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# UNIVERSITY PATENTS, R&D COMPETITION, AND SOCIAL WELFARE

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Although university patenting has increased dramatically over the past three decades, debates persist regarding the broad economic implications of the phenomenon. This article examines the social welfare implications of university patenting in a model of R&D competition in which firms develop innovations on the basis of the disclosure of a university invention. When such disclosure does not preempt the patenting of downstream innovations, university patenting enhances social welfare only if a regime of open access to university inventions is characterized by excessive aggregate R&D from the viewpoint of social welfare. When the university invention disclosure preempts patenting on firms' innovations, the nature of the open access equilibrium in the R&D market depends on the threat of imitation *ex post*. Only when the threat of imitation is sufficiently strong firms will not invest in downstream R&D in the open access regime. In this case, university patenting promotes R&D investment and increases social welfare.

*Keywords*: University patents; R&D competition; Licensing

*JEL Classification*: O310; O340

## 1 INTRODUCTION

The growing extent to which intellectual property rights (IPRs) mediate the transfer to industry of university research results has been argued to reflect the influence of multiple factors (Jaffe, 2000; Mowery and Sampat, 2001a; Gallini, 2002). Of particular relevance from a public policy standpoint is the encouragement that such a phenomenon has received in the US from legislative action beginning with the Bayh–Dole Act of 1980. Analysts who overemphasize the significance of this law have lavished praise on the US legislators (The Economist, 2002). More generally, the empirical trends revealing the growing number of university patents, licensing agreements, start-up companies established to develop university inventions, and universities' royalty income, have been enthusiastically hailed in the US (AUTM, 2003), and provided much of the impetus for similar changes elsewhere (OECD, 2004).

Support for the Bayh–Dole Act was based on two kinds of arguments, focusing, respectively, on the costs of technology transfer and on the incentives to industrial R&D, according to which the establishment of IPRs on the results of federally funded research would contribute to a greater and faster yield of commercial innovations (Eisenberg, 1996). From the perspective of technology transfer costs, it was argued that IPRs would lead to more effective dissemination

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among industrial firms of information about university research results compared to the policy of committing such results to the public domain. Furthermore, university scientists would have financial incentives to become involved in technology transfer activities that are poorly rewarded within the academic community, thus reducing the costs incurred by adopting firms in order to learn about university research findings and facilitate the transmission of tacit knowledge from academic researchers to employees at the licensed firms.[1]

The second kind of arguments focuses on the incentives faced by firms potentially interested in downstream R&D efforts. Supporters of Bayh–Dole maintain that the costs and uncertainty associated with such downstream R&D activities would not be incurred by firms when the knowledge about university inventions is publicly available. The reason for this is that open access to the university invention would make it impossible for the firms investing in downstream R&D to appropriate the rents from successful innovations. Implicitly, this argument presumes that successful firms cannot defend themselves from imitation or competition by latecomers as patents on the results of downstream R&D activities cannot be taken or in any case cannot provide sufficient protection. This incentive argument is the primary focus of investigation in this article.

In light of the limited evidentiary basis supporting the view that the universities' growing reliance on IPRs is an unambiguous plus, it is not surprising that a few dissenting voices have expressed concerns regarding the consequences of the encroachment of IPRs on the transfer of technology from university to industry. In general terms, these concerns question whether IPRs favor or hinder the transfer and diffusion of technological knowledge, and the development of commercial innovations (Mazzoleni and Nelson, 1998).[2] Behind these worries is a presumption that, contrary to the assertions of the incentive argument behind Bayh–Dole, the diffusion of knowledge about university inventions among firms engaged in R&D would occur even in the absence of IPRs. A number of studies support the proposition that the question whether or not IPRs are needed in order to promote the diffusion of university inventions to industry cannot be answered in general terms. IPRs appear to be useful or needed in some circumstances, but in others open access by industrial firms to knowledge about university inventions appears to be preferable (Colyvas *et al.*, 2002; Oliver and Liebeskind, 2003). This viewpoint is central to the theoretical model developed in this article.

The focus of the model is a comparative analysis of the social welfare properties associated with R&D and product markets equilibria under: (1) a regime of open access to university inventions; and (2) a regime of university patenting and licensing. This comparative analysis is carried out under alternative assumptions about the patentability of the results of downstream R&D. Two cases are distinguished. In the former, it is assumed that downstream R&D leads to patentable results regardless of the policy adopted by the university with respect to its own inventions or discoveries. In the latter, it is assumed that the results of downstream R&D results cannot be patented, so that the incentives for such R&D investment depend entirely on non-patent-based appropriability conditions. Accordingly, the model differentiates among innovative environments on the basis of the opportunities for inter-firm imitation and the effects of product market competition on firms' profits. The results of the model can be summarized as follows.

[1] A variety of studies have focused on the theoretical and empirical analyses of this argument, including Jensen and Thursby (2001), Thursby and Thursby (2002, 2003, and 2004), and Zucker and Darby (1996).

[2] In the area of biomedical technologies, critics have focused on the proliferation of IPRs on inventions and discoveries that represent valuable tools for ongoing research (National Research Council, 1997; Heller and Eisenberg, 1998; Rai, 1999; Eisenberg, 2001). Insofar as these research tools are exclusively licensed, university patenting and licensing policies may restrict the number of firms participating in downstream R&D. Furthermore, the need for access to multiple research tools may increase the transaction costs that downstream R&D firms have to incur.

When downstream R&D results can be patented, a switch in university policy from one allowing open access to one of patenting and licensing for royalty income maximization has no effects on the set of university inventions that are the focus of downstream R&D. University patenting decreases the number of firms engaged in R&D and the overall level of R&D investment. Social welfare decreases if the open access equilibrium is characterized by less than socially optimal R&D investment. It may increase when a patent race forms under the open access regime.

