Patent Protection As A Stimulant for Risky Innovation. Could TRIPS be Counterproductive?

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Abstract

This paper introduces the idea that strong patent protection can lead innovators to rest on their laurels, into a simple tournament based framework. Concentrating on optimal patent protection, the one that maximizes production, the model shows that there is a positive relationship between the ability of the economy (firm) to innovate and how strong patent protection should be. This line of thinking runs counter to the unified intellectual property regime, as introduced by TRIPS.

Keywords: Intellectual property, sequential innovation, tournaments.

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1 Introduction

The idea that a competitor's breath behind one's back forces tournament contestants to adopt riskier strategies is not a new one. It goes back to Harris and Vickers (1987) and Beath, Katsoulakos and Ulph (1989). Nevertheless, this idea has not yet found its way into the intellectual property protection literature, eventhough there is a well known historic precedent that displays how lack of competition can lead an innovator to rest on his laurels. Specifically, in the 1890s Edison successfully patented his light-bulb filament invention; however, until the patent expired, General Electric did not improve on this technology. In addition, even though other companies had created a better light bulb, General Electric managed (through successful litigation) to keep competitors out of the market, increasing its market share and sales.

In the light of the above argument, this paper is based on a tournament between two competing innovating firms, where an innovation is a twofold process, based on prior art and risky experimentation. These two firms innovate sequentially and the winner is the only firm to put its innovation into production. The variable of choice for the firm is the amount of R&D effort that will be diverted to risky research paths, i.e. research that can lead to breakthroughs, as well as pitfalls. The production side of the economy is a simple growth framework based on Aghion and Howitt (1992). Within this context, the role of a central planner (who acts on behalf of the courts and the PTO) is to maximize production, using patent breadth as his choice variable. Patent breadth is indicated by how much the losing firm can copy (within the boundaries of legal protection) the winner's innovation. Overall, if the looser can fully copy the winner then they both have a similar technology at hand, which indicates that there is more competition between them during the tournament. Patent breath in this model is best captured by the number of patent claims allowed by the PTO, as well as the courts' attitude towards infringement.

The literature connecting growth theory to intellectual property is rather slim, see Gallini (2002) for a survey. A notable exception, from a theoretical point of view, is Horowitz and Lai (1996) who show that there is an inverted U relationship between the rate of innovation and patent length. The argument that they present is that an increase in patent length leads to larger, but less frequent, innovations. Moreover, from an empirical perspective, Lerner (2004), in an international analysis of the relationship between patent strength and innovation, examines 177 policy shifts in 60 countries over 150 years and finds some support for a non linear relationship.

Notwithstanding the above, when one is working on tournaments, in which innovators innovate in a specific technology, he must be careful when addressing the nature of the technology in use and the ability of the innovator, because then the above-mentioned idea may not be applicable. For example, certain firms (economies) may not be in a position to successfully incorporate more risk into their innovating effort. By the same token, some technologies, such as the internal combustion engine, or sailing ship technology, are understood to have reached the end of their evolution, contrasting new technological paradigms, such as biotechnology. For the latter technologies the adaptation of risky innovation strategies may lead to unexpected results, while risky strategies in the former give relatively foreseeable results.

Overall, the aim of this paper is to study optimal patent breadth, the one that maximizes production. As the paper shows, there is an increasing relationship between how strong the optimal patent protection should be (patent breadth) and the ability of the economy (firm) to successfully follow risky innovation strategies. In an analogous fashion, new technological paradigms may require stricter protection compared to more mature technologies, where risky innovation paths may prove less productive. Bearing in mind that developing economies lack the capacity to successfully follow risky innovation strategies, this finding suggests that developing economies should adopt a more lenient intellectual property policy, compared to the ones followed by more advanced economies. Thus, the introduction of TRIPS and its unified intellectual property policy may be counter productive for developing economies, even though it may promote innovation and production for advanced economies.

The notion of patent breadth differs from the ones used in the literature. For example, Gilbert and Shapiro (1990) suggest that a greater breadth is one that increases the flow rate of the innovator's profits, while Klemperer (1990) concentrates on the quality advantage of the patent holder. In addition, Gallini's definition, Gallini (1992), is one involving the cost of imitation, while Scotchmer and Green (1995) focus on the division of profits. In broad terms the definition of patent breadth suggested here is closer to Matutes, Regibeau and Rockett (1996), who also concentrate on new technological paradigms.

