Sequential Innovations and Intellectual Property Rights

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Abstract

We analyze a two-stage patent race. In the first phase firms seek to develop a research tool, an innovation that has no commercial value but is necessary to enter the second phase of the race. The firm that completes the second phase of the race first obtains a patent on the final innnovation and enjoys its profits. We ask whether patent protection for the innovator of the research tool is beneficial from the ex ante point of view. We show that there is a range of values of the final innovation such that firms prefer to have no Intellectual Property Rights for research tools.

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1 Introduction

Should gene sequences be patentable?

This question is at the heart of a heated debate between Myriad Genetics, a Salt Lake City based firm, and a large group of European based institutions, lead by the Curie Institute, the Assistance Publique-Hôpitaux de Paris, and the Gustave-Roussy Institute. Myriad Genetics obtained two patents from the United States Patent and Trademark Office on genes BRCA1 and BRCA2 , both linked to a predisposition to breast and/or ovarian cancer. In 2001 the firm developed diagnostic tests for these genes and obtained three supplementary patents granted by the European Patent Office (EPO). Because Myriad Genetics refused to grant licenses on genes BRCA1 and BRCA2, patent protection effectively permitted Myriad Genetics to exert monopoly power on genetic testing. The European institutions questioned Myriad Genetics policy on various grounds. Arguments brought forward include in particular that a monopoly on genetic testing is unethical per se and disables institutions other than the patent holder from performing research building on the gene sequences. Moreover, the markups charged by Myriad Genetics were seen as out of line with Santé Publique goals in France. In late 2001, the European institutions filed a complaint to the EPO and in 2005, the EPO essentially revoked Myriad Genetic's patents on genes BRCA1 and BRCA2. Myriad Genetics appealed in late September 2007, but to date the EPO has maintained its decision to revoke the patents.[1]

One difficulty in the debate is probably the diversity of arguments in favor and against patent protection for gene sequences. The conventional economic argument in favor of patent protection is that some profits must be guaranteed to the innovator in order to give private firms an incentive to conduct research in the first place. Arguments against patent protection in the particular case are based among other things on ethical and public interest grounds. In view of the perceived wisdom, our contribution is perhaps surprising: we show that there may in fact be no conflict between the private goal of profit maximization and the public goal of increasing welfare (in the broad sense). In other words, private, profit maximizing firms may prefer to have no patent protection for gene sequences, because their ex ante expected profits without such Intellectual Property Rights are higher.

The genes BRCA1 and BRCA2 in our opening anecdote have per se no commercial value, but they are a necessary tool to construct tests, which do have commercial value. Intermediate

[1] A summary of the European position can be found in a Curie Institute press release (2nd Oct 2007), available at http://www.curie.fr/home/presse/communiques.cfm/lang/_fr.htm

inventions or discoveries that are valuable primarily for subsequent innovations have been termed research tools (Nass and Stillman (2003)). Examples include databases and reagents, that is substances used in chemical reactions. The purpose of this paper is to develop a framework to assess the optimality of patent protection for such research tools. While it is clear who wins and who loses when a patent is filed or revoked ex post, it is less clear what the effects of patent protection versus non-protection on ex ante profits and welfare are. We show that both firms' ex ante profits as well as consumers' expected welfare can be higher in a regime without patent protection on research tools.