When the results of downstream R&D cannot be patented, the creation of IPRs on university inventions may be necessary to restore incentives for downstream R&D investment. This will happen when the appropriability conditions for downstream R&D are so weak that no firm will invest in R&D under the open access regime. However, when imitation costs and lags are relatively high and the negative effect of competition in the downstream product market on the expected profits for innovating firms are not too strong, the effects of university patenting on aggregate R&D investment and social welfare are ambiguous.

An important result of the model is also that exclusive licensing of patented university inventions increases social welfare only under specific conditions of the downstream innovation environment, namely that downstream R&D results cannot be patented and the weakness of appropriability conditions effectively preempts any R&D investment under the open access regime. Under all other circumstances, exclusive licensing restricts entry by firms in the downstream R&D market and thus is likely to reduce social welfare. On the other hand, the model confirms the proposition that non-exclusive licensing of university patents has no positive effects on downstream R&D incentives and simply decreases the social welfare effects of university inventions by restricting firms' entry into the R&D market.

In the next section, the incentive argument behind Bayh–Dole is articulated and relevant empirical evidence on university patenting and licensing patterns is presented. Next, the basic model is introduced, followed by the comparative analysis of the two innovation environments, dealing with the cases of, respectively, patentable and non-patentable downstream R&D results. The final section provides a discussion of the assumptions and results of the model, as well as some reflections on future theoretical and empirical research.

## 2 UNIVERSITY PATENTING AND LICENSING: SOME EMPIRICAL BACKGROUND

For a long time, the consensus among economists has been that the contributions of university research to a public domain of scientific and technological knowledge are an important source of technological and innovative opportunities for private firms (Levin *et al.*, 1987; Dasgupta and David, 1994; Nelson and Rosenberg, 1994; Narin *et al.*, 1997; Cohen *et al.*, 1998, 2002; Agrawal and Henderson, 2002). These views were challenged during the 1960s and 1970s by the supporters of the Bayh–Dole Act. Claiming that 'what is available to everyone, is of interest to no one' (Bremer, 2001), it was argued that firms would refrain from bearing the costs and uncertainty inherent in developing commercial products on the basis of university inventions made available to the public under conditions of open access.[3]

A key obstacle to appropriating returns from such investments is the lack of patentability of firms' own innovations as a result of the university's disclosures. Allowing universities to

[3] The argument concerned publicly funded research and the patterns of patenting and licensing policies of the public sector. Eisenberg (1996) and Mowery and Sampat (2001a) discuss at length the heterogeneity among government departments and agencies with respect to these policies. Furthermore, the general presumption that university research results have always been committed to the public domain of knowledge ought to be tempered in light of the history of patenting and licensing by universities detailed in Mowery and Sampat (2001b).

establish IPRs creates an effective means of securing control over who can access and use the knowledge disclosed by the university. Thus, the encroachment of intellectual property institutions in the dissemination of university research results is represented as a win-win-win situation for industry, universities and consumers, as socially desirable R&D investment is promoted to transform concepts and discoveries languishing in the public domain into useful products and processes.

This argument calls for an empirical investigation of whether or not the university disclosure of an invention or discovery preempts the patentability of downstream innovation. Moreover, even when the disclosure of university inventions preempts the patentability of downstream R&D research results, the appropriability conditions for R&D investment need not be so weak as to discourage firms from undertaking it. In fact, many empirical studies have found that patents are not always necessary or important means for firms to appropriate the returns from R&D (Taylor and Silberston, 1973; Mansfield, 1986; Levin *et al.*, 1987; Cohen *et al.*, 2000). In particular, imitation costs and time required to imitate may be substantial even for innovations that are not protected by a patent.

To the extent that the incentive argument is correct, one would expect that the patents (or other IPRs) on university inventions would be licensed exclusively such as to ensure that successful firms will be able to profit from their innovations in the product markets. Non-exclusive licenses would enable multiple firms to develop innovative products and to compete in the downstream product markets, recreating the adverse competitive conditions for R&D profitability that motivated the creation of university patents in the first place. However, data collected by the Association of University Technology Managers indicate that about half of the licensing agreements entered into by the US and Canadian universities are non-exclusive (AUTM, 2003). Exclusivity terms dominate only licensing activities with start-up companies, which however represent a small fraction of the total.

The universities' reliance on non-exclusive licensing takes on a different light when its frequency is measured by the fraction of inventions (or patents) that are licensed non-exclusively. As comprehensive data of this sort are not available from the AUTM surveys, the only evidence comes from case studies of specific institutions and publicly released data from academic technology transfer offices. Accordingly, Mowery *et al.* (2001) report that exclusive licenses accounted for nearly 60% of all licensed invention disclosures at Stanford University and Columbia University, and for more than 90% at the University of California.

Even harder is to establish the importance of exclusive and non-exclusive licenses from the viewpoint of their relative contribution to universities' royalty income. In this respect, it is worth remarking that the distribution of licensed university patents in terms of the resulting royalty income is highly skewed. AUTM (2003) indicates for example that only 145 out of 20,086 active licenses in 2002 generated more than $1 million in licensing income. This pattern of concentration of income on just a few university patents is confirmed by the analysis of the data at Stanford, Columbia, and the University of California in Mowery *et al.* (2001). At Harvard University, the most lucrative patent (Cardiolite) for the years 1999–2003 is exclusively licensed to DuPont Radiopharmaceuticals (now a unit of Bristol–Myers–Squibb Medical Imaging) and has accounted for nearly half of all licensing income. On the other hand, it is well known that at least two of the most lucrative university patents of the past quarter century were licensed non-exclusively. Stanford University received about $250 million in royalties from licensing the Cohen–Boyer patents on recombinant DNA techniques and Columbia earned nearly $400 million by some estimates from licenses on the Axel patents on co-transformation (Agres, 2003).[4]

[4] Sampat (2003) points out that the revenues from these two patents account for 15% of cumulative licensing income for all the US universities in the post-Bayh-Dole era.