This paper is not the only one examining patent breadth in the context of a tournament.[1] Tournaments have also been studied by Denicolò (2000 and 1996). However, the emphasis here is on the patent breadth that maximizes output. Therefore, the model distances itself from Denicolò (2000), Chang (1995), Gilbert and Shapiro (1990), Klemperer (1990) and Nordhaus (1969) who concentrate on social welfare.

This model is not without its limitations. Specifically, to simplify the analysis the model considers a static problem. Therefore, it cannot shed light on issues such as leading and lagging breadth, as in O'Donaghue, Scotchmer and Thisse (1998). Moreover, the model examines only patent breadth and it does not allow for a discussion on patent length. Such a simplification allows for results that are less prone to interpretation. Furthermore, there is no cross-licencing and the treatment of risk is effectively the simplest possible, hence there is no varying degree of risk. In addition, following a risky innovation path does not carry an extra cost. These essential complications are unfortunately left out for future research.

In what follows, sections 2-3 introduce the model, section 4 discusses the ways patents foster innovation, while section 5 derives the optimal patent protection.

2 Introducing the general framework

In this section I will first sketch out the main assumptions that accompany the growth model that is to follow (these assumptions are based on Aghion and Howitt (1992)) and then I will outline the model's main assumptions on how an innovation is created. Specifically, I will assume two innovating firms i, j that operate in an economy with no credit markets and have full information about each other. This economy is inhibited by a continuum of infinitely-lived individuals, with identical intertemporal additive preferences defined over lifetime consumption and a constant rate of time preference $r > 0$. Furthermore, only three classes of tradeable objects exist. The first one is labour, the second one is a consumption good and the third one

[1] For a review of tournament models see Reinganum (1989).

is an intermediate good. Assuming no disutility from supplying labour, there is one category of labour (excluding the innovating firm, which can also be assumed as a an innovator), unskilled labour x. Unskilled labour can be used in the production of the intermediate good and as a producer of the final consumption good. Unskilled workers are all equipped with one unit of labour.

Innovating firms and production workers split the profits and, since no credit market exists, unskilled workers consume their wage at each instant. Specifically, the innovating firm keeps a set fraction $1-\epsilon$ of the profits, $\epsilon \in (0,1)$, while production workers receive the remaining ϵ. This fraction will be assumed to be exogenous. This exogeneity is introduced for two reasons. First, production workers and innovators (innovating firms) do not have the same skills, thus they are not homogeneous. Therefore, it is difficult to justify a labour market condition where, similar to Aghion and Howitt (1992), both parties receive the same wage, which is based on the value of the innovation. In addition, if one introduces a similar labour market condition making it endogenous to the model's main variable of interest (the patent breadth), then the results of the paper would be introduced via the labour market, when, as far as I know, there is no empirical data in support of such an argument. Nevertheless, one can assume, similar to Jones (2001), that the greater patent breadth is the greater the monopoly power that the innovator enjoys, which increases his bargaining power and his share of the profits. Hence, ϵ could be endogenous on patent breadth. However, introducing the above argument in the model does not alter the model's final results and formulas. Thus, I will allow ϵ to be exogenous.

As regards to innovation, firms carry out research programs that result in a sequence of innovations. Each innovation is drastic and it consists of the invention of a new intermediate good, which is produced using x unskilled workers. The use of the intermediate good as an input allows more efficient methods to be used in producing a consumption good. However, only one firm will produce an intermediate good, with a tournament being the mechanism that determines which one. The intermediate good that the winner of the tournament produces will increase technology A by a factor of ΔA. This means that technology is sequential in nature. Thus, technology A is the sum of all past innovations $\sum \Delta A$.

In this framework, with certainty only one innovation will be developed every period t,[2] where t also corresponds to the ranking of each innovation. In view of the above, one tournament will take place every period. The winner of each tournament, the firm that has the greater A, will be a monopolist since it will be the only one whose intermediate good will be used in producing the final consumption good. Since innovations and tournaments must coincide, the index t will also be used to indicate the ranking of tournaments and of winners.