In our model two ex ante identical firms race for a final innovation. To complete the innovation, a research tool has to be found first. The research tool has no commercial value but is a necessary ingredient for a valuable innovation that uses the tool. With patent protection, the firm that finds the research tool first completes the second phase of research unchallenged by the other firm. Without patent protection, both firms can use the research tool regardless of which one found it in the first phase of the race. Patent protection versus non-protection of the research tool is subject to the following trade-off. With patent protection, the inventor of the research tool enjoys a relatively high expected profit when doing research for the final innovation, because the competing firm lacks an essential ingredient to complete the innovation. On the other hand, both firms have high incentives to find the research tool, because the firm that is too slow to develop the tool will be excluded from the second, decisive phase of the race. This is costly because firms are trapped in a situation where they invest excessively. Without patent protection, firms face low incentives in the first phase of the race, because they can use the research tool even when the rival develops it; but on the other hand the expected profit of a firm engaged in research for the final innovation is relatively low because there is now competition at the second stage. We show that, depending on the value of the final innovation, firms may prefer the regime without patent protection. The beneficial cost saving in the first phase of the race due to a reduction of research incentives outweighs the ex post loss induced through competition in the second phase of the race. Moreover, the overall expected time to make the final innovation available to consumers is shorter without patent protection; hence consumers prefer to have no patent protection for research tools.

The literature on innovations is vast, so we only mention the main building blocks of our analysis here. Patent protection is generally seen as a necessary evil to generate incentives for innovations. If firms were unable to appropriate any rents from their innovations, they would have no incentive to invest into research in the first place. Hence, innovations would remain undiscovered and consumers would lose their part of the surplus. Hence, from a welfare perspective patents of limited length can be seen as the prize society offers to firms to generate incentives for research. This reasoning relies crucially on the assumption that innovations are one-shot; it does not apply in our multistage innovation framework.

We follow Grossman and Shapiro's (1987) approach of a stochastic two-stage research and development race where arrival times of innovations follow independent Poisson distributions. We view patent protection from a property rights perspective à la Grossman and Hart (1986). A main theme in the property rights literature is how under-investment can be overcome by efficiently allocating property rights. In contrast to this, we find that property rights may generate overinvestment - a familiar result from the patent race literature. Hence, the absence of property rights may become optimal.

Closest in spirit to this result is Bessen and Maskin (2008), which analyzes costs and benefits of of patent protection when innovation is sequential and complementary and imitation is costless. Bessen and Maskin show that innovators in a sequential patent race might be better off without patent protection, because incentives for research are enhanced without patent protection. While the absence of property rights serves exactly the opposite purpose in our paper - as a device to coordinate on a more efficient equilibrium with lower research expenditures - we find as they do that firms may prefer to have no property rights.

Multi-stage patent races have previously been analyzed by Scotchmer and Green (1990) and Green and Scotchmer (1995). Scotchmer and Green (1990) find that patenting interim knowledge is beneficial because it accelerates aggregate innovation through disclosure of inventions. The difference to our approach is the strength of patent protection: while they assume that patenting around an invention is possible, we assume that patent protection is sufficiently broad. Green and Scotchmer (1995) argue for a strong patent protection in a cumulative innovation process. However, they assume sequential innovations are undertaken by different firms, while we allow for patent races at each stage of the innovation process. Similar to our approach, though different in focus, is Denicolò (2000), which shows that in a sequential two-stage patent race a weak patent protection for final innovations may be better than a strong protection. The difference to our paper is that we take patent protection for the final innovation as given and vary the patent protection of intermediate results.

Our paper is organized as follows. In section 2, we lay out the main model and describe the basic trade-off between the two regimes with and without property rights. In section 3, we analyze this trade-off in detail and characterize the optimal patent policy. We provide a welfare analysis and discuss extensions in section 4. All proofs have been relegated to an appendix.

2 The Model

Two firms race to find an innovation that generates a flow profit π to the innovator. The innovation is protected by an infinitely-lived patent, so the value of finding the innovation to the innovator is $\Pi = \frac{\pi}{r}$, where r is the interest rate, assumed to be sufficiently small, in a sense to be clarified as we go along. Finding the innovation takes two steps. The first is an intermediate step of research - inventing a research tool - and the second is finding the actual innovation. We assume that the intermediate step has no intrinsic value; however, the step is essential for the overall innovation process in the sense that a firm that does not complete the first step cannot complete the final step at all.[2]