These facts suggest that an assessment of the effects of university patenting ought to pay attention to the diffusion of non-exclusive licensing among universities, a practice that Reimers (1998) characterizes as imposing a tax on firms' R&D and whose ability to promote innovation and social welfare is highly dubious, as well as to the implications for downstream innovative activities and for social welfare of the exclusive licensing agreements that structure the transfer of many university inventions to business enterprises.

To the extent that the transfer would be prevented by committing these inventions to the public domain, exclusive licensing agreements provide both a source of licensing income for universities and a benefit for consumers. If the transfer would occur under a regime of open access, exclusive licensing agreements may be detrimental from a social welfare viewpoint (and more so than non-exclusive licenses) even if they prove lucrative for universities. The evidence that university technology transfer offices have pursued exclusive licensing only in the former type of environment and eschewed it when the latter conditions apply is scant.[5] However, it should be noted that questions about the appropriateness of university patenting and restrictive licensing have been central to the debate that has focused on the diffusion of biomedical research tools developed at universities (National Research Council, 1997; Eisenberg, 2001; Walsh *et al.*, 2003).

Although in some cases research tools double up as product concepts, many are simply useful in conducting research. Thus, their existence and public availability is unlikely to have consequences on the patentability of the innovations developed by their users. For these kinds of university inventions the argument that IPRs are needed to promote their diffusion appears to be wrong. For example, the results of a survey presented by Walsh *et al.* (2003) report the existence of some concerns about restrictive licensing of patents on targets, a particular class of inventions including 'any cell receptors, enzymes, or other protein implicated in a disease and consequently a promising locus for drug intervention' (p. 287, fn.5). In this area, R&D aimed at discovering drugs, therapeutic and diagnostic applications related to specific targets can in general lead to patentable results, so that the incentive justification for university patenting is highly suspicious.

Although the incentive rationale for university patents has been argued to apply to so-called embryonic technologies or product concepts, whose commercial application requires substantial development expenses by interested firms, such definition does not imply the need for IPRs on the university invention without any further assumption or explanation as to why no firm would incur these development expenses. It is a contention of this article that such assumptions or explanations would have to hinge on the lack of patentability of the results of downstream R&D.

Some indications that the domain of university inventions where this condition holds need to be carefully examined can be found in a few prominent cases of litigation involving universities or their licensees as plaintiffs against alleged infringers. For example, the University of California was involved in a prolonged legal battle against Genentech, alleging that the company's sales of two human growth hormone drugs, Nutropin and Protropin, infringed on a patent granted to the university in 1982. The patent had been licensed exclusively to Eli Lilly, but Genentech itself had been granted patent rights for techniques for producing human

[5] Rai (1999) suggests that the licensing policies pursued until now by many technology transfer offices at the US universities have been oriented in many instances by this distinction. Likewise, in a recent testimony before the Committee on Science of the US House of Representative, Guschl (2000) praised federal agencies like the National Institutes of Health and the Agricultural Research Service for 'recognizing some situations where patents and licenses are needed to encourage commercialization and other cases where the platform is ready for commercialization and use by many and no patenting of government work is necessary.'

growth hormone and marketed its product as early as 1985.[6] More recently, the University of Rochester filed a suit against a number of pharmaceutical companies alleging that sales of anti-arthritic drugs such as Celebrex infringed on a patent received in 2000 on a method for screening inhibitors of the COX-2 enzyme responsible for arthritic pain. Although the patent has been declared invalid by the federal district and appeals courts hearing the case, it is important to notice that the commercialization of the COX-2 inhibitor drugs by the pharmaceutical companies had begun a few years before the university patent was granted, and that the pharmaceutical companies had been granted patents on the discovery of specific drugs achieving the desired inhibiting effect on the COX-2 enzyme.

Overall then, it appears that university patenting and licensing practices have different implications for R&D competition and social welfare depending on specific characteristics of the university inventions and the appropriability conditions that shape the firms' incentives to engage in downstream R&D activities. The theoretical models analyzed in the next three sections of this article aim to identify these characteristics and to provide a framework for future empirical research.

## 3 UNIVERSITY RESEARCH AND R&D COMPETITION

The following model of R&D competition is an adaptation of the model in Dasgupta and Stiglitz (1980). A university invention is described by two parameters $(\lambda, y)$ defining the essential elements of the innovative R&D projects that firms can undertake as a result of the invention. Firms can undertake an innovative R&D project by incurring an investment $y$. Although the R&D investment is committed at once at $s = 0$, the duration of the project is a random variable whose probability density function is exponential with parameter $\lambda$. Thus, the expected time for completion of the project is $1/\lambda$. It will be presumed that entry into the research sector is unrestricted and that all firms operate according to the same R&D technology. A natural interpretation of the two parameters is that the parameter $\lambda$ represents a measure of the efficiency of the R&D projects (Nelson, 1982) generated by the university discovery, whereas the cost of the R&D project $y$ is defined broadly so as to include the knowledge acquisition costs that firms may need to incur in order to learn about the university discovery and set up their R&D project.

An important assumption of the model is that the uncertainties faced by each firm are independent of one another, so that the random variables $s_i$ representing the duration of the project for the $i$th firm will be assumed to be independently distributed.