The model assumes that the winning firm patents its innovation and does not licence it. If the firm does not patent its innovation, since there is full information, the rival firm will be able to appropriate it. This patent, along with the intermediate good, will be employed by the firm in production, where production takes place in a perfectly competitive market (alternatively one can assume that the innovating firm sells its patent to a producer who operates in a perfectly competitive environment). The time span of the patent is assumed to be at least one period long.

If the winner of tournament t is i, then i will create an innovation that increases its past technology $A_{t-1,i}$ by $\Delta A_{t,i}$. The firm that failed to win, the follower j, will not be able to use $\Delta A_{t,i}$. This is because the patent of the winner on $\Delta A_{t,i}$ does not allow such use. However, j can re-innovate around $\Delta A_{t,i}$. This means that j can legally bypass some aspect of the winner's technology and by doing so it can legally develop some technology of its own. This re-innovating will take place during the $t+1$ tournament. In this context, j will be able to advance its past technology $A_{t-1,j}$ by $\max\{\Delta A_{t,j}, \lambda\Delta A_{t,i}\}$, where $\lambda \in [0,1]$ indicates how much re-innovating around $\Delta A_{t,i}$ the follower can do.[3] Therefore, the technology of j at time t is,

$$A_{t,j} = A_{t-1,j} + \max\{\Delta A_{t,j}, \lambda\Delta A_{t,i}\} \tag{1}$$

Accounting for the above, $1-\lambda$ can be considered as patent breath. For example, if λ is zero then the follower cannot re-innovate around the innovation of the winner. On the contrary, if λ is one then the follower can fully re-innovate around. This means that the follower will end up with an innovation that is of equal size to that of the winner.

[2] This assumption accords with the evidence offered by Panagopoulos (2004 a).

[3] US law has an experimentation exemption. However, here the winning innovation leads directly to a final product. Therefore, any re-innovation will translate itself in a commercial product and this is prohibited.

The model's time-line is the following. Every period a tournament t takes place during which i, j create an innovation in the form of an intermediate input. All research oriented decisions (such as what type of research path to follow) will be taken during the tournament. After the tournament, the winner uses its technology in producing the consumption good.

3 Innovations

In this section I will model innovation as an ongoing twofold process. On the one hand an innovation will be the result of research that is based on prior art. This type of research should create an innovation of expected magnitude since it is the creation of techniques whose potential and limitations must be well understood. On the other hand, an innovation can be the result of experimentation. When one experiments he is working on the frontier of science where prior art is seldom in existence. Due to the lack of prior art and the absence of a full understanding of the potential of technologies on the frontier of science, the outcome of this research is uncertain.[4] Henceforth, I will use the term fundamental research to describe the research that takes place in such a situation.

An example of an innovation, which in its development involved fundamental research, is the invention of the transistor by Bell Laboratories in 1947. The aim of this research was to create a better electron emitting diode, one that was superior to the traditional 'bulbs' that were in use at the time. From its start, Bell Laboratories had two choices, to either continue working on the traditional diode and try to improve it. Or, alternatively, try and concentrate on an entirely new line of physics, namely solid-state physics. Solid-state physics, had only been introduced in the graduate curriculum of the top US universities in the mid 1930s and at the time there was little understanding (and a lot of uncertainty) involved around its potential. Therefore, solid-state physics was a research path that could have provided a dead end result. Successful, as it turned out to be, it led to applications that at the time where beyond the imagination of the creators of the transistor.[5]

[4]For a discussion on the uncertainty surrounding innovation see Rosenberg (1996).

[5]The transistor was, at the time, perceived as an innovation with limited potential. In fact, Bell was initially

However, in addition to the work that Bell carried out on solid-state physics applications, a great deal of the research that led to the invention of the transistor was supplemented by the use of well understood technologies. For example, in order to put theory into use Bell had to work on well known metallurgy technologies, which were needed in order to create the silicon sandwich material in which the transistor is bonded into.[6]

Accounting for the above, firm i has a choice on the way it uses its research effort (e.g. the time spent on research during tournaments) which for simplicity is normalized to one for both i and j. On the one hand, i can choose to work on a research path that uses traditional methods and techniques, which generate a fully expected and linear-increasing innovation. Alternatively, it has the choice to work on a research path that uses fundamental research (suggesting that results can vary both upwards and downwards and thus the nature of the resulting innovation is unforeseen). Accordingly, i splits its research effort between the two different research paths, spending $\sigma_{t,i} \in (0,1)$ in the latter research path and $(1-\sigma_{t,i})$ in the former.

