequence of sales) and all imitators who entered by imitating, simultaneously announce (f_j^t, p_j^t) for each imitator j who has not entered. (ii) The yet to enter imitators simultaneously decide whether to enter the market—by imitating, licensing, or buying knowledge—or not to enter.

All parties observe the history of the game up to the beginning of time period t and all contracts offered at the beginning of time period t. We focus on Markov perfect equilibria (MPE) of the game where the state variable will be specified later depending on whether the inventor is a producer or not.[1] We directly study the continuous-time version

[1] An MPE is a subgame perfect equilibrium in which the contract-offering strategy depends only on the state variable and the decision functions of the imitators yet to enter depend on the state variable and the contracts being offered.

of the game, which should be considered as the limit of a sequence of discrete-time games as $\Delta \to 0$ (see Simon and Stinchcombe 1989). In what follows we start with a baseline model that examines a producer and an NPI facing a small cost of imitation and then proceed with the case of a greater cost.

4 Small cost of imitation, $\kappa < \Pi_{n+1}$

4.1 Producer innovators

We start by examining a producer innovator i who faces a cost of imitation $\kappa < \Pi_{n+1}$. In this section our results are underpinned by proposition 4 of HP, who model a similar framework. We differ from HP in assuming that i employs the threat of free riding, whilst HP base their results on a transferable contract. As both free riding and the transferable contract trigger Bertrand competition between i and imitator j, in practical terms the only difference between this and HP is that in HP i captures a licensing fee of κ, while in this setting (since i does not make any licensing offer) she does not capture κ. This price κ is the difference between what a prospective imitator stands to gain when she is licensed the technology (Π_{n+1}) and her ($\Pi_{n+1} - \kappa$) payoff from imitating. Yet, as κ is very small, foregoing κ does not affect the ensuing comparison. Proposition 4 of HP can be summarized as:

Proposition HP: *Suppose that i is also a producer, her knowledge faces a cost of imitation $\kappa < \Pi_{n+1}$, and transferable contracts are feasible as well as licensing and sale of knowledge. There is an MPE in which (i) i sets the price for transferable contract to κ for all imitators until there is an entry; (ii) the distribution of entry times of every imitator is exponential with hazard rate equal to $\lambda_n = \frac{r(\Pi_{n+1}-\kappa)}{(n-1)\kappa}$; (iii) once there is an entry, all remaining imitators enter for free due to Bertrand competition between i and the first entrant in the knowledge market; and (iv) i's expected payoff is $V_i(n) = \mu_n \Pi_1 + (1-\mu_n)(\kappa + \Pi_{n+1})$ where $\mu_n = r/(r + n\lambda_n)$.*

The above result is driven by the following insight: imitators are deterred from entry by the prospect that any entry (by transferable contract) triggers Bertrand competition between i and the entrant licensee, rendering the innovation freely available to all imitators. As it is not viable for entry to never occur because $\kappa < \Pi_{n+1}$, in equilibrium imitators randomize their entry time in such a way that entering and waiting are equivalent until the first entry; a "waiting game". The expected length of delay until the first entry, μ_n, increases without bound as $\kappa \to \Pi_{n+1}$, allowing i to recoup the entire monopoly profits.

4.1.1 Payoff from inducing a waiting game by not offering to license

We now examine how i can abate imitation and recoup her monopoly profits by refusing to license/sell the technology. By not offering to license/sell, i can replicate the equilibrium of Proposition 4 of HP in the following manner: i does not make any offer until downstream producer j imitates by incurring a cost of κ, after which all remaining producers would be licensed for free due to Bertrand competition in licensing between i and j. In this equilibrium, the prospect of a free license after imitation induces the same delay of imitation as in Proposition HP.

The reasoning behind Proposition HP and this setting differs only along two lines: A) i does not garner the licensing revenue of κ because the first entry takes place via imitation rather than transferable contract. Therefore, $i's$ payoff upon imitation is no longer $(\kappa + \Pi_{n+1})$, its just Π_{n+1}; B) As i has no aim to license the technology she has to set a price that is greater than the price of the transferable contract, which was equal to the difference κ between what an imitator gains upon licensing (Π_{n+1}) and her $(\Pi_{n+1} - \kappa)$ payoff from imitating. Consequently, we find that Proposition HP prevails with the following two modifications along points (i) and (iv): (i) the innovator sets price $p_n > \kappa$ (or she does not offer a license); and (iv) $i's$ payoff is $V_i(n) = \mu_n \Pi_1 + (1-\mu_n)\Pi_{n+1}$, where $\mu_n = r/(r + n\lambda_n)$ and $\lambda_n = \frac{r(\Pi_{n+1}-\kappa)}{(n-1)\kappa}$