Completion of the R&D project enables a firm to sell an innovative product in the market. If the results of the firms' R&D projects can be patented, the winner of the R&D competition earns a stream of monopoly profits $\{\pi(s)\}$, $s = [s_i, \infty)$.[7] For simplicity then, patents are assumed to have infinite life. When patenting is not possible on the results of the downstream R&D projects, firms that successfully complete their R&D project earn a stream of profits that depends on the intensity of product market competition from the time of their success onwards. In this case, the magnitude of the profit stream is affected by the number of firms engaging in R&D, the possibility and timing of entry into the product market by imitators, and the nature of competition among firms in the product market. For example, under an assumption that Bertrand competition dominates the product market, only the first firm to innovate would earn

[6] The tangle of lawsuits involving these companies was resolved with two settlements in 1995 (Eli Lilly to pay $145 million to Genentech) and in 1999 (Genentech to pay $200 million to University of California).

[7] The profits $\pi(s)$ are gross of R&D investment costs.

monopoly profits until a second firm's R&D project succeeds. At that point in time, both firms' instantaneous profits become zero.

The analysis compares the R&D market equilibria corresponding to two scenarios identified as 'open access' and 'licensing' equilibria. Which of the two obtains for a particular innovation depends on whether the university places the relevant knowledge in the public domain or establishes IPRs on it and licenses it with the goal of maximizing its own licensing revenues.[8] A central purpose of the model is to investigate the conditions describing R&D and product market competition under which the licensing equilibrium enhances social welfare and whether such result obtains as a result of an increase in the number of firms that are active R&D performers.

## 4 PATENTABLE DOWNSTREAM INNOVATION

The first case discussed concerns a hypothetical university discovery $(\lambda, y)$ that has no effect on the patentability of downstream innovation, regardless of whether the university places its invention in the public domain or obtains IPRs on it. Therefore, we can define the expected value $W(1)$ of the monopoly profit stream earned by the first firm to complete the R&D project as:

$$W(1) = \int_0^\infty \left[ \int_{d_1}^\infty \pi(1) \exp\{-rs\}\, \mathrm{d}s \right] N\lambda \exp\{-N\lambda d_1\}\, \mathrm{d}d_1 = \frac{\pi(1)}{r} \frac{N\lambda}{N\lambda + r} = V \frac{N\lambda}{N\lambda + r}$$

where $d_1$ (an exponentially distributed random variable with parameter $N\lambda$) is the date of the first success among $N$ firms, and $V$ is the value at $s = 0$ of the monopoly profit stream. As each firm has an equal chance to be the first to market, the expected value of a R&D project for a representative firm is:

$$\mathrm{EW} = \frac{1}{N} W(1) - y = V \frac{\lambda}{N\lambda + r} - y$$

For any firm to undertake the R&D project following the university invention $(\lambda, y)$, $\mathrm{EW} > 0$ for $N > 1$. This requires that $(\lambda, y)$ satisfy the following inequality:

$$\lambda > \frac{ry}{V - y}$$

For a profitable university invention, the open access equilibrium in the R&D market will be defined by the number of firms $N^*$ that satisfies the zero profit condition $\mathrm{EW} = 0$. It can be easily verified that:

$$N^* = \frac{\pi(1)}{ry} - \frac{r}{\lambda} = \frac{V}{y} - \frac{r}{\lambda}$$

The social welfare created by the innovation can be easily characterized because the monopoly rents accruing to the innovating firm are dissipated by the aggregate R&D investment. Thus, the social welfare is proportional to the present value of the static consumer surplus in the

[8] Although the evidence so far indicates that revenue maximization is not the only objective of the many actors involved in the technology transfer process, Jensen and Thursby (2001) argue that it is certainly a prominent one. It is adopted here as a default assumption about the goals of licensing policy.

product market CS($s$) with proportionality factor determined by the aggregate spending in R&D ($N^*y$):

$$\mathrm{SW}(N^*) = \frac{\mathrm{CS}}{r}\frac{N^*\lambda}{N^*\lambda + r} = \frac{\mathrm{CS}}{r}\frac{N^*y}{V}$$

Before considering the outcome of a university licensing policy, it is useful to evaluate whether or not the open access equilibrium will be characterized by too much or too little R&D relative to the socially efficient level. This amounts to a comparison between the equilibrium and the efficient number of firms actively involved in R&D. Note that the social welfare from R&D can be expressed as:

$$\mathrm{SW}(N) = V_{\mathrm{S}}\frac{N\lambda}{N\lambda + r} - Ny$$

where $V_{\mathrm{S}}$ denotes the (instantaneous) total surplus in the product market. Thus, the socially efficient level of $N$ can be easily determined to be:

$$N_{\mathrm{eff}} = \left[\frac{V_{\mathrm{S}}}{y}\frac{r}{\lambda}\right]^{1/2} - \frac{r}{\lambda}$$

The following proposition identifies the conditions on the parameters ($\lambda$, $y$) for the number of firms at the open access equilibrium to be not lower than the socially optimal level.

PROPOSITION *Let $N_{\mathrm{eff}}$ be the socially efficient number of R&D projects and $N^*$ the number of firms at the open access equilibrium in the R&D market. Then*

$$N^* \geq N_{\mathrm{eff}} \Longleftrightarrow \lambda \geq \frac{V_{\mathrm{S}}r}{V^2}y$$

*where $V_{\mathrm{S}}$ is the net present value of the static surplus from the innovation*; *and $V$ is the net present value of the successful innovator's profits.*

In general, for any given level of $y$, a patent race is more likely the larger is the corresponding value of $\lambda$. In fact, the set $\Psi = \{(\lambda; y)|\lambda = (V_{\mathrm{S}}r/V^2)y\}$ partitions the space of university inventions into two subsets corresponding to open access equilibria with too many or too few firms.