As indicated above $\sigma_{t,i} \neq 1$. This is because even for the most novel innovations one must make use of prior art by using tools and techniques developed in the past (traditional methods). In addition, $\sigma_{t,i} > 0$. This assumption accords with everyday experience, which suggests that some experimentation is always needed and cannot be avoided.

As regards the linear part of the innovation, the productivity of research is set as $\gamma > 0$. Thus, if during tournament t firm i uses $(1-\sigma_{t,i})$ of its research effort on traditional techniques, there will be a linear set increase $(1-\sigma_{t,i})\gamma$ in the magnitude of technology $A_{t,i}$. This increase in innovative capability is attributed to learning by doing and the knowledge spillovers generated by other technologies. Since the research of j must also spillover to i, one should express γ as a function of $A_{t,j}$. However, Pakes and Schankerman (1979), suggest that knowledge does not spillover spontaneously and that research takes 2-3 years to spillover. On account of this considerable time lag, noting that both firms have full information about each other and operate

hesitant on applying for a patent.

[6]Many of the subsequent improvements on the transistor, even to this day, have been based on improving this sandwich so that it allows less current to pass through, while permitting finer and more even transistors to be manufactured.

under the same patent system (revealing the details of all new innovations) I will treat γ as an exogenous parameter that is common for both firms.

Overall, γ is designed to capture the economy's increase in research productivity that does not result from fundamental research. If one is to provide a historical example, γ can account for the overwhelming increase in efficiency of the methods used to built the Liberty ship during WWII. This shipbuilding project was carried out in many different US shipyards, owned by different firms, over a four year period, under the guidance/control of the US ministry of defence, see Thorton and Thompson (2000).

Adding to the linear increase described above, there will be an innovation of magnitude $\sigma_{t,i}v_i$, where v_i is distributed having an exogenously given mean $\mu_i \geq 0$. This innovation is the result of fundamental research. In this model μ_i expresses the ability of i to successfully carry out fundamental research.

In total, the innovation created by i is given by,

$$\Delta A_{t,i} = (1 - \sigma_{t,i})\gamma + \sigma_{t,i}v_i$$

having an initial value of $\Delta A_{t=0,i} > 0$. The above formulation treats $(1 - \sigma_{t,i})\gamma$ and $\sigma_{t,i}v_i$ as perfect substitutes. In reality, $(1 - \sigma_{t,i})\gamma$ is the expected part of an innovation and $\sigma_{t,i}v_i$ is the unexpected part. However, since i has a choice to employ or not in its research some a priori unexpected research path, it is irrational for i to contact its research mainly using $\sigma_{t,i}v_i$. This is because, as the above intuition implies, $\sigma_{t,i}v_i$ can attain negative values as well. Subsequently, if i chooses to follow a high σ strategy it might end up with an innovation $\Delta A_{t,i}$ which is less than expected. On account of the above, the expected innovation should be,

$$E\Delta A_{t,i} = \gamma + \sigma_{t,i}M_i \tag{2}$$

where $M_i = \mu_i - \gamma$ and E is the expectations operator.[7] Since $\mu_i \geq 0$, $\gamma > 0$ and $\sigma_{t,i} \in (0, 1)$, $E\Delta A_{t,i}$ should be greater than zero.