However, unlike the transferable contract which is a one-off transaction, in this setting i could also issue some ℓ licenses before inducing a waiting game as above. Then, the waiting game starts at $t = 0$ by the property of MPE among non-licensees who get the payoff of $\Pi_{n+1} - \kappa$ from imitating first and Π_{n+1} otherwise. These payoffs are the same as in the waiting game without licensees, but $i's$ profit is lower at $\Pi_{\ell+1}$ rather than Π_1 until imitation occurs. Hence, $i's$ payoff excluding the initial license revenue is $\mu_m \Pi_{\ell+1} + (1 - \mu_m)\Pi_{n+1}$ which is also each initial licensee's surplus gross of license fee, where $m = n - \ell$ and $\lambda_m = \frac{r(\Pi_{n+1}-\kappa)}{(m-1)\kappa}$. Thus, the aggregate industry surplus in the product market is $\mu_m(\ell + 1)\Pi_{\ell+1} + (1 - \mu_m)(n + 1)\Pi_{n+1}$.

As imitators other than the licensees derive an expected payoff of $\Pi_{n+1} - \kappa$, the maximum initial license fee is $\mu_m\Pi_{\ell+1} + (1 - \mu_m)\Pi_{n+1} - (\Pi_{n+1} - \kappa) = \mu_m(\Pi_{\ell+1} - \Pi_{n+1}) + \kappa$, which must be the equilibrium license fee. Consequently, $i's$ total surplus is the total industry surplus minus the total expected surplus of all imitators, i.e.,

$$\mu_m(\ell + 1)\Pi_{\ell+1} + (1 - \mu_m)(n + 1)\Pi_{n+1} - (n + 1)(\Pi_{n+1} - \kappa)$$

which is decreasing in ℓ because the derivative of $\mu_m = \frac{\kappa(1+\ell-n)}{\kappa-(n-\ell)\Pi_{n+1}}$ with respect to ℓ is $\frac{\kappa(\kappa-\Pi_{n+1})}{(\kappa-(n-\ell)\Pi_{n+1})^2} < 0$. Therefore, i does not issue any licenses before inducing a waiting game because it would reduce her payoff.

4.1.2 Payoff from offering license/sale without inducing a waiting game

Turning our attention to the case of licensing the technology, the licensing fee in this case is equal to κ; and there is no reason for i to reduce it below κ in any future time point. Given this, all firms would not delay entry if the license fee is κ, which is the maximum acceptable level. Hence, $i's$ maximum surplus is $n\kappa + \Pi_{n+1}$, consisting of licensing revenue from all n firms at $t = 0$ and $i's$ share of the product market profits.

If on the other hand, i sells the technology (becoming a perspective imitator) transferring ownership to a new sole "owner" who can then license, the buyer's profits are $n\kappa + \Pi_{n+1}$ if she buys the technology and $\Pi_{n+1} - \kappa$ if she imitates. Therefore, $i's$ maximum surplus is $(n+1)\kappa$, which is less than what i derives from licensing because $\kappa < \Pi_{n+1}$.

This rational would hold if i sells the technology after issuing some licenses first. Considering that both i and the buyer would license the technology for a fee equal to κ, $i's$ payoff is $n\kappa + \Pi_{n+1}$ minus what the seller makes if she chooses to imitate instead i.e. $\Pi_{n+1} - \kappa$. Since $i's$ maximum surplus is again equal to $(n+1)\kappa$ it is always optimal for i to license.

4.1.3 When does the result of HP prevail?

It is routinely calculated that $V_i(n) > n\kappa + \Pi_{n+1}$ holds if and only if

$$\Pi_1 \;>\; (n+1)\Pi_{n+1} + \frac{n}{n-1}(\Pi_{n+1} - \kappa). \qquad (1)$$

Therefore, if (1) holds, i provokes a waiting game (by not offering to license), which results in strategic delay of entry. The classes of environments in which the condition (1) holds include, but not limited to, a) κ is sufficiently close to Π_{n+1}, and b) the market demand is linear when $\kappa \in (0, \Pi_{n+1})$ and $n \geq 3$.

4.2 The innovator is an NPI

We now consider the case the innovator is an NPI (denoted by S -for startup) facing $n+1$ downstream firms. The main difference between an NPI and a producer is that the NPI cannot induce a waiting game. Lacking production capacity she has to transfer the technology.

Accordingly, assuming that (1) holds, if S sells to a firm, say i, then i would earn $V_i(n)$ by inducing a waiting game as described above. Since in such an occasion the other firms' expected payoff is $\Pi_{n+1} - \kappa$, i would buy the technology if $V_i(n)$ net of the price is no lower than $\Pi_{n+1} - \kappa$.