Firms choose in each phase of the race a research intensity that determines the likelihood of a success. Time is continuous and the arrival time of a firm's innovation follows a Poisson distribution with parameter λ_{ih}, $i = 1, 2$ denoting firms and $h = 1, 2$ denoting stages (or phases) of research. Firms have available in each phase three pure strategies; they can drop out, they can innovate with a hazard rate of $\underline{\lambda}$ at flow cost $\underline{c}$, or they can innovate with a hazard rate of $\overline{\lambda}$ at a flow cost of $\overline{c}$, where $\underline{\lambda} < \overline{\lambda}$ and $\underline{c} < \overline{c}$. To capture decreasing returns to innovative activity we will assume $\frac{\overline{\lambda}}{\underline{\lambda}} < \frac{\overline{c}}{\underline{c}}$. We allow for mixed strategies between the two strategies contingent on participation and let z_{ih} denote the probability that firm i chooses the relatively fast and costly innovation strategy.[3] Hazard rates and flow costs are then given by

$$\lambda(z_{ih}) \equiv z_{ih}\overline{\lambda} + (1 - z_{ih})\underline{\lambda} \text{ and } c(z_{ih}) \equiv z_{ih}\overline{c} + (1 - z_{ih})\underline{c} \text{ for all } z_{ih} \in [0, 1]. \tag{1}$$

We will use W to denote ex ante values at the beginning of phase one, and V to denote continuation values at the beginning of phase two. $R \in \{P, N\}$ will denote regimes, with P denoting the property right (on the research tool) regime and N denoting a regime without property rights on research

[2] Thus, we assume that the follower cannot innovate around the patent. Indeed, Scotchmer (2005) has argued that *"the patent claim is deemed to cover any product that "does the same work in substantially the same way to accomplish substantially the same result"* (Scotchmer, 2005: p. 69).

[3] This formulation of the race follows Loury (1979), Dasgupta and Stiglitz (1980), Lee and Wilde (1980) and Reinganum (1982). The race is standard due to its analytical convenience, although it has some well known unpleasant features; e.g., there is no memory. We restrict attention to stationary policies, because it is well known that optimal strategies are stationary in this model.

tools. We let V_R^+ denote the continuation value of the firm that has invented the research tool in regime R; V_R^- denotes the continuation value of the firm that has not invented in phase one. The ex ante value of the race for firm i can now be written as

$$rW_{iR}(z_{j1})\,dt = \max_{z_{i1}} \left\{ \lambda(z_{i1}) \left(V_R^+ - W_{iR}(z_{j1}) \right) + \lambda(z_{j1}) \left(V_R^- - W_{iR}(z_{j1}) \right) - c(z_{i1}) \right\} dt. \qquad (2)$$

(2) states that over a small time interval of length dt the return to holding a claim on firm i's assets must in equilibrium be equal to the real return the firm obtains over the same interval of time. With likelihood $\lambda(z_{i1})\,dt$, the firm successfully innovates and the firm's value jumps up to V_R^+. Firm j innovates with likelihood $\lambda(z_{j1})$, in which case firm i loses its current value and gets continuation value V_R^-. The flow costs of innovation over the interval of time are $c(z_{i1})\,dt$. Note that the continuous time formulation implies that events where both firms innovate at the same time have measure zero.[4] Dividing by dt on both sides of (2), and rearranging, we can solve for $W_{iR}(z_{j1})$:

$$W_{iR}(z_{j1}) = \max_{z_{i1}} \frac{\lambda(z_{i1}) V_R^+ + \lambda(z_{j1}) V_R^- - c(z_{i1})}{r + \lambda(z_{i1}) + \lambda(z_{j1})} \qquad (3)$$

The numerator of (3) is the instantaneous net return of firm i; the denominator is the effective discount rate which adjusts the time preference by the expected length of the race. We will adopt formulations similar to (3) in what follows without further discussion.

The value of the inventor of the research tool in the regime with patent protection depends on whether the firm chooses to license its research tool to the other firm and if it does so, on the licensing fee. We assume that firms engage in Nash bargaining to determine the licensing fee. Let V_m denote the value of a firm that continues searching optimally for the final innovation while the other firm drops out of the race and let V_d denote the equilibrium value of a firm searching optimally for the innovation when the other firm stays in the race. Standard Nash bargaining gives

$$V_P^+ = V_m + \max\left\{ \frac{1}{2}(2V_d - V_m); 0 \right\} \qquad (4)$$

and

$$V_P^- = \max\left\{ \frac{1}{2}(2V_d - V_m); 0 \right\}. \qquad (5)$$

Each firm obtains the value of its outside option plus one half of the additional surplus created through a licensing arrangement. To keep our analysis as simple as possible, we will assume that

[4] The continuous time formulation is convenient because it gives rise to tractable value functions. However, it should be stressed that time plays no crucial role in our model. Everything we wish to show could also be demonstrated with a simple two period model. However, the alternative model would be much less convenient to handle analytically.

$2V_d - V_m < 0$, so no licensing will occur in equilibrium. This assumption captures the essence of the Myriad Genetics example. Moreover, for our purpose - to establish a possibility result - the assumption is not restrictive.[5] The condition $2V_d - V_m < 0$ amounts to a restriction on Π, the value of the final innovation. We characterize the restriction explicitly below. For the time being, it suffices to note that $V_P^+ = V_m$ and $V_P^- = 0$. In case there is no patent protection, we simply have $V_N^+ = V_N^- = V_d$.

We will restrict attention throughout our analysis to symmetric equilibria. Let z_1^R denote the equilibrium strategy contingent on participation in phase 1. The induced equilibrium hazard rate and flow cost are denoted accordingly. We can write the ex ante firm value in the regime with patent protection for research tools as

$$W_P = \frac{\lambda_1^P V_m - c_1^P}{r + 2\lambda_1^P}. \tag{6}$$

and in the regime without patent protection for research tools as

$$W_N = \frac{2\lambda_1^N V_d - c_1^N}{r + 2\lambda_1^N}. \tag{7}$$

The difference to (6) is that the firm obtains continuation value V_d regardless of which of the two firms invents the research tool, which implies firstly that the continuation value is V_d instead of V_m and secondly that the likelihood of arrival is the joint likelihood that at least one of the firms is successful. Finally, in the first regime, the value is evaluated at equilibrium z_1^P while in the latter regime the equilibrium is z_1^N. Firms prefer the regime without property rights on research tools if and only if the difference

$$W_N - W_P = \frac{2\lambda_1^N V_d - c_1^N}{r + 2\lambda_1^N} - \frac{\lambda_1^P V_m - c_1^P}{r + 2\lambda_1^P}$$

is positive. To understand how this possibility may arise, we add and subtract the term $\frac{\lambda_1^N V_m}{r+2\lambda_1^N}$ on the right-hand side, so we have

$$W_N - W_P = \underbrace{\frac{\lambda_1^N (2V_d - V_m)}{r + 2\lambda_1^N}}_{\text{ex post efficiency effect}} + \underbrace{\frac{\lambda_1^N V_m - c_1^N}{r + 2\lambda_1^N} - \frac{\lambda_1^P V_m - c_1^P}{r + 2\lambda_1^P}}_{\text{ex ante incentive effect}}. \tag{8}$$

The comparison of regimes is driven by the following trade-off. On the one hand, the absence of property rights on research tools induces an inefficient number of participants in the second phase of the race. Under our assumption that $2V_d - V_m < 0$ the joint value of both firms would be larger

[5] We sketch at the end of the paper how the analysis extends to the case where ex post licensing occurs in equilibrium.

when only one firm enters the second phase of the race, but without patent rights on the research tool both firms have access to the essential input. We term this an ex post efficiency effect and note again that this effect is negative by assumption. On the other hand, the equilibrium