[7] To provide a present day analogue of equation (2), as suggested by John Beath, one can think of this relationship as one that describes the efficiency of the national health system (NHS). Specifically, the NHS employs, in broad terms, two categories of workers, medical staff (nurses and doctors) and researchers. The former accord to x and the latter to the innovating firms. Accounting for the above, one can think of this

In the light of the above, if i has a μ_i that is equal to zero i is not expected to produce an innovation that is beyond expectations. In fact, the expected innovation is $E\Delta A_{t,i} = (1-\sigma_{t,i})\gamma$. Contrary to that, if i has the capacity to follow a research strategy where $\sigma > 0$ and, on average, derive some positive innovation, then it will have a μ_i that is greater than zero. Thus, i is expected to create an innovation that is greater than $(1 - \sigma_{t,i})\gamma$.[8]

Since v_i can attain negative values it is possible for $\Delta A_{t,i}$ to be less than zero. If this turns out to be true, it implies that research has followed the wrong path. In this case, the firm will make use of the technology that it has developed up to tournament $t - 1$.[9] An example of a technology that did not generate the expected results would be the High Definition TV (HDTV). In the late 1980's this was a promising European TV standard that turned out to be costly and outdated (when compared to the USA TV technology of its time).[10]

Accounting for the above discussion, one should ask the following question. Is there any reason to believe that μ_i can be greater than γ (the set rate of technological change)? One can think of the following two situations where the above is plausible. If the firm has advanced fundamental research capabilities, which allows it to successfully use new and not well understood techniques, or if the technology is a new technological paradigm. In the latter case γ must be small because there is no prior learning and no prior experience in the form of knowledge spillovers. For example, computers in the early 1950's were a brand new technological paradigm on which the use of prior art had limited effects. Therefore, one could not base his research

framework as one that deals with how to best split medical and research staff in a way as to increase NHS efficiency.

[8] In view of the Bell Laboratories example, Bell was employing some of the best US scientists (and some later Nobel price winners) and made a lot of effort to diffuse the knowledge created by US universities in its research program. Thus, one can allow Bell to have a μ that is higher than the μ of a firm for which the above do not apply.

[9] Hence, equation (1) must be re-expressed as, $A_{t,j} = A_{t-1,j} + \max\{0, \Delta A_{t,j}, \lambda\Delta A_{t,i}\}$.

[10] In 1991 the European Commission, in an initiative that was backed up by various satellite interests, proposed an expensive plan, which was worth of 850 million Euro, to support the HDTV standard plan. There was considerable debate in the Council about the budget, but finally the issue was dropped, with the justification being that a more advanced technology was already available in the US. For a detailed discussion of the HDTV project see Braithwaite and Drahos (2000).

on already established research paths. On the contrary, one had to experiment with new tools and ideas on which there was limited prior knowledge and understanding.

I have up to now created two quality ladders that correspond to two different competing firms. As it will become apparent in the following section, competition in this framework will depend on the distance that separates the technologies created by the two competitors. If the two quality ladders are of dissimilar magnitude, since there is a clearly defined leader (the firm with the higher A), there is limited competition. Symmetrically, if the two quality ladders are of similar magnitude there exists competition. This is because i, j are close enough to be able to leapfrog each other. Accordingly, the closer i, j get the easier it will be for i, j to leapfrog each other. In this context, one way of increasing competition is to increase λ, making it easier for the follower to re-innovate around the leader's technology. This way, the follower will increase its technology getting closer to the leader.

4 Solving the model

Every firm has an expected probability $Ep_{t,i}$ of winning tournament t, where $Ep_{t,i} \in (0,\ 1)$. Since this section will concentrate on a static problem the subscript t will be omitted. In addition, I will assume that Ep_i does not become either one or zero, thereby the duopolistic structure of the tournament never deteriorates to a monopoly.[11] Ep_i expresses the expected probability that i has of creating a technology that is greater than the one created by j, i.e. $Ep_i\left(A_i > A_j\right)$. This line of reasoning suggests that the greater EA_i is, the more likely it will be for i to win the tournament. On the contrary, if j has a large EA_j, it will decrease the chances that i has of winning. Therefore, for $Ep_i\left(A_i, A_j\right)$,

$$\frac{\partial Ep_i}{\partial EA_i} > 0, \frac{\partial Ep_i}{\partial EA_j} < 0. \tag{3}$$

where for simplicity I am making the assumption that all cross derivatives and second order derivatives are small enough to be effectively considered as zero. Nevertheless, one can suggest that $\frac{\partial^2 Ep_i}{\partial EA_i^2} < 0$, which implies that, as EA_i increases, probability Ep_i will increase with a

[11] This should always be true if $\Delta A_{t=0,i} \sim \Delta A_{t=0,j}$.

diminishing rate of increase. This could be the result of knowledge spillovers. Specifically, having allowed for knowledge spillovers, the greater EA_i is the more the knowledge spillovers available to j. This means that as EA_i increases it will increase γ, leading to an increase in EA_j, which should negatively affect Ep_i. However, as I noted in the previous section, Pakes and Schankerman (1979) find that spillovers diffuse slowly. Therefore, one can allow for $\frac{\partial^2 Ep_i}{\partial EA_i^2} \to 0$.