Thus, the maximum payoff of S from selling the technology is $V_i(n)$ less $\Pi_{n+1} - \kappa$. If one the other hand S licenses, her maximum revenue is $n\kappa + \Pi_{n+1}$ less $\Pi_{n+1} - \kappa$. Therefore, since by (1) $V_i(n) > n\kappa + \Pi_{n+1}$, it is optimal for S to sell the technology for a price of

$$\mu_n(\Pi_1 - \Pi_{n+1}) + \kappa \;=\; \frac{\kappa((n-1)\Pi_1 + \Pi_{n+1})}{n\Pi_{n+1} - \kappa}$$

resulting in strategic delay of entry by other firms due to the waiting game that will subsequently prevail.

To summarize, when $\kappa < \Pi_{n+1}$ and (1) holds, a producer innovator will induce a waiting game and garner profits that are equal to $V_i(n)$, while an innovator who is an NPI will sell her technology for a price of $\frac{\kappa((n-1)\Pi_1+\Pi_{n+1})}{n\Pi_{n+1}-\kappa}$, in which case the buyer will induce a waiting game. In both cases diffusion is minimal.

5 Greater costs of imitation

We now examine the case of an imitation cost greater than Π_{n+1}, which is now depicted as k. The fact that $k > \Pi_{n+1}$ adds a particular degree of complexity to the model. As in Galini (1992), imitation should stop after a certain number of downstream producers have imitated due to price dissipation. Since not all the downstream producers are able to imitate, the innovator i is faced with a dilemma: *should i license to few or to all*? When licensing to fewer producers the model's dynamics may change because, as an imitator j is no longer certain to obtain a license, $j's$ incentives to wait are watered down. This argument places the emphasis on the number of entrants.

Assuming that it is best for i to license to few, let us focus on the last instance where entry by imitation is possible. As in this case there are $\widetilde{m} < n+1$ firms that have not entered, and since no further entry is forthcoming, any firm who can license would license these $\widetilde{m}$ remaining firms for a fee of Π_{n+1} each as long as the $\widetilde{m}\Pi_{n+1}$ revenue that it would raise is greater that the drop in its operating profit, which is $\Pi_{n-\widetilde{m}+1} - \Pi_{n+1}$. This can be beneficial only if $(\widetilde{m}+1)\Pi_{n+1} \geq \Pi_{n-\widetilde{m}+1}$. Accordingly, we introduce the following equilibrium condition on the product market with $n+1$ potential producers:

$$2\Pi_{\widetilde{m}} \geq \Pi_{\widetilde{m}-1} \;\text{ if }\; \widetilde{m} \geq 3 \;\text{ and }\; (\widetilde{m}+1)\Pi_{n+1} \geq \Pi_{n+1-\widetilde{m}} \;\text{ iff }\; 0 < \widetilde{m} \leq \hat{m} \tag{2}$$

for some integer $\hat{m}$ such that $\hat{m} < n$ and $\hat{m}/n \to 1$ as $n \to \infty$. As long as (2) holds i will license to few firms.

Considering that the model operates within a Cournot oligopoly and assumes a linear demand $p(Q) = 1 - aQ$, where $a > 0$, routine calculations indicate that $\pi_{\widetilde{m}} = \frac{1}{a(\widetilde{m}+1)^2}$, $2\pi_{\widetilde{m}} - \pi_{\widetilde{m}-1} = \frac{\widetilde{m}^2-2\widetilde{m}-1}{a\widetilde{m}^2(\widetilde{m}+1)^2}$ and

$(\widetilde{m}+1)\pi_{n+1} - \pi_{n+1-\widetilde{m}} = \frac{\widetilde{m}(\widetilde{m}^2+n^2+2n-\widetilde{m}(3+2n))}{a(n+2)^2(2+n-\widetilde{m})^2}$. Hence, in particular, $2\pi_{\widetilde{m}} \geq \pi_{\widetilde{m}-1}$ if $\widetilde{m} \geq 3$ and $(\widetilde{m}+1)\pi_{n+1} \geq \pi_{n+1-\widetilde{m}}$ if and only if $0 < \widetilde{m} \leq \hat{m} := \lfloor n + \frac{3-\sqrt{9+4n}}{2} \rfloor$ where $\lfloor x \rfloor$ is the largest integer not exceeding x. Note that $\hat{m} < n$ and $\hat{m}/n \to 1$ as $n \to \infty$.

In what follows $\hat{m}$ is used to indicate the maximum number of perspective imitators who cannot enter by imitation and, consequently, $m = n - \hat{m}$ indicates the maximum number of entrants. Since $m := \lfloor -\frac{3-\sqrt{9+4n}}{2} \rfloor > 0$, m is not a function of k (or the corresponding strength of IP protection); it only depends on n. In short, in terms of human ingenuity the model bases its logic on the conception that the greater the n the greater the number of dexterous individuals.