We can now consider what would happen if the university established IPRs on its invention and restricted access to the R&D technology through licensing. Suppose that the licensing contracts require a fixed royalty fee and that the university can set the fee in such a way as to extract the full value of the licensees' expected rents. Then, the problem of identifying the royalty fee and the number of licensees that generates the maximum licensing revenues for the university is equivalent to choosing the number of licensees $L$ that maximizes the industry-wide expected profits. The university licensing revenues UR are:

$$\mathrm{UR}(L) = V\frac{L\lambda}{L\lambda + r} - Ly$$

If the maximization of UR($L$) over $L \geq 1$ has an interior solution, the optimal number of licensees is defined by the first order condition:

$$\frac{V\lambda r}{(L^*\lambda + r)^2} = y \Longrightarrow L^* = \left[\frac{V}{y}\frac{r}{\lambda}\right]^{1/2} - \frac{r}{\lambda}$$

When an interior solution does not exist, then $L^* = 1$ and the university would maximize its revenues by licensing the R&D technology exclusively. Comparison of the relevant expressions shows that $L^* < N^*$, as should be expected. As a result, the expected time of innovation for the market as a whole under the licensing regime will be later than under open access. Furthermore, it is easy to verify that $L^* < N_{\text{eff}}$.

The social welfare effects of the change in university policy can be only partially determined without specific assumptions on the functional forms. Under all circumstances, university patenting delays innovation. It also effects a transfer of surplus from consumers in the product market to the university. Whether or not such a transfer increases overall social welfare depends on the rate at which the reduction in aggregate R&D spending reduces consumer surplus, while it increases industry profits in the product market (or more precisely, university licensing revenues). Although consumer welfare declines unambiguously under university patenting, increases in social welfare may result; but when that is the case it is because the universities' licensing policy reduces the level of private R&D invested as a result of the university discovery.

## 5 NON-PATENTABLE DOWNSTREAM INNOVATION

In this second scenario, it is assumed that the disclosure of the university invention $(\lambda, k)$ renders non-patentable the results of downstream development activities by firms in the relevant industry. As patents cannot be relied upon by firms in order to appropriate the returns from R&D, whether or not firms will have incentives to engage in R&D depends on their ability to earn in expected value terms supernormal profits for a sufficiently long period of time. For example, the first firm to innovate could enjoy a temporary monopoly position and earn profits until new firms enter the product market as a result of either success in independent R&D projects or imitative efforts.

In general, two factors play a crucial role in determining the characteristics of the R&D market equilibrium. First, private incentives to R&D investment will be influenced by the imitative opportunities available to rival firms as innovative products are introduced in the market. Second, the same incentives will be influenced by the effects of entry by firms in the product market and the (instantaneous) level of net profits earned by each firm. The model specifications of these two context conditions of the innovative markets determine whether or not any firm will invest in R&D and whether or not any firm will imitate. The analysis to follow will first strive for generality by describing the nature of the tradeoffs underlying the firm's decision whether or not to invest in R&D and/or to imitate successful firms. Then, a few cases (corresponding to specific descriptions of the two context conditions above) will be analyzed in more detail.

We begin by considering a simple specification of the model where imitation is not possible. The expected profits from R&D for a firm depend on the timing of its project completion date relative to the rival firms. Upon completion of the project at time $s_i$ and depending on the number of rivals $n - 1$ that have already completed their own project, a firm will start earning a stream of net profits $\{\pi(n(s))\}$ in the product market, where $n(s)$ is a random variable indicating the number of firms that are active in the product market (alternatively, that have successfully completed their R&D project) at time $s$. It can be noted that on the basis of the characteristics of the R&D competition, $n(s)$ is a stochastic 'pure birth' process. Accordingly, we can define as $d_i$ the time between the $(i - 1)$th and the $i$th R&D successes or the sojourn time between birth events. As the success time for each firm is exponentially distributed with parameter $\lambda$, the probability density function of $d_i$ is also exponential with parameter $(N - [i - 1])\lambda$. Thus, the expected duration of sojourn times $d_i$ increases with the number of R&D projects already successfully completed.

The product market profits $W(1)$ (gross of R&D costs) for the first firm to complete the R&D project can then be expressed as:

$$W(1) = \int_{d_1}^{d_{(2)}} \pi(1)\exp\{-rs\}\,\mathrm{d}s + \int_{d_{(2)}}^{d_{(3)}} \pi(2)\exp\{-rs\}\,\mathrm{d}s + \cdots + \int_{d_{(N)}}^{\infty} \pi(N)\exp\{-rs\}\,\mathrm{d}s$$

where $d_{(i)} = \sum_{j=1}^{i} d_j$ is the date of the $i$th success. The product market profits $W(2), W(3), \ldots, W(N)$, can be expressed in similar fashion or recursively. For example:

$$W(2) = W(1) - \int_{d_1}^{d_{(2)}} \pi(1)\exp\{-rs\}\,\mathrm{d}s$$

Clearly, the profits $W(n)$ for the $n$th firm to complete the R&D project are a function of the random variables $\{d_i\}$, $i = 1, \ldots, N$. The expected values at $s = 0$ are:

$$\mathrm{EW}(n) = \sum_{i=n}^{N} \frac{\pi(i)}{(N-i)\lambda + r} \left( \prod_{j=N-(i-1)}^{N} \frac{j\lambda}{j\lambda + r} \right) \qquad n \in \{1, 2, \ldots, N\}$$

At $s = 0$, each firm has an equal chance of being the $i$th firm to complete the R&D project. Thus, the expected value of profits from the R&D project can be expressed as:

$$\mathrm{EW} = \frac{1}{N} \sum_{n=1}^{N} \mathrm{EW}(n) - y = \sum_{i=1}^{N} \left[ \frac{i}{N} \frac{\pi(i)}{(N-i)\lambda + r} \prod_{j=N-(i-1)}^{N} \frac{j\lambda}{j\lambda + r} \right]$$

It can be noted from the expression above that each firm's expected profits from R&D are a decreasing function of the number of competing firms $N$. Assuming free entry into the R&D market, the equilibrium number of competitors $N^*$ is defined by the zero profit condition:

$$\mathrm{EW} = 0 \Longleftrightarrow \frac{1}{N} \sum_{n=1}^{N} \mathrm{EW}(n) - y = 0$$

We can now remove the assumption that imitative entry is not possible. It will be assumed that imitative R&D projects can be undertaken at $d_1$, when the first innovative R&D success occurs. The cost of imitation is a fraction $\beta$ of the innovative R&D project cost $y$ and it takes a fixed amount of time $T$ to accomplish. Thus, if imitation is profitable, a number $M$ of imitative firms will enter the product market at time $d_1 + T$. Although the imitation technology is deterministic, the payoff from imitative entry is stochastic because the stream of net product market profits for imitators depends on the timing of success of the R&D projects of the $N - 1$ firms other than the first to market. When imitation is possible, the payoffs to innovative R&D are also altered as the stream of profits from time $d_1 + T$ onwards will reflect the presence of $M$ imitating firms in the product market.

It will be useful to note that the payoffs for both imitators and innovating firms will depend on the timing of entry by the imitating firms relative to the timing of success of innovating firms. For example, if $T < d_2$ the second firm to complete the R&D project will earn a stream of profits $\{\pi(M + n(s))\}$, with $n(s) \geq 2$ for $s > d_{(2)}$. Defining $\tilde{T} = d_1 + T$, the net profits for imitators discounted at $s = 0$ can be described as:

$$\begin{aligned}\tilde{\mathrm{EW}} = &\sum_{i=2}^{N} \Pr(d_{(i-1)} \leq \tilde{T} < d_{(i)}) \left\{ \int_{\tilde{T}}^{d_{(i)}} \pi(M + (i-1)) \exp\{-rs\}\, \mathrm{d}s \right. \\ &\left. + \sum_{j=i}^{N-1} \left[ \int_{d_{(j)}}^{d_{(j+1)}} \pi(M + j) \exp\{-rs\}\, \mathrm{d}s \right] + \int_{d_{(N)}}^{d_{(\infty)}} \pi(M + N) \exp\{-rs\}\, \mathrm{d}s \right\} \\ &+ \Pr(d_{(N)} \leq \tilde{T}) \int_{\tilde{T}}^{\infty} \pi(M + N) e^{-rs}\, \mathrm{d}s - \beta y\end{aligned}$$

where the $\Pr(\cdots)$ terms should be understood as integration operators with the inequalities in parentheses identifying the range of integration in the space $\{d_1, d_2, \ldots, d_N\}$. When imitation by at least one firm is profitable, entry by imitators will continue until $\tilde{\mathrm{EW}} = 0$. Similar reasoning makes it possible to restate the expected value of profits for innovative firms as:

$$\begin{aligned}\mathrm{EW} = &\sum_{i=1}^{N-1} \frac{i}{N} \left[ \Pr(d_{(i)} \leq \tilde{T} < d_{(i+1)}) \left\{ \int_{d_{(1)}}^{\tilde{T}} \pi(i) \exp\{-rs\}\, \mathrm{d}s \right. \right. \\ &\left. \left. + \int_{\tilde{T}}^{d_{(i+1)}} \pi(M + i) \exp\{-rs\}\, \mathrm{d}s \right\} + \Pr(d_{(i+1)} \leq T) \int_{d_{(i)}}^{d_{(i+1)}} \pi(i) \exp\{-rs\}\, \mathrm{d}s \right] \\ &+ \Pr(d_{(N)} \leq \tilde{T}) \left\{ \int_{d_{(N)}}^{\tilde{T}} \pi(N) \exp\{-rs\}\, \mathrm{d}s + \int_{\tilde{T}}^{\infty} \pi(M + N) \exp\{-rs\}\, \mathrm{d}s \right\} - y\end{aligned}$$

For any given value of $M$, EW is a decreasing function of $N$ so that entry by innovative firm will continue until the zero profit condition (EW $= 0$) is met.

Although characterizing the number of innovating and imitating firms at the R&D market equilibria is not possible without introducing specific assumptions about parameters and functions, it is possible to describe the equilibria that may arise in the R&D market. To this aim, notice that the zero profit condition EW $= 0$ defines a mapping $N = N(M)$ from the number of imitating firms $M$ to the number of innovating firms $N$. Likewise, the condition $\tilde{\mathrm{EW}} = 0$ defines a mapping $M = M(N)$ from the number of innovating firms $N$ to that of imitating firms $M$. An equilibrium for the R&D market can thus be defined as a pair of values $(N^*, M^*)$ such that $N^* = N(M^*)$ and $M^* = M(N^*)$. Three kinds of equilibria are possible in principle.

A first kind of equilibria consists of those equilibria $(N^*, M^*)$ for which both $N^* > 0$ and $M^* > 0$. At equilibria of this sort, $N^*$ enter the competition to be first to market and $M^*$ imitators join the product market after an interval $T$ from the date of commercialization of the first innovative product. A second class of equilibria is characterized by the absence of imitative entry ($M^* = 0$). In these equilibria, the number of firms competing in the R&D market is such as to deter entry in the product market by imitators given the costs and lags involved in imitation. Finally, a third class of equilibria would be characterized by the absence of any innovating firm ($N^* = 0$). Here, the threat of imitation is powerful enough so as to destroy the incentives for any firm to engage in innovative R&D.

Clearly, high costs of imitation (high-$\beta$) and long lags in imitation (high-$T$) reduce the profitability of entry. Trivially, if $T \to \infty$ imitative entry becomes non-profitable and a R&D market equilibrium with $M^* = 0$ will result. On the contrary, as costs and lags decrease, the profits for innovating firms are reduced. Thus, for sufficiently low values of $\beta$ and $T$, $E(W|N = 1) < 0$ and the R&D market shuts down.

Under the condition that the university disclosure of an invention $(\lambda, y)$ renders the result of downstream development work non-patentable, a university policy that establishes IPRs on the invention would restrict entry in the R&D market and in the product market to the licensed firms. The key question is to identify the effects of the switch from the open access policy to the licensing policy on the number of firms competing in the R&D market and on the social welfare associated with the resulting equilibria. A few qualitative results can be presented for the three classes of 'open access' equilibria described earlier.

Consider first the case of university inventions $(\lambda, y)$ that support 'open access' equilibria where $M^* = 0$ so that the threat of imitative entry does not eliminate the incentives for firms to engage in innovative R&D. The switch in the university policy can only lead to a reduction in the number of firms that do engage in R&D. The university's optimal decision about the number of licensees will be determined by a comparison of the benefits and costs of increasing the number of licensees. A larger number of licensees speeds up the time it will take for innovative products to reach the market, so that the licensees will start earning profits earlier. But a larger number of licensees will also create the conditions for more intense product market competition and the dissipation of aggregate industry profits. This will reduce the value of a license for each of the firms. In any event, the number of licensees will be smaller than the number of innovative firms at an 'open access' equilibrium.

At an equilibrium where the threat of imitation is strong enough that $N^* = 0$, no firm has an incentive to develop the invention, the introduction of IPRs by the university will effectively restore the firms' incentives to develop an invention $(\lambda, y)$ by preventing imitative entry. Here too, the decision about the optimal number of licensees reflects the tradeoffs described in the previous paragraph. However, the switch from the 'open access' policy to the licensing policy has unambiguously positive effects on social welfare.[9]

Finally, consider the case of those inventions $(\lambda, y)$ that support an 'open access' equilibrium with both positive innovative R&D investment and imitation. In this case, the switch to a licensing policy by the university may increase or decrease the number of firms with active innovative R&D programs. In the former case, the time to market would be shortened although the degree of competition in the product market as $s \to \infty$ may be reduced if the number of licensees is less than $N^* + M^*$. In the latter case, the time to market will be delayed and the degree of competition will be reduced further.

In order to sharpen the model predictions, the following two subsections will present a couple of special cases where it will be assumed that the form of competition in the product market is of the Bertrand-oligopoly type. Accordingly, it will be assumed that $\pi(i) = 0$ for any $i \geq 2$ and therefore:

$$W(1) = \frac{\pi(1)}{(N-1)\lambda + r} \frac{N\lambda}{N\lambda + r}$$

$$W(i) = 0 \quad \text{for } i \geq 2$$

Any firm will decide whether or not to enter the R&D market on the basis of a comparison of the temporary monopoly profits that can be earned in the product market and the costs of R&D.

[9] Implicitly, we are assuming that the licensing contracts offered by the university can prevent any licensee from waiting until another licensee has developed the innovation and then imitate. If this monitoring task cannot be performed, then an exclusive license would be the only way to ensure that a licensee will engage in innovative R&D.

### 5.1 The Case of Impossible Imitation

When imitation is not possible ($T \to \infty$), the expected profits from innovative R&D can be described as:

$$\mathrm{EW} = \frac{1}{N} W(1) - y = \frac{\pi(1)}{(N-1)\lambda + r} \frac{\lambda}{N\lambda + r} - y$$

when $N$ firms are active in the R&D market. At the 'open access' equilibrium, the number of firms $N^*$ is defined by the zero profit condition $\mathrm{EW} = 0$.

Under a licensing policy, the university would charge a fixed royalty payment $l$ to licensees so that the expected profit from innovative R&D would be:

$$\mathrm{EW_L} = \frac{1}{L} W(1) - (y + l) = \frac{\pi(1)}{(L-1)\lambda + r} \frac{\lambda}{L\lambda + r} - (y + l)$$

where the subscript L is used to identify the relevant variables in the licensing equilibrium. It is simple to verify that $L^* < N^*$ for $l > 0$, as the optimal number of licensees will be determined by $\mathrm{EW_L} = 0$ for any choice of $l$ by the university. Furthermore, the optimal choice of $L^*$ will reflect a tradeoff between the reduction in the expected time before an innovation is brought to market and the faster dissipation of industry profits resulting from greater competition. In particular, the expected time to innovation would decline according to $1/(L\lambda)$ as the number of licensees increases, but the expected duration of the temporary monopoly profits would also fall as the number of licensees increases according to $1/[(L-1)\lambda]$ when the number of licensees grows past two. Thus, exclusive licensing will likely be the optimal policy but for very large values of the discount rate.

The social welfare consequences of the switch in university policy can be conjectured to be negative because the reduction in the number of innovating firms from $N^*$ to $L^*$ will delay the introduction of the innovative product to market and the onset of competitive conditions.

### 5.2 The Case of Costless and Rapid Imitation

We will assume in this case that $\beta = 0$ and $T$ is sufficiently small that $\mathrm{EW} < 0$ even for $N = 1$. In this case, no firm would find it profitable to engage in R&D at the 'open access' equilibrium ($N^* = 0$). Under these circumstances, the switch to a licensing policy by the university restores private incentives for innovative R&D by removing the threat that imitators will enter the product market shortly after the first success. If a fixed licensing fee $l$ is charged by the university to $L$ licensees, then the expected profits will be:

$$\mathrm{EW_L} = \frac{1}{L} W(1) - (y + l) = \frac{\pi(1)}{(L-1)\lambda + r} \frac{\lambda}{L\lambda + r} - (y + l)$$

The choice of $L$ by the university will respond to the tradeoffs highlighted in the previous section. However, the social welfare implications of the switch from 'open access' to 'licensing' are unambiguously positive. The university patenting policy promotes rather than stifles R&D investment relative to the open access regime.

## 6 CONCLUSIONS

This article investigates through the lens of a theoretical model of R&D competition how alternative university policies regarding the disposition of inventions and discoveries may influence the R&D activities of firms, and social welfare. The central premise for the analysis presented here is that the policy argument according to which the patenting of university inventions is needed in order to provide or strengthen the incentives for private firms to engage in the associated downstream R&D work is too general. Its validity hinges on specific characteristics of the innovative environment that may or may not be present in the relevant empirical contexts. In the latter case, the effects of university patenting may be altogether different. The two basic models presented in this article are a preliminary attempt at characterizing innovative environments that differ essentially in terms of the patentability of downstream innovation after the disclosure of the university invention.

The first model considers a university invention disclosure that does not preclude the granting of a patent on downstream innovation, so as to render the threat of imitation ineffective. This scenario appears to capture the case of pure research tools, whose main function is to enhance the effectiveness of R&D in the relevant domains. In these circumstances, patenting and licensing the university invention is not necessary to restore R&D incentives for firms. Indeed, the resulting restrictions on the number of competing firms in the R&D market delay the expected date of introduction of the innovative products. As a result, consumer surplus in the product market is also reduced. Contrary to a central argument supporting the Bayh–Dole Act, any social welfare gains that may be attributed to the adoption of a patenting and licensing policy by universities would come about as a result of curbing the excessive R&D investment typical of patent races.

The second model presumes that the disclosure of a university invention makes the downstream development work insufficiently inventive from the viewpoint of patent law and therefore non-patentable. In this case the threat of imitation plays an important role in defining the equilibrium level of R&D investment when the university invention is dedicated to the public domain. Under such open access conditions, the R&D market may operate as long as the imitation costs and lags ensure successful innovators a sufficiently long window of time during which they can earn a return on their R&D investment. Else, the threat of imitation will eliminate firms' incentives to engage in innovative R&D. A patent on the university invention removes the threat of imitation.

If this threat is not sufficiently strong to keep at least some firms from investing in innovative R&D, the university licensing policy is likely to reduce the aggregate level of R&D. This will delay the expected date of introduction of innovative products and the onset of increasingly competitive conditions in the product markets. It appears plausible to argue that such changes will reduce social welfare as the open access equilibrium is unlikely to be characterized by the racing phenomenon.

However, if no R&D investment takes place because of the threat of imitation under conditions of open access to the university invention, then university patents have the desired positive effect on the level of R&D investment. It is only in these circumstances that consumers will gain from the university patenting policy at the same time that the university licensing revenues increase.

These remarks suggest that assessments of the net social welfare impact of university patenting policies on the basis of licensing royalties ought to be informed by an understanding of the context within which such royalties are generated. Note that only in the case of no R&D investment under open access, the licensing revenues received by the university underestimate the social welfare gains resulting from university patenting. In all other cases, losses in consumer surplus either partially offset the university licensing revenues or exceed them, reversing the change in social welfare. The use of university licensing revenues as a proxy for measuring the economic benefits from the recent changes in the institutional mechanisms supporting the transfer of invention-related knowledge from university to industry may provide badly misleading results.

The argument presented build upon a rather specific model of R&D competition and a few comments on the limits of the model are in order.

First of all, the model disregards the possibility that patents may provide an institutional device for reducing the cost of knowledge transfer from university to industry. Theoretical arguments and empirical evidence have been marshaled to support the argument that patenting provides a vehicle for motivating the university scientist to collaborate with industrial R&D personnel and thus increase the effectiveness of the technology transfer process (Zucker and Darby, 1996; Jensen and Thursby, 2001). These important issues have been set aside in this article in order to focus on the interactions between university policy and R&D competition. Future work will be directed to linking these two avenues for theoretical inquiry. It could be noted that the analysis carried out in this article suggests that the most significant source of net social benefits from the change in university policy may be precisely the reduction in the costs of knowledge transfer.

Second, the model could be criticized on the grounds that its perspective on R&D competition is too narrow. It assumes free entry in R&D and portrays the R&D work as aimed at a single innovative target, whereas many university inventions are general enough that they can find application in different areas of industrial R&D. However, the model's purpose was to identify a few factors influencing the appropriability conditions for private R&D that lend support to the policy argument stated at the outset. With that purpose in mind, it can be argued that the model of R&D competition chosen is more likely to support the policy argument than others. Consider the free entry assumption. Entry barriers in the R&D market are likely to strengthen the appropriability conditions for firms that are not specialized R&D boutiques. Likewise, differentiation of the downstream R&D activity is likely to foster R&D competition and stronger incentives for adopting university research results. Thus, the modeling choices appear to be well suited to the goal of the analysis.

Theoretical investigations are not a substitute for empirical work. The model predicts that two conditions have to be simultaneously satisfied if university patenting is to at once promote industrial R&D on the basis of university research results in industrial R&D and increase social welfare. These conditions are that the disclosure of university invention substantially reduces the patentability of downstream innovation, and that the innovative firms would not be able to appropriate sufficient returns, absent patent protection. Although a considerable body of evidence already exists that would permit a general assessment of what areas of technology or industrial R&D display the second of these characteristics, the relationship between university disclosure of inventions and patentability of industrial innovation is relatively unexplored. Future work will be directed to investigating more systematically this issue.

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