Intuitive as $Ep_i\left(A_i,A_j\right)$ may be it is always preferable to provide some mathematical intuition and an exact mathematical function that backs such an assumption. As Appendix one shows, this can be done by working in continuous time, viewing equation (2) as an Ito's stochastic differential equation. This being the case, using the Kolmogorov's backward equation one can derive the probability that i has of creating a technology that is greater than $j's$. The main drawback of this approach, even though it leads to similar results as the rest of the paper, is its increased mathematical difficulty, and its reliance on graphical interpretations.

The consumption good is produced in the following fashion,

$$y = A_i x^a \; a \in (0,1) \tag{4}$$

where the subscript i in y and x has been omitted because there is always only one winner. Similar to Aghion and Howitt (1992), the producer's profits are,

$$\pi_i = aA_i x^a - wx - cx$$

where $c > 0$ is the production cost per unit x of the intermediate input (which is produced by x production workers all equipped with one unit of labour). Production workers x receive a set fraction of the profits $\epsilon\pi_i$, i.e. $w = \frac{\epsilon\pi_i}{x}$. Thus,

$$\pi_i = \frac{aA_i x^a - cx}{1+\epsilon} \tag{5}$$

The winner will maximize its profits π_i subject to x. This maximization problem has the following FOC,

$$x = \left(\frac{a^2 A_i}{c}\right)^{\frac{1}{1-a}} \tag{6}$$

Since the firm must choose its σ at the beginning of the tournament, before its innovation is materialized, firms solve the following problem,

$$\max_{\sigma_i} Ep_i\left(A_i,\, A_j\right) E\pi_i$$

Using equations (5)-(6) the FOC from this maximization is given by the following implicit function,

$$F(\sigma_i) = \frac{\partial Ep_i}{\partial \sigma_i} E\pi_i + Ep_i \frac{\partial E\pi_i}{\partial \sigma_i} = 0 \tag{7}$$

Bearing in mind that $\frac{\partial Ep_i}{\partial EA_j} < 0$, using the implicit function theorem on equation (7), the following condition is derived,

$$\frac{\partial \sigma_i}{\partial EA_j} = -\frac{\frac{\partial Ep_i}{\partial EA_j}}{M_i\left(2\frac{\partial Ep_i}{\partial EA_i} + \frac{\alpha}{1-a}\frac{Ep_i}{EA_i}\right)} \tag{8}$$

In equation (8), $\frac{\partial \sigma_i}{\partial EA_j}$ is always greater than zero if $M_i > 0$, which suggests that, if $\mu_i > \gamma$, the greater the expected technology of firm j is the greater the choice of σ_i for firm i will be.

Overall, the above discussion allows one to concentrate on the following question, how will the leader respond to an increase in A_j? As it turns out, if $\mu_i > \gamma$ any increase in EA_j should ceteris paribus lead i to respond by adopting a greater σ_i. In a similar fashion, if $\mu_j > \gamma$, when the follower j faces the leader's higher technology, it must also adopt a greater σ_j in its innovation process; because $\frac{\partial \sigma_j}{\partial EA_i} > 0$. The above intuition implies that if between two tournaments there is an increase in λ, which leads to more competition, then there will be an increase in σ. As a result, considering that $E\Delta A_i = \gamma + \sigma_i(\mu_i - \gamma)$, if $\mu_i > \gamma$, increases in λ lead to a greater σ, a greater expected innovation and a greater expected technology EA_i.[12]

5 The optimal patent protection

The objective of a central planner is to maximize expected output y with respect to λ. Accordingly, the central planner's maximization problem is,

$$\max_{\lambda} Ey = EA_i x_t^a$$

[12] In proving the above point I have assumed that there is no cost in choosing σ. Since, there is no cost it does not matter how far apart the firms are positioned, because (as long as $\mu_i > \gamma$) to any increase in EA_j firm i will always respond with an increase in σ_i. Panagopoulos (2004 b), working in a similar framework, relaxes these restrictions and shows that there exists a Nash equilibrium where both firms choose to increase their σ only if they are positioned very close to each other; if they are positioned far apart they will abstain from increasing σ.