5.1 The innovator is a producer

We start with the case that i is also a producer and there are n potential imitators. Suppose k is such that

$$\Pi_{n+1} \ < \ k \ < \min\left\{1, \frac{\hat{m}+1}{n-1}\right\} \cdot \Pi_{n-\hat{m}}. \tag{3}$$

We first examine the possibility that i does not sell the technology, so other firms may enter either by imitating at a cost k or through licensing. Our first task is to examine when entry stops and if imitation is possible at that point. In defining when entry stops we will employ the equilibrium condition of (2) and in doing so we identify three possible scenaria.

A) First, consider the contingency that at least $m = n - \hat{m}$ firms other than i have entered at some point t in an MPE. If $m < n$ and no further entry is forthcoming according to the MPE, then any firm who can license may deviate by licensing all remaining firms at a fee of Π_{n+1} each, which would raise a fee revenue of $(n-m)\Pi_{n+1}$ but reduce the continuation operating profit of the licensing firm by $\Pi_{m+1} - \Pi_{n+1}$. As this is beneficial because $(n-m)\Pi_{n+1} - (\Pi_{m+1} - \Pi_{n+1}) = (\hat{m}+1)\Pi_{n+1} - \Pi_{n+1-\hat{m}} \geq 0$ by (2), we deduce that all firms eventually enter. This argument further implies that as soon as at least m other firms have entered in any MPE, all remaining firms enter immediately for a license fee of Π_{n+1} each if no firm entered by imitating, and for free otherwise due to Bertrand competition in licensing.

B) Next, consider a time point t along an MPE at which $m-1$ other firms have entered. Then, if there is any further entry, at that point all $\hat{m}$ remaining firms enter simultaneously as argued above. Hence, the total license fee revenue from further entry is no higher than $(\hat{m}+1)\Pi_{n+1} = (n-m+1)\Pi_{n+1}$. At the same time licensing would reduce the continuation operating profit of the licensing firm by $\Pi_m - \Pi_{n+1}$. However,

$(n-m+1)\Pi_{n+1}-(\Pi_m-\Pi_{n+1})=(\hat{m}+2)\Pi_{n+1}-\Pi_m\leq 0$ by (2). Thus, no firm benefits by licensing. Nor any firm would benefit by imitating because the cost exceeds the expected profit Π_{n+1}. Therefore, once $m-1$ other firms have entered, it constitutes a continuation equilibrium that no further entry takes place.

C) Given this, consider the contingency that $m-2$ other firms have entered at some point t. It is not viable for there to be no further entry, because if it was anticipated then it would be a profitable deviation for a firm to enter by imitating as there would be no further entry as asserted above, so that the deviating firm's revenue is Π_m and the cost of entry, k, is lower due to (3). Consequently, it constitutes a continuation equilibrium that one remaining firm[2] is licensed immediately for free if there is an imitator and for a fee k otherwise (because any higher fee would prompt the entry by imitating rather than licensing). Analogously, if $m-j$ other firms have entered at some point t, then it constitutes a continuation equilibrium that certain $j-1$ remaining firms are licensed immediately for free if there is an imitator and for k otherwise. We focus on MPE's with this property.

We now proceed to examine the payoffs from all the possible strategies of licensing, imitating, or randomizing over time. Starting with licensing, the above argument indicates that, at $t=0$, i has a choice to either license the $m-1$ perspective entrants for k, or license comprehensively for Π_{n+1}. Since the comparison between these two strategies is not obvious we now compare them. Accordingly:

(a) If i licenses $m-1$ firms for a fee of k each, $i's$ total surplus is $(m-1)k+\Pi_m$ and each licensee's surplus is Π_m-k.

(b) If i licenses all n firms for a fee of Π_{n+1} each, $i's$ total surplus is $(n+1)\Pi_{n+1}$ and every other firm's surplus is 0. Note that $i's$ payoff is lower than that of case (a) because $(n+1)\Pi_{n+1}<\Pi_{m+1}<\Pi_m$ by (2).

When i does not license any firm at $t=0$, any initial entry is by imitation and takes place at $t=0$ unless all potential entrants randomize over time (due to the property of MPE). Focusing on imitation only, there are three possible cases.

(c) If $m-1$ firms imitate at $t=0$, then there is no more entry. Each imitator's surplus is $\Pi_m-k>0$ and $i's$ surplus is Π_m.

[2] The identity of this firm is determined by the set of remaining firms.

(d) If $j \in (0, m-1)$ firms imitate at $t = 0$, then $m - 1 - j$ more firms get licensed immediately for free after which there is no more entry. Each imitator's surplus is $\Pi_m - k > 0$, each licensee's surplus is Π_m, and $i's$ surplus is Π_m.

(e) If more than $m - 1$ firms imitate at $t = 0$, then all remaining firms enter immediately for free. Each imitator's surplus is $\Pi_{n+1} - k < 0$, $i's$ surplus is Π_{n+1}, and each licensee's surplus is also Π_{n+1}.

When i does not license and no firms imitate then by the property of the MPE either no firm enters or there is randomization over time as examined below.

(f) If no firm imitates at $t = 0$, then by the property of the MPE either no firm enters at all or firms $1 \sim n$ engage in a waiting game by continuously randomizing over time. The former is not viable because if any firm deviates by imitating then it gets a payoff of $\Pi_m - k > 0$ by (d).

Thus, in terms of (f) consider the following symmetric waiting game that may prevail. If one out of the n firm imitates at some point, then by (d) every other firm has a $\frac{m-2}{n-1}$ chance of being offered to license for free, thus their expected payoff is $\frac{m-2}{n-1}\Pi_m$. But, as this is lower than $\Pi_m - k$ by (3), a payoff it can get for sure by imitating at $t = 0$, all firms would prefer to imitate immediately at $t = 0$ rather than randomizing over time. Hence, a symmetric waiting game is not viable, either. This establishes that case (f) cannot arise in an MPE under consideration.[3] Furthermore, this argument also implies that i cannot sell a few licenses before inducing a waiting game. Such licensing would further reduce every other firm's chance of being offered to license for free, forcing firms to imitate immediately at $t = 0$ rather than randomizing over time.

Comparing (a)–(f), we deduce that (a) is optimal. Thereby, in the (considered) MPE it is uniquely optimal for i to license $m-1$ firms for a fee of k each at $t = 0$, after which no further entry occurs, and $i's$ payoff is $(m-1)k + \Pi_m$.

Turning our attention to the case where i sells the technology. In such an occasion, by (a), the buyer would charge each of the $m - 1$ licensees a fee of k and her profits would be $(m - 1)k + \Pi_m$. However, as in this

[3] A waiting game may arise (in which no imitation ever takes place) if the continuation equilibrium after one firm imitated is such that all remaining firms are licensed for free immediately after. But this continuation equilibrium is supported by the weakly dominated strategy, by both the inventor and the imitator, of offering license to all remaining firms for free.

occasion a perspective buyer could also try to imitate she can charge a rent that is at least equal to her profits from imitating. Thereby, the maximum surplus that i can attain would be less than $(m-1)k+\Pi_m$ by the rent that the buyer would charge. Equally, if i offers a few licenses for a fee of k before selling the technology to a buyer who would also charge each licensee a fee of k, since only $m-1$ will be licensed, the maximum surplus that i can attain is again $(m-1)k+\Pi_m$ minus the rent the buyer would charge. Since in both occasions $i's$ payoff is less than (a) we conclude that i will license $m-1$ firms for a fee of k each at $t=0$.

5.2 The innovator is a non-producing startup

We now consider the environment in which the innovator is a startup S who may either sell or license the patent to potential $n+1$ downstream firms. Overall S is faced with the following choices:

1. Starting with the case of a patent sale, if S sells the patent, say to firm i, then (as argued in the previous section) i will license $m-1$ firms for a fee of k each at $t=0$ and in the process derive a payoff of $(m-1)k+\Pi_m$. This payoff constitutes the upper bound of $S's$ revenue from selling the patent.

2. Next, consider the MPE in which no patent sale takes place. In such an occasion S must license at $t=0$ for a positive fee (as S cannot commit not to do so). In doing so S has two options:

2a To license to m firms for k, in which case $S's$ total revenue is mk.

2b Or, to license all remaining firms, if any, for a fee of Π_{n+1} each, generating a total revenue of $(n+1)\Pi_{n+1}$.

In the previous section the comparison between a strategy of licensing to m instead of $n-1$ firms was in favour of the former due to (2). In this occasion $S's$ total revenue from licensing to m is reduced because S is not a producer, and $S's$ total revenue is no longer $(m-1)k+\Pi_m$ as in case (a) in the previous section. This means that it is not directly evident which of the two strategies is dominant.

3 Finally, consider $S's$ strategy of licensing some ℓ firms, where $\ell \geq m$ or $\ell < m$, before selling the patent. We assume that in this case, all prior licenses will be honored after the sale. Note that any licensing takes place immediately at $t=0$ because S, being a non-producer, has no incentive to delay licensing. In addition, $S's$ offer of patent sale takes place immediately after completion of

prior licensing due to the property of MPE, thus at $t = 0$. Hence, if the patent sale were to take place at a deterministic time, it would be at $t = 0$. Alternatively, patent sale may not take place at $t = 0$ but stochastically over time, which is the case when prospective buyers randomize over time *à la* a waiting game. We consider these two cases separately; for both $\ell \geq m$ and $\ell < m$.

3a If the sale takes place at $t = 0$ after $\ell \geq m$ have been already issued, as we have already explained in case (A), the patent buyer i will immediately license all remaining firms for a fee Π_{n+1}, in which case $i's$ payoff is $(n - \ell)\Pi_{n+1} + \Pi_{n+1}$. By contrast, if the sale takes place stochastically over time because i opts to wait (and abstains from buying the patent) $i's$ payoff would be naught, which contradicts randomization over time.

3b If the sale takes place at $t = 0$ after $\ell < m$ have been already issued, analogous to cases (a) and (b), the patent buyer i either immediately licenses $m-\ell-1$ remaining firms for a fee k and gets a payoff of $(m - \ell - 1)k + \Pi_m$, or licenses all remaining firms for Π_{n+1} and gets a payoff of $(n - \ell)\Pi_{n+1} + \Pi_{n+1}$, whichever is larger. If the sale takes place stochastically over time because i opts to wait, considering that the payoff of the $m - \ell - 1$ firms that are lucky to be licensed afterwards is $\Pi_m - k$, which is also the payoff from imitation, i has no incentive to wait, again contradicting randomization over time.

From the discussion of (3) above, we deduce that: i) unlike the case of a cost of imitation κ, there is no randomization over time and ii) i buys at $t = 0$ and immediately licenses either all remaining firms for a fee Π_{n+1} or $m-\ell-1$ remaining firms for a fee k. In the former case, $i's$ revenue is $(n - \ell)\Pi_{n+1} + \Pi_{n+1}$ and the prior licensee's revenue is Π_{n+1} each and $\ell\Pi_{n+1}$ in total. Therefore, $S's$ surplus is no higher than their sum, $(n+1)\Pi_{n+1}$, which is what S can equally derive if it chose to license to all firms for a fee of Π_{n+1}. By contrast, if i licenses $m - \ell - 1$ firms for a fee k, its revenue is $(m - \ell - 1)k + \Pi_m$ and the prior licensee's revenue is Π_m each and $\ell\Pi_m$ in total . Bearing in mind that the fee for the prior license is at most k, $S's$ surplus in this case is no higher than $(m - 1)k + \Pi_m$.

Summarizing, it is optimal for S either to license to $\ell \in \{0, 1, \cdots, m-1\}$ firms then sell the patent at $t = 0$ for a price of $(m - \ell - 1)k + \Pi_m$ minus a suitable rent to firm i (who will license $m - \ell - 1$ firms for a fee of k), or license to all firms for a fee of Π_{n+1} each at $t = 0$, for a total revenue of $(n + 1)\Pi_{n+1}$, whichever is larger.

When S sells the patent the amount of rent i charges is determined by the payoff i can get by not buying the patent, in which case i would get a payoff of $\Pi_m - k$ in the continuation game. Thus, the rent must be at least $\Pi_m - k$, which means that the sale price cannot be higher than $(m-\ell)k$. As the fee for prior license is at most k, $S's$ surplus is no higher than mk from selling the patent after licensing to $\ell \in \{0, 1, \cdots, m-1\}$ firms. Therefore, it is optimal for S to license to all $n+1$ firms if $k \leq k^*$ where k^* solves $mk = (n+1)\Pi_{n+1}$, i.e.,

$$k^* = \frac{(n+1)\Pi_{n+1}}{m} > \Pi_{n+1}. \tag{4}$$

Thus, if $k \in (\Pi_{n+1}, k^*)$, a startup with a patent licenses to all firms for a total surplus of $(n+1)\Pi_{n+1}$.

6 Patent vs. TS and the diffusion of knowledge

6.1 The innovator is a producer

The model operates under the assumption that when a TS has to be shared it either manages to retain its secrecy, in which case there is no imitation, or it does not and faces a cost of imitation $\kappa < \Pi_{n+1}$. Accordingly, when we examined the case where the cost of imitation is less than Π_{n+1} we found that a producer innovator would provoke a waiting game among imitators by not offering any contract if (1) holds, resulting in strategic delay of their entry. In short, irrespective of weather a TS faces imitation or not, secrets restrict diffusion.

Patents on the other hand face a cost of imitation that depends on the patent's ability to exclude. When IP rights are very strong patents should fully exclude, in which case there can be no imitation nor any diffusion. When IP rights are weak all $n+1$ perspective imitators could imitate. In such a situation, as $\kappa < \Pi_{n+1}$, there is no diffusion. By contrast, for intermediate IP rights, as explained in section 5.1 case (a), since the cost of imitation is greater than Π_{n+1}, a producer innovator would license $m-1$ licensees for a fee of k each at $t = 0$, after which no further entry occurs, and her profits would be $(m-1)k + \Pi_m$. In this case there is restrained diffusion.

We compare payoffs under a linear demand function $p(Q) = 1 - aQ$ for m entrants within a Cournot oligopoly with a marginal cost of production of naught where $\Pi_m = \frac{1}{a(m+1)^2}$, $\Pi_1 = 1/4a$, and $V_i(n) = \mu_n\Pi_1 + (1-\mu_n)\Pi_{n+1}$, where $\mu_n = r/(r+n\lambda_n)$ and $\lambda_n = \frac{r(\Pi_{n+1}-\kappa)}{(n-1)\kappa}$. In such an occasion the producer innovator profits are given by Figure 1, which maps the producer innovator's profits for a cost of imitation that either greater or less than Π_{n+1} for an $a = .01$ and $n = 10$.

As k increases $i's$ profits from patenting, $((m-1)k+\Pi_m)$, increase. This is clearly depicted in Figure 1. Furthermore, as n increases it increases m, thereby increasing $i's$ profits from patenting; this is not captured by Figure 1 which is plotted for an $n=10$. Therefore, depending on κ there exist combinations of k and n that make patenting the dominant strategy. We capture this logic via the following proposition.

Proposition 1 *Suppose (1), (2) and (3) hold. There is a MPE in which a producer-innovator either keeps the technology as TS and provokes a waiting game by not offering any contract; or gets a patent and licenses to $m-1$ firms for a fee of k each, after which no further entry occurs. Diffusion of knowledge is delayed in the former case, and stops short of reaching all firms in the latter.*

6.2 The innovator is an NPI

Looking at the case of an NPI, recall from Section 4.2 that when an NPI is faced with $\kappa < \Pi_{n+1}$ it sells the technology for a price of $\mu_n(\Pi_1 - \Pi_{n+1}) + \kappa$ which converges to naught as $\kappa \to 0$ because $\mu_n \to 0$ as $\kappa \to 0$; and from Section 5.2 that for an imitation cost $k > \Pi_{n+1}$ an NPI with a patent licenses to all firms for a total surplus of $(n+1)\Pi_{n+1}$ if $k \in (\Pi_{n+1}, k^*)$. Between these two cases, an NPI obtains a higher surplus from patenting if $\kappa < \kappa^*$ where

$$\kappa^* = \frac{(n-1)\Pi_1 + (n+2)\Pi_{n+1} - \sqrt{((n-1)\Pi_1 + (n+2)\Pi_{n+1})^2 - 4n(n+1)\Pi_{n+1}^2}}{2} \in (0, \Pi_{n+1})$$

solves $(n+1)\Pi_{n+1} = \mu_n(\Pi_1 - \Pi_{n+1}) + \kappa$. This κ^* acts as a demarcation point indicating from which point below Π_{n+1} and up to k^* an NPI would license her patent to all firms instead of opting for secrecy. Accordingly, in order to clarify the relationship between κ^* k^* and Π_{n+1}, in Figure 2 we plot κ^* k^* and Π_{n+1} for a range of $n \geq 3$ and for an $a = .01$. In total, the above logic is summarized in the following proposition.

Proposition 2 *Suppose (1), (2) and (3) hold. If $\kappa < \kappa^*$ and $k < k^*$, there is a MPE in which (i) the NPI gets a patent and licenses to all $n+1$ firms immediately, and (ii) Proposition 1 governs the continuation equilibrium ensuing sale of knowledge by the NPI to a firm. Diffusion of knowledge is swift and complete in this MPE.*

Thus, provided that under secrecy the imitation cost is small enough relative Π_{n+1}, there is a range of IP protection levels under which the startup's optimal strategy is to get a patent and license to all $n+1$ firms for a fee of Π_{n+1}. Note that this outcome is the same independently of the precise strength of IPRs so long as it is within the range, and results in an immediate and full diffusion. In displaying this point, in Figure 3, we map an NPIs profits and indicate the point where this cost is equal to κ^*, to Π_{n+1} and to k^*. Similar to Figure 1 the payoffs are calculated for a linear demand function $p(Q) = 1 - aQ$ for m entrants within a Cournot oligopoly with a marginal cost of production of naught for an $a = .01$ and $n = 10$.

6.2.1 Consumer surplus

Operating under patents, we now compare the loss in consumer surplus (CS) stemming from a policy of comprehensive licensing that takes place when $\kappa < \kappa^*$ and $k < k^*$, with that of the restricted licensing we get when $k > k^*$. Accordingly, following Scotchmer (2004, Technical Note 4.7.1, pg 119), allow $s(0)$ to depict the CS for a competitive price $p = 0$, $s(p)$ the CS for a price p, and T the patent length. Assuming a marginal cost of production that is naught, the purpose of the exercise is to compare a policy of (T, p_{n+1}) with a policy of (T, p_m) where p_{n+1} is the price that prevails when the patent is licensed to all, and p_m is the price when licensed to just m.

In this spirit, the consumer is better off with a policy (T, p_{n+1}) if $s(p_{n+1})T + \left(\frac{1}{r} - T\right) s(0) > s(p_m)T + \left(\frac{1}{r} - T\right) s(0)$. In the latter inequality the first term is the CS during the life of the patent, while the second term is the CS after the patent tenure terminates. This inequality can also be written as $[s(0) - s(p_{n+1})] < [s(0) - s(p_m)]$, where $s(0) - s(p_{n+1})$ and $s(0) - s(p_m)$ respectively depict the loss in CS by imposing a price that is greater than the competitive price. However, for a price of p_{n+1} the loss in CS can also be written as the sum of profits $p_{n+1}q(p_{n+1})$ plus the DWL $d(p_{n+1})$, where $q(p_{n+1})$ is the inverse demand stemming from $p(Q) = 1 - aQ$. In other words, $s(0) - s(p_{n+1}) = p_{n+1}q(p_{n+1}) + d(p_{n+1})$ and correspondingly, $s(0) - s(p_m) = p_m q(p_m) + d(p_m)$, where $p_m q(p_m)$ depicts the sum of profits. Accordingly, a consumer is better off with a policy of (T, p_{n+1}) instead of (T, p_m) if $p_{n+1}q(p_{n+1}) + d(p_{n+1}) < p_m q(p_m) + d(p_m)$.

In this setting the $p_m q(p_m)$ sum of profits is given by $(m - 1)k + \Pi_m$ (which is equal to $S's$ payoff plus $i's$ payoff) and the $p_{n+1}q(p_{n+1})$ sum of profits is given by $(n+1)\Pi_{n+1}$. This implies that the comparison between the losses in CS becomes $(n+1)\Pi_{n+1} + d(p_{n+1}) < (m-1)k + \Pi_m + d(p_m)$. By (4) $mk > (n + 1)\Pi_{n+1}$, plus since $k < \Pi_m$ and considering that $d(p_{n+1}) < d(p_m)$, it must always be true that $(n + 1)\Pi_{n+1} + d(p_{n+1}) < (m - 1)k + \Pi_m + d(p_m)$ holds, indicating that a policy of comprehensive licensing is socially optimal.

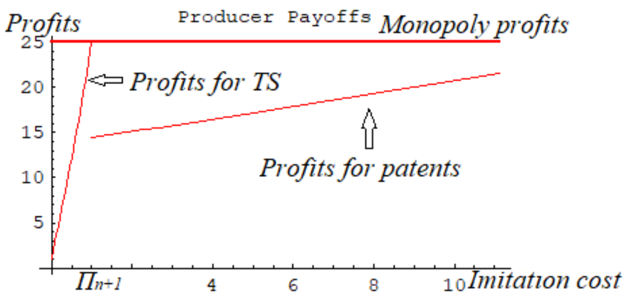

Figure 1:

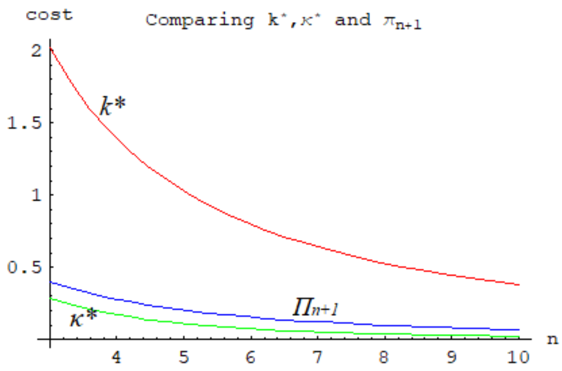

Figure 2:

7 Conclusions

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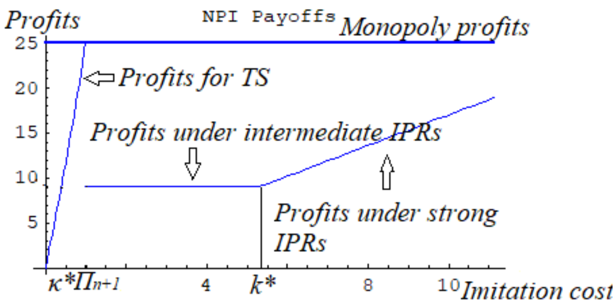

Profits
NPI Payoffs
Monopoly profits
25
20
15
10
5
Profits for TS
Profits under intermediate IPRs
Profits under strong IPRs
κ*Πn+1
4
k*
8
10
Imitation cost

Figure 3: