European Political Economy Review
http://www.epic.ac.uk/eper
Vol. 1, No. 1 (Spring 2003), pp. 80-104

Intellectual Property Protection for Fast Evolving Technologies

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Abstract

This paper studies the effects of market competition and intellectual property protection in emerging technologies such as software. In doing so, this research aims at contributing to the ongoing discussion on the possibility of broadening the scope of patent protection, in the EU, in order to cover many of the newly evolving technologies. The model indicates that optimal patent protection is case specific, while its degree of protection should vary depending on the rate of growth of the particular technology, as well as the degree of market competition. The main argument of the paper is that intellectual property protection has a dual effect, allowing the innovator to fully appropriate his R&D, at the cost of limiting the number of innovators who will be able to innovate, reducing knowledge spillovers

Keywords: *Intellectual property, competition*

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1. Introduction

In recent years, there has been an ongoing debate in the EU regarding the possibility of broadening the scope of patent protection so that it includes new technologies such as software.[1] [2] Advocates of change[3] have been using the recent US patent experience as an example.[4] Critics of such an approach, such as Bessen and Maskin (2001), maintain that similar changes in the US did not increase R&D. Specifically, evidence offered by Hall and Ziedonis (2001) point that even though the number of patents in some sectors of the US economy have more than doubled, R&D did not increase.[5] It would appear, that in many cases US firms create patent portfolios, with the view to license them to other firms, in exchange for patents that are vital to their innovations. These transactions have increased the litigation cost of firms, especially starting ones, which as Gallini (2001) notes, they need 2 to 3 million dollars in litigation expenses.[6]

In the light of the above, this paper will address the problem of Intellectual Property (IP) protection for fast evolving technologies, such as software. As the paper points out, IP protection should be case specific, taking into account the degree of competition of the market and the fast evolving nature of the new technologies. The main argument of the paper is that intellectual property protection has a dual effect, allowing the innovator to fully appropriate his R&D, at the cost of limiting the number of innovators who will be able to innovate, reducing knowledge spillovers.

My results, indicating a lower IP protection for fast evolving technologies, are similar to the ones of Ben-Shahar and Jacob (2001). However in their case, the innovator may optimally choose a low IP protection policy to lock-in other innovators and hence monopolize the market.

In what follows, section 2 introduces the "*technology generating*" function, section 3 describes production, while section 4 explains the maximization problem of the innovator, to be followed by sections 5 and 6, that solve the maximization problem of the innovator and the central planner.

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1 Software in particular is protected only by means of copyright.

2 Changes in patent enforcement can also result from changes in the policy of the European Patent Office (EPO). For software in particular, the EPO seems to have changed its policy, allowing for patent protection. Independent sources, such as Eurolinux claim that more than 20000 patent applications have been granted. However, these claims are hard to verify using EPO data. In addition to changes in EPO policy, patent enforcement may strengthen if the Verne convention allows for extraterritorial claims against EU firms who use non-EU patents.

3 This change is anticipated by many software firms which have, for the past few years, been lobbying the Internal Markets Directory of the European Commission.

4 During the 80's the US increased its patent protection, in some cases (such as for microprocessors) by means of specific measures enacted by the Congress.

5 If one looks at sectors of the US economy, such as microprocessors, the attitude of most major firms has not changed drastically since the increase in patent protection. As Gallini (2001) indicates, in an environment in which they have to use many other technologies, created by many different firms, these firms are not using patents as the primary means of protecting their innovation. Instead, they rely on quality and speed of innovation.

6 For a discussion on the problems that starting firms face, when they attempt to innovate in an environment where they face increased competition (from other firms which hold patent portfolios), Lerner and Merges (1998).

2. Technology

2.1 An Overview and some Definitions

In this section I will define, and provide examples, of the terms (such as innovation) that I will henceforth be using. In addition, I will present a summary of the way that individual innovators generate innovations and their objectives (the mathematical definitions will be provided in the sections that follow).

Specifically, heterogeneous innovators create patentable innovations, with a patent length of at least 2 years, through a discrete time technology generation process. At each point t in time, each innovator i creates an innovation, $\Delta A_{t,i}$, *"an invention* [an innovation, a technological advance] *is a new means of achieving some function not obvious beforehand to someone skilled in the prior art"*, Kline and Rosenberg (1986).[7] The sum of the innovations created by the innovator up to that time, makes the innovator's technology $A_{t,i}$. This is similar to many different quality ladders,[8] each one representing only one technology and the only factor that displays how good one technology is compared to another is its size.

Each innovator conducts research on only one technology. The technology that each innovator is working on will be a substitute to the technologies that the rest of the innovators are working on. In the context of a *"PC"* environment, one can think of such substitute technologies as the work of many individual innovators who at the same time try to create a better *"MP3 Player"*, or a better *"Media Player"*, In this setting, the knowledge created by each innovator would be potentially beneficial to the research carried out by all other innovators in the form of knowledge spillovers, however, some form of tacit knowledge will be assumed, which does not allow an innovator to fully appropriate such spillovers. These knowledge spillovers are created when the innovator patents his innovation. Thereby, the work carried on the *"MP3 Player"* can be beneficial to the innovator working on the *"Media Player"*.[9] The objective of each innovator is to create a better technology, since, as it will become apparent in later sections, one increases the demand for his technology by improving it further.

I define patent breadth as the amount that an innovator can reinnovate around the technology of any other innovator, without being found guilty of copying one's technology and thus use it in his research, in the form of knowledge spillovers, without paying any property rights. The larger the patent breadth is, the harder it is for an innovator to fully reinnovate around one's technology. In what follows, I will assume that if the patent breadth is equal to 1, then innovator i must make full use of the technology created by innovator j $j \neq i$, similarly, if the patent breadth is 0, then innovator i can freely copy the technology created by innovator j, without paying any property rights. My definition of patent breadth corresponds to that of Denicolo (1996). However, based on the assumptions provided in the above paragraph, the patent breadth can neither be 0, nor 1. Specifically, having assumed the existence of tacit knowledge, the patent breadth cannot be equal to 0, because even if innovator j could freely appropriate the innovation of innovator i, he would still find it

7 The brackets where not included in the original.

8 See Grossman and Helpman (1991).

9 Thereby, the technologies generated by the innovators are substitutes which generate knowledge spillovers that are complements. This assumption attempts to capture the multidimensional nature of innovation, where knowledge spillovers can be beneficial even though they may have been generated by a technology that is a substitute. This accords with the evidence offered by Hall and Ziedonis (2001), who study the microprocessor's industry, noting that firms use overlapping technologies, many of which have been discovered by other firms who share the same market.

impossible to use it as well as its inventor. In addition, one should cancel out full IP protection, because in reality, due to spillovers, such a thing does not exist.[10]

For an innovator to innovate he needs knowledge spillovers. However, unless one is willing to assume that all innovators are homogeneous in their innovative capacity, the knowledge spillovers generated by one innovator should not have the same effect on one's research, as those created by another innovator. This generates the problem of discriminating among the spillover-generating capacities of many innovators, each working on different technologies. In order to avoid such a simplification, I will assume that a patent race takes place, in which each innovator races against himself in order to reach an exogenously set *"social target"* for technology. In the setting of the *"Windows"* environment, a *"social target"* could be the demand for an *"MP3 Player"* that has double compressing ability. The ability of the innovator who works on the *"MP3 Player"* to create such a player, will determine how useful his spillovers are to all the other innovators.

2.2 Technology Generation

Technology is produced by risk neutral innovators, who employ a specific *"technology generating"* function. Specifically, there exist a continuum of innovators, operating in an economy that lacks a credit market and faces no population growth, who create innovations $\Delta A_{t,i}$, using knowledge spillovers *s*, as well as some funding through past profits $\pi_{t-1,i}$. However, accounting for the lag between the publication of the patent and the time that it spillovers into research, Pakes and Schankerman (1979), innovators will be using s_{t-1}. Overall, the innovations created by innovator $i \in [0, N]$, are generated through the following *"technology generating"* function,

$$\Delta A_{t,i} = s_{t-1}\pi_{t-1,i} + \upsilon_i, \quad \upsilon_i \in (0, \sigma), \quad i \in [0, N] \tag{1}$$

The sum of the $\Delta A_{t,i}$, is a distinct technology line $A_{t,i}$, which is created by innovator i, having the following initial condition for $A_{t,i}$, $A_{0,i} > 0$. Hence, $A_{t,i} = A_{0,i} + \sum_0^t \Delta A_{t,i}$. Equation (1), implies that s_{t-1}, π_{t-1} are substitutes that curry the same weight. Even though, this is a *"convenient"* simplification, there is no consensus among economist regarding the effect that spillovers have. Specifically, depending on the author, spillovers can account for 15% to 40% of an innovation, Griliches (1998). In equation (1), υ_i is a Normally distributed component with mean 0 and variance σ, where σ is assumed to be exogenous. Due to υ_i innovators who have similar s_{t-1}, π_{t-1} will not produce innovations of the same magnitude. In that respect, υ_i represents the innovator's ability to innovate. Since υ_i, can attain negative values it is possible for $\Delta A_{t,i}$ to be less than zero. If this turns out to be the case, it implies that research has followed a wrong path producing a technology $A_{t,i}$ that is less than past technology $A_{t-1,i}$. Accordingly, the innovator will not make use of $\Delta A_{t,i}$ in production, using his past technology instead. An example of a technology that did not generate the expected

[10] There is a large empirical literature pointing to this. For example, the research of Pakes and Shankerman (1979), has identified the effect that spillovers, diffused from major research centres (such as universities), have in fostering innovation, while Jaffe (1986) displayed the importance of the R&D spillovers, which are generated using a local pool of R&D, on the patent productivity of a firm.

results, and in many respects was judged as inferior to its predecessor, would be High Definition TV (HDTV). In the late 1980's this was a promising European TV standard that turned out to be far costly and outdated (when compared to the USA TV technology of its time).[11]

Each innovator aims at reaching some exogenously set "*social targets/goals*" for technology. These goals can be set by either a governmental body or a social planner (acting for the benefit of the society). An example of such a goal set by the society is the goal to create medication for AIDS. An example for a government set target would be the standards set in defence contracts. In both cases, innovators try to create innovations that can reach these goals. These standards will be assumed to change each year with a set rate of change $\Delta\phi > 1$. This way, the "*social target*" t periods from now will have evolved by $t\Delta\phi$. In this context, $\Delta\phi$ is a qualitative index of technology, in contrast to ΔA which is a quantitative index. In simple terms, $\Delta\phi$ expresses how useful this technology is to society (the more useful a technology is to the society, the faster the society will want it to move, allowing for a greater $\Delta\phi$), while ΔA expresses the magnitude of the technology, when compared to its initial starting point A_0.

Each innovator will be endowed with a probability of reaching such a target. This probability will be exogenous and it will be a function of the innovator's ability to innovate $p(\upsilon_i) \in [0,1]$, where $Ep(\upsilon_i) \neq 0$[12] and $\frac{\vartheta p(\upsilon_i)}{\vartheta \upsilon_i} > 0$, $\frac{\vartheta^2 p(\upsilon_i)}{\vartheta \upsilon_i^2} > 0$. In this context, $p(\upsilon_i)$ (for simplicity p_i) describes how far the innovator will advance compared to the "*social target*". If $p_i = 1$, then he will manage to create an innovation that is equal to the full magnitude of $\Delta\phi$, if p_i is less than one then his innovation will be $p_i\Delta\phi$. Hence, each innovator i is expected to generate an innovation of magnitude $Ep_i\Delta\phi$. It should be noted that, if an innovator creates an innovation that is greater than the "*social target*" $\Delta\phi$, then only he would be able to fully appreciate his innovation. All the other innovators have a limited foresight, hence they will not be able to comprehend the innovation's full magnitude. In this case, the innovator will have created some tacit knowledge, in the form of an additional increment, that can only be used by him and it will not spillover to others.

In this framework, the "*social target*" $\Delta\phi$, introduces a multidimensional tournament effect, which allows one to discriminate among otherwise homogeneous agents. Hence, each innovator competes not with others, but with an exogenously set target $\Delta\phi$. How well the innovator performs in such a race, depends on his ability to innovate υ_i. Thereby, $p(\upsilon_i)$ displays how good the innovator's technology is. In other words, $p(\upsilon_i)$ is a weight indicating to the rest of the innovators how useful the innovator's technology is, and how much of it should they use i.e. $p(\upsilon_i)\Delta\phi$.

Accounting for N innovators, the average spillovers that each innovator attains are equal to,

(2) $$s_t = \zeta_t \Delta\phi \int_0^{N-1} p_i dj$$

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[11] 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).

[12] E is the expectation's operator.

where ζ_t is the percentage of innovator's who actually innovate.[13] For simplicity equation (2) can be expressed as,

(3) $$s_t = \zeta_t \Delta\phi\delta$$

where $\delta = \int_0^{N-1} p_i dj$. Substituting this equation into the *"technology generating"* function, one can derive the expected innovation created by innovator i as,

(4) $$E\Delta A_{t,i} = \zeta_{t-1}\pi_{t-1,i}\Delta\phi E\delta$$

In the above discussion, for simplicity, the *"social target"* is assumed as being exogenous and fixed. As a more intuitive *"social target"* one could suggest one that takes into account the recent innovation history. Accordingly, the social planner, having full knowledge of the recent technological capabilities, can set realistic goals for future research. However, since all innovators work on technologies that produce substitute goods, a *"social target"* should account for the innovation history of all innovators.[14] This way, it will be a *"social target"* that is common for all innovators. Based on the above, Panagopoulos (2003) allows for a *"social target"* that is a function of the average innovation created by all innovators who choose to innovate at time *t*-1. This assumption endogenizes the $\Delta\phi$, and makes it time depending. However, as that model shows, the main results of this paper remain unchanged.

3. Production

This section will concentrate on describing the demand for a good that is produced using a specific technology, in a frictionless Walrasian market of size *M*. In this economy, at time *t*, each innovator i, $i \in [0, N]$ will produce one innovation $\Delta A_{t,i}$, which will be used in the production of one good. The good produced through the use of innovation $\Delta A_{t,i}$, will be consumed by a homogeneous mass of consumers who are infinitely lived, have identical additive preferences defined over lifetime consumption and a constant rate of time preference *r*. Goods are substitutes and innovations are assumed to be non-drastic. As a result, there is demand for all innovations. Specifically, the demand $Q_{t,i}$ for a good i, that has been manufactured through the use of the innovation made by the i innovator at time *t*, is given by the following expression,

(5) $$Q_{t,i} = M \frac{\Delta A_{t,i}}{\int_0^1 \Delta A_{t,j} dj}, \Delta A_{t,i} \in (0, \infty)$$

Equation (5) explains the demand for the good produced using the technology $A_{t,i}$ only as a function of the latest innovation $\Delta A_{t,i}$. Thus, consumers are primarily interested in vintage technologies. Evidently, the demand for the good employing the $\Delta A_{t,i}$ innovation will depend positively on $\Delta A_{t,i}$, and negatively on the collective magnitude of the innovations created by

[13] As it will become apparent in the sections that follow not all innovators find it profitable to innovate.
[14] Hence, one accounts for how productive have all the innovators who work on this technology been.

the rest of the innovators, i.e. $\int_0^1 \Delta A_{t,j} dj$. Furthermore, equation (5) implies that the total demand for all goods will be equal to *M*. Equally, if there is only one innovator i, $Q_{t,i}$ will also be equal to *M*.

Each good can be manufactured directly by the innovator making use of his technology $A_{t,i}$, or alternatively the innovator can sell his innovation to a perfectly competitive manufacturing sector. In either case, in producing a good, the manufacturers makes use of the following production function,

$$y_{t,i} = A_{t,i}^a x^b, a + b = 1 \tag{6}$$

where *x* represents production workers.[15]

4. The Innovator's Profits

In this framework, when an innovator creates an innovation he immediately patents his innovation and licences it to competitors for a royalty that is equal to the size of the innovation. This being the case, if innovator i chooses to use $p_j \Delta\phi$ of the research that is carried out by innovator *j*, then he must pay him $p_j \Delta\phi$ in property rights. However, how much of $p_j \Delta\phi$ innovator i will make use of will depend on the patent breadth z_t^2, where $0 < z_t^2 < 1$. In what follows, I will assume that patent breadth is a choice variable for the innovator. In reality, patent breadth is set out by the patent office. However, it is up to the innovator to seek litigation if he feels that someone has been freely using his technology. Thus, the amount of technology transfer that takes place is up to the innovator's discretion. Accordingly, what I am modelling as a choice variable is not patent breadth *per se*, but technology transfer. For this reason, I will use the generic term IP protection in order to describe how much of his technology the innovator decides to freely share.

Assumption 1: *The choice of* z_t^2 *applied by innovator* i *on his innovation, when licensing it to innovator j, will be the same to the one that innovator j chooses.*

This assumption implies that there exists some form of reciprocality among innovators. Hence, if innovator i licences his innovation to innovator *j* applying a z_t^2 degree of IP protection, innovator *j* will reciprocate using a z_t^2 degree of IP protection towards innovator i. Bessen (2002), and Shapiro (2001), have displayed that many major firms have created patent thickets (patent portfolios) which they can use (if they chose to) to block, not just similar innovations, but also innovations that may follow alternative techniques. In reality, most firms seldom use their patent portfolios in order to block innovation. Nevertheless, such patent thickets act as deterrents to any firm which may act as a challenger. This analysis seems to suggest that there exist principal agents who have the means and power to enforce their will. Thus, less prominent firms have no choice but to follow on the footsteps of the major ones.

Thereby, if the major patent portfolio holders choose to litigate a lot, the other firms are left with no other choice but to go to court. Similarly, if the major patent portfolio holders choose to avoid litigation, it is not to the interest of less prominent firms to litigate against them (for if they choose to go to court larger firms have two advantages: a greater patent

[15] All terms are per capita.

portfolio and more money, thus they should be the most likely to win any court case against them). In the light of the above, assumption 1 is not unrealistic.

Following assumption 1, innovator i will apply a z_t^2 degree of IP protection to his innovation. Thus, innovator i will receive $z_t^2 p_i \Delta\phi$ in royalties by each innovator who uses his innovation and at the same time he has to pay property rights that are equal to $z_t^2 p_j \Delta\phi$ to each innovator j whose innovation he makes use of. Assuming that ζ_t percent innovators will choose to innovate, the average property rights that innovator i has to pay to the other innovators are equal to,

(7) $$z_t^2 \zeta_t \Delta\phi\delta$$

In line with the assumption that innovator i has to pay property rights for the use that he makes of the innovations created by others, innovator i will also receive royalties for the use of his technology. As a result, innovator i will receive $z_t^2 \zeta_t p_i \Delta\phi\delta$ in property rights. In all, each innovator will derive some income, because his innovation ΔA_i is used in the production of the good i, moreover, he will benefit from the royalties that he receives from the other innovators who make use of his technology. However, he also has to pay some royalties in order to benefit from the research of others. Accordingly, the innovator's average gross income will be equal to,[16]

(8) $$I_{t,i} = Q_{t,i} + \zeta_t z_t^2 p_i \Delta\phi - \zeta_t z_t^2 \Delta\phi\delta$$

However, as Segerstrom (1988) notes, as the technology level increases it becomes harder to innovate. This is because starting technologies are easier to comprehend, while the more they develop they increasingly need more and more expertise. Thereby, the innovator has to pay a cost c for innovating, a cost that must be proportional to the innovation. Accounting for such a cost implies that technological growth will not follow an explosive path, allowing for a steady state solution. In what follows, I will model such a "*technology development cost*" as, $\frac{c\Delta A_{t,i}}{s_t}$.

Using a formula as such implies that, the greater the degree of spillovers s_t that the innovator can attain (through the use of the work carried out by others) the less the innovation cost that he has to incur. In other words, the more the people working on one field, the easier it is for one to innovate. Including such a "*technology development cost*" in equation (8), equation (8) becomes,

(9) $$I_{t,i} = Q_{t,i} + \zeta_t z_t^2 p_i \Delta\phi - \zeta_t z_t^2 \Delta\phi\delta - \frac{c\Delta A_{t,i}}{s_t}$$

where I assume that $M > 1$ and $c < 1$, so as for $Q_{t,i} > \frac{c\Delta A_{t,i}}{s_t}$, implying that the perplexity of an innovation cannot be large enough to hinder innovation.

Assuming that innovations are distributed Normally, only a few innovators will actually have a Q that is high enough to guarantee them a high income. Keeping in mind that p_i is

16 In both the property rights that the innovator receives, as well as the royalties that he has to pay, I have not included the innovator's own contribution $p_i \Delta\phi$, because they cancel out.

also Normally distributed, this line of thinking implies that the amount of royalties paid to the innovator, i.e. $z_t^2 \zeta_t p_i \Delta\phi$ will be limited for the majority of the innovators. Consequently, some innovators will be adversely affected by the royalties that they have to pay, since their average gross income $I_{t,i}$ will not be greater than zero. This implies that an increase in the degree of IP protection z_t^2 would decrease the number of innovators who find it profitable to innovate; the ones whose average gross income $I_{t,i}$ is greater than zero.

Proposition: *There is a negative relationship between the number of innovators who find it profitable to innovate and* z_t^2.

Proof: *Innovator* i *will find it optimal to innovate only if his gross income* $I_{t,i}$ *is greater than zero. This suggests that the following inequality must hold,* $Q_{t,i} - \frac{c\Delta A_{t,i}}{s_t} > \zeta_t z_t^2 p_i \Delta\phi(\delta - p_i)$. *Since I have assumed that* $Q_{t,i} > \frac{c\Delta A_{t,i}}{s_t}$, *and* δ *is greater than p for the majority of the innovators (assuming that innovations are distributed Normally), both sides of the above inequality are positive. Thus, increases in* z_t^2 *imply that, for some innovators, the above inequality will not hold. Moreover, further increases in* z_t^2 *will affect a greater number of innovators.*

A point as such, is in line with evidence offered by Lerner (1995), who finds that in the biotechnology industry, when firms are faced with a strong patent barrier, they choose to redirect their innovating effort to projects where the patents that competitors have will not pose as many problems. This finding seems realistic, if one accounts for the increased litigation that accompanies broadening patent protection.[17] Indirect evidence for this negative relationship is provided by Aghion et al (2002). Specifically, measuring innovative activity through the use of a weighted patent index, they find that a non-linear (inverted U) relationship exists between innovation and market competition.[18] [19]

For mathematical convenience, I will assume that the number of innovators who find it profitable to innovate is equal to εz_t^{-1} where $\varepsilon \in (0,1)$.[20] Subsequently, if one substitutes equation (3) in equation (9) and replaces εz_t^{-1} in place of ζ_t the innovator's average income will become,

(10) $$I_{t,i} = Q_{t,i} + \varepsilon z_t p_i \Delta\phi - \varepsilon z_t \Delta\phi\delta - \varepsilon z_t^{-1} \frac{c\Delta A_{t,i}}{s_t}$$

In this framework, following Jones (2001), the innovator will not appropriate all of the income that is created from producing output $Q_{t,i}$. He will appropriate only a share $z_t^2 Q_{t,i}$. Hence, the innovator's average profits at time *t* are,

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17 Galini (2001) reports that starting firms must be ready to spend 2-3 million $ in litigation, if they want to either use other people's patents, or protect their own. In addition, as Lanjouw and Schankerman (2001) note, *"for the most valuable drugs and health patents the estimated probability of litigation during the lifetime of the patent is more than 25%, and more than 10% in other technology fields. As a percentage of utilized patents, these litigation rates would be even higher"*.

18 Hence, after a point, fierce competition reduces the number of patents.

19 To this finding, one should add the evidence offered by Panagopoulos (2002), who finds a similar, non linear, relationship with respect to growth.

20 The assumption that $\varepsilon \in (0,1)$ is included so as to have $z^{-1} \in (0,1]$.

(11) $$\pi_{t,i} = z_t^2 Q_{t,i} + \varepsilon z_t \Delta\phi\left(p_i - \delta\right) - \varepsilon z_t^{-1} \frac{c\Delta A_{t,i}}{s_t}$$

5. The innovator's maximisation problem

Innovators maximize their profits subject to their *"technology generating"* function. Their choice variable is the degree of IP protection z_t^2 and their state variable is $\Delta A_{t,i}$. The innovator's *"technology generating"* function is given by $\Delta A_{t,i} = s_{t-1}\pi_{t-1,i} + \upsilon_i$. Accounting though for equation (3), this equation becomes $\Delta A_{t,i} = \zeta_{t-1}\Delta\phi\delta\pi_{t-1,i} + \upsilon_i$. However, $\zeta_{t-1} = \varepsilon z_{t-1}^{-1}$, allowing one to express the innovator's *"technology generating"* function as,

(12) $$\Delta A_{t,i} = z_{t-1}^{-1}\Delta\phi\delta\pi_{t-1,i} + \upsilon_i$$

In all, the innovator's problem can be written down as,

$$\max_{z_t} \sum_{t=0}^{t} \beta^t \pi_{t,i} \ \text{ s.t. } \ \Delta A_{t,i} = z_{t-1}^{-1}\Delta\phi\delta\pi_{t-1,i} + \upsilon_i$$

with initial condition $A_{0,t} = A_0 \to 0^+$. Accounting for equation (11), one can restate the innovator's expected maximization problem as,

$$\max_{z_t} E\sum_{t=0}^{t} \beta^t \left[z_t^2 Q_{t,i} + \varepsilon z_t \Delta\phi\left(p_i - \delta\right) - \varepsilon z_t^{-1} \frac{c\Delta A_{t,i}}{s_t} \right] \ \text{ s.t. } \ E\Delta A_{t,i} = z_{t-1}^{-1}\Delta\phi\pi_{t-1,i}E\delta$$

Suppressing, henceforth, the expectations operator *E*, the steady state FOC is,

$$\tilde{z} = \frac{1+c}{\varepsilon\delta\Delta\phi M}\int_0^1 \Delta\tilde{A}_j\, dj - \left(\frac{\varepsilon\Delta\phi(p_i - \delta)(1+r)}{M}\int_0^1 \Delta\tilde{A}_j\, dj \right)^{1/2}$$

where $\Delta\tilde{A} = \frac{\beta\varepsilon\Delta\phi(P_I - \delta)}{m}\int_0^1 \Delta\tilde{A}_j\, dj$. Allowing *M* to be a large number, this equation can be re-expressed as,

(13) $$\tilde{z} \sim \frac{1+c}{\varepsilon\delta\Delta\phi M}\int_0^1 \Delta\tilde{A}_j\, dj$$

From the steady state solution, it is clear that increases in *r*, in the size of the *"social target"* $\Delta\phi$, or in the size of the market *M*, will cause a downward shift in $\tilde{z}$. Contrary to that, increases in the size of the market, which the other innovators occupy (i.e. $\int_0^1 \Delta \tilde{A}_j \, dj$), will cause an increase in $\tilde{z}$.

The above discussion implies that markets where the technology progresses quickly (i.e. the $\Delta\phi$ is big) allow for a small degree of IP protection. The capacity of the model to allow the innovator to choose a low degree of IP protection when dealing with a fundamental technology, accords with the historical evidence offered by Rosenberg (1994), Mowery and Rosenberg (1989), and Nelson (1962), with respect to the invention of the transistor. In addition, this finding accords with Gort and Klepper's study of technology product life cycles. Specifically, they find that most of the firm's patenting takes place in the latter stage of its research, and not during its early stages.[21]

In contrast to the low degree of IP protection in markets where technology progresses quickly, tougher competition can lead to a high degree of IP protection. More formally, the innovator's decision on choosing the optimal degree of patent protection must be a balanced act which accounts for the following two factors, affecting the innovator's choice in divergent ways: a) how well the competitors innovate (i.e. how successful they are in reaching the *"social target")*, as well as b) how much they threaten the innovator's market power. The intuition behind this line of thinking is straightforward. The more innovative the competitors are, the more the spillovers that the innovator will be able to use in his own research, increasing his innovation. However, if competitors are good enough to occupy a large share of the market, then they decrease his profits and thus decrease future innovation.

6. The Central Planner's Problem

In the previous section I concentrated on the innovator's choice of IP protection. In this section I will concentrate on the central planner. The objective of the central planner is to intertemporally maximize output *y*, where $y_{t,i} = A_{t,i}^a x^b$. Consequently, the central planner solves the following problem,

(14)
$$\max_{z_t} x^b E \sum_{t=0}^{t} \beta^t A_{t,i}^a \ \text{ s.t. } E\Delta A_{t,i} = z_{t-1}^{-1} \Delta\phi \pi_{t-1,i} E\delta$$

where $\pi_{t,i} = z_t^2 Q_{t,i} + z_t \Delta\phi(p_i - \delta) - z_t \frac{c\Delta A_{t,i}}{\Delta\phi\delta}$. Assuming no population growth, it is straight forward to show that *ceteris paribus* the steady state FOC to the above problem is,

(15)
$$\tilde{z}_{cp} \sim \frac{c}{\varepsilon\delta\Delta\phi M} \int_0^1 \Delta \tilde{A}_j \, dj$$

Comparing the expression of equation (15) to the innovator's choice of $\tilde{z}$, equation (13), one can see that $\tilde{z}_{cp}$ is less than $\tilde{z}$. However, the central planner's choice is affected by the degree of market competition and by $\Delta\phi$ in the same way as the innovator's choice. In detail, in markets that display a greater degree of competition, reducing the innovator's profits, both the

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[21] Gort and Klepper, (1982).

central planner and the innovator will opt for a greater degree of protection. Conversely, in markets where innovators feel more comfortable, either because the market is big, or because they do not face a lot of competition, their choice will be lower. Similarly, in markets where technology evolves faster, the ones with a greater $\Delta\phi$, they will both opt for a reduction in z. The intuition behind this result is simple. In markets where the innovators do not feel threatened, they can allow for a lower z that will permit more innovators to innovate. This way, the innovator can benefit from the increase in spillovers. As a result, their innovation will be greater; leading to greater future profits.

7. Conclusions

Allowing innovators to choose their preferential degree of IP protection, in a market where innovators licence their innovations to competitors, IP protection proves to be case specific. Specifically, the degree of IP protection chosen by the innovator will depend on how fast the technology is evolving, as well as on the degree of market competition. This finding is due to the negative relationship between the spillovers that the innovators use in creating a new technology, and the degree of IP protection. A negative relationship as such is based on the assumption that increases in IP protection reduce the number of innovators who find it profitable to innovate.

This research suggests that markets where either technology progresses quickly, or market conditions are such that the innovator feels secure, allow for a small degree of IP protection, in contrast to competitive markets (or markets where technological progress is slow). This line of thinking corresponds well with the evidence offered by Gallini (2001), who finds that firms in the microprocessors industry patent a lot but recognize that they do not do so in order to protect their innovation. Overall, the innovator's choice of IP protection must be a balanced act accounting for the following two factors, affecting the innovator's choice in divergent ways: a) how well the competitors perform, b) as well as how much they threaten the innovator's market power. If competitors do well (they are innovative), then the spillovers from their research will be beneficial to the innovator as well, at the cost of loosing market power.

My results seems to suggest that innovators will optimally choose a level of IP protection that is not far from the one chosen by the central planner. However, noting that the number of patents has increased a lot in the past years, increasing the litigation cost considerably, see Gallini (2001), and keeping in mind that firms use patents for many other purposes apart from protecting their innovation, see Bessen (2002), there is scope for government intervention. From a policy perspective the aim of this paper is not to suggest that the IP policy followed by the government should be case specific in all cases. It only suggests that the government should follow such policies only when dealing with technologies that are at their first stages of development. The example of the *"Microprocessors Act"* is suggestive in this case.

Acknowledgements

I am grateful to P. Aghion, J. Bessen, N. Fabra, P. Rey, K. Sideri, and J. Tirole for helpful comments. All errors remain the author's responsibility.

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