Accounting for equations (2), (6) and (8), the FOC is,

$$Q(\lambda) = \frac{\frac{\partial Ep_i}{\partial EA_j} E\Delta A_i \left(\frac{a^2 EA_i}{c}\right)^{\frac{\alpha}{1-a}} \left(1 + \frac{1}{1-a}\frac{c}{aEA_i}\right)}{2\frac{\partial Ep_i}{\partial EA_i} + \frac{\alpha}{1-a}\frac{Ep_i}{EA_i}} = 0 \tag{9}$$

Having at hand a suitable function for p one can solve the above implicit function for λ. Nevertheless, even in the absence of such a function an important result can be reached. Specifically, using the implicit function theorem,

$$\frac{\partial \lambda}{\partial M_i} = \frac{\frac{1-a}{a}\sigma_i EA_i \left(2\frac{\partial Ep_i}{\partial EA_i} + \frac{\alpha}{1-a}\frac{Ep_i}{EA_i}\right)}{\frac{\partial Ep_i}{\partial EA_j} E\Delta A_i} \left(1 + \frac{\frac{1}{(1-a)}\frac{E\Delta A_i c^2}{aEA_i^2}}{a(1-a)EA_i + c}\right)$$

Since $\frac{\partial Ep_i}{\partial EA_j} < 0$, this function is always less than zero if $\mu_i > \gamma$.

What does the above inequality imply in terms of optimal patent breadth? Bearing in mind that a greater λ implies that more re-innovation can take place, the above result suggest that, when $M_i > 0$, if the firm has advanced research capabilities allowing $\mu_i >> \gamma$ (or alternatively, if the technology involved is that of a new technological paradigm) it requires greater patent protection compared to a firm for which $\mu_i > \gamma$. Notwithstanding the above, and in the context of the economy as a whole, μ_i is an institutional parameter expressing not only the ability of i to foster fundamental research, but the ability of the economy in which the firm operates as well. This is because i is the tournament's winner. Thus, by definition μ_i represents the whole economy, because i is the only firm producing (one can think of i as a national champion). Using such an interpretation for μ_i, one can suggest that different national systems of innovation (NSI) may require a different intellectual property protection policies because their ability to foster fundamental research varies.[13]

An example of such differences and on the approach that different NSIs use when innovating may be educational. If one is to make a general comparison between the US NSI and the

[13] There is a growing literature that examines the differences between various NSIs, see Nelson (1992), Mowery and Rosenberg, (1998). This literature suggests that different NSIs employ state, university, laboratory and firm research in different ways. In fact, as Soskice (1999) notes, the most important elements of this framework are, the corporate governance system, the financial system, the industrial relations/worker training system, the education system, the organization of employer associations and the relations among firms. How countries employ the above elements affects their ability to innovate and the type of innovation they can produce.

European one,[14] eventhough there is no doubt that each NSI has its strong points,[15] there is a general consensus that the US system is better suited to promote fundamental research. As Goyer (2001) notes, 'By contrast [to the German system of innovation], the American system.... is well suited for radical innovation, which requires the introduction of radical innovative design and rapid development based on pure scientific research'. This difference is highlighted in the different research paths US and German firms follow in the field of biotechnology. Specifically, German firms follow a low-risk innovation strategy, concentrating on proteins whose therapeutic properties are already well established. In contrast, the US firms, as Henderson et al. (1999) note, have used biotechnology as a search technique and their primary focus is on the discovery of small molecules designed to increase the productivity of synthetic drugs. Therefore, the above framework suggests that Germany may find it optimal to allow for a less strict patent protection in order to stimulate (through greater competition) its firms to produce greater innovations and greater output.

6 Conclusions

In the 1990s a large part of the intellectual property literature concentrated on the trade-off between patent breadth and patent length. The main argument used was that greater patent breadth gives the innovator more protection from imitators (which acts as an incentive to innovate) at the cost of offering monopolistic rights to the innovator. However, as Scotchmer (1991) noted, if innovation is sequential, as it frequently is, then the patent holder can block all other innovators from employing his patent in the future. Subsequently, unless cross-licensed, patents can decrease competition between innovators (competition for the next innovation), allowing only the patent holder to use the latest technology in developing a better one.

Working within the context of a patent race, this model concentrates on patent-induced lack of competition when innovation is sequential. The view that this model takes is that the

[14] Which is broadly comprised by three independent and different national systems, the French, the German and the UK one.

[15] In the US the firm in cooperation with universities is central to research, while in European NSIs the state has a larger role to play

resulting lack of competition can be detrimental for innovation, because it leads innovators to rest on their laurels and abstain from pursuing innovation strategies that can potentially lead to radical innovations.

Specifically, there is a large literature that points to the excessive risk that competitive tournaments can lead to.[16] In the context of a patent race, bearing in mind that innovation is a twofold process, which (in general) relies on the use of both prior art and experimentation, risky experiments can potentially lead to radical innovations, such as the transistor, or to dead end results. The success, or not, of experiments largely rests on the quality of research. One should expect that innovators that operate on the edge of the technology frontier, have high quality researchers and allow for links with universities and laboratories, must be better equipped to successfully handle risky experiments, compared with ones that don't. Such innovators can benefit from the risk involved in competitive patent races and through successful experimentation can create radical innovations.

Accounting for the above, the paper's main result is that, for economies with an advanced ability to perform research, or in the presence of a new technological paradigm, there is a positive relationship between the economy's ability to innovate and the optimal patent protection.

Appendix one

Working in continuous time, without loss of generality equation (2) can be expressed as, $dA_i = \gamma dt + \sigma dz_i$, where z is Wiener process. As Malliaris and Brock (1987, ch. 2, pg. 101, theorem 7.6) note, the probability density function ϕ of the innovator's technology can be written, using the Kolmogorov's backward equation as, $\frac{1}{2}\sigma_i^2 \phi''_{A_i} - \gamma \phi'_{A_i} - \frac{d\phi}{dt} = 0$. Assuming that the distribution of A does not change, making the density function ϕ time invariant, the above differential equation will give the following solution, $\phi = g \exp\left(\frac{2\gamma}{\sigma_i^2} A_i\right)$, where g is a constant. Based on the latter equation, innovator i's expected probability of innovating to a technology level that is between some minimum technology level A_0 and the upper technology limit $\bar{A}$, is given by, $Ep\left(\bar{A} > EA_j > A_0\right) = g \int\limits_{A_0}^{\bar{A}} \exp\left(\frac{2\gamma}{\sigma_i^2} A_i\right) dA$, and it should be equal to 1; since $A_i \in (A_0, \bar{A}]$. Thereby one can express innovator i's expected probability of innovating to a

[16] See Harris and Vickers (1987), as well as Dasgupta and Stiglitz (1980).

technology level A_i that even though it is greater than A_0 it is less than the expected technology level created by innovator j as, $Ep\left(EA_j > EAi > A_0\right) = g \int_{A_0}^{EA_j} \exp\left(\frac{2\gamma}{\sigma_i^2} A_i\right) dA$. Moreover, since $Ep\left(\bar{A} > EA_i > A_0\right) = Ep\left(\bar{A} > EA_i > EA_i\right) + Ep\left(EA_j > EA_i > A_0\right)$, the expected probability that innovator i has of over passing innovator j is given by,

$$\begin{aligned} Ep_i &= Ep\left(\bar{A} > EA_i > A_0\right) - Ep\left(EA_j > EA_i > A_0\right) \\ &= 1 - g \int_{A_0}^{EA_j} \exp\left(\frac{2\gamma}{\sigma_i^2} A_i\right) dA \\ &= 1 - \frac{g\sigma_i^2}{2\gamma A_i}\left[\exp\left(\frac{2\gamma EA_j}{\sigma_i^2}\right) - \exp\left(\frac{2\gamma A_0}{\sigma_i^2}\right)\right] \end{aligned}$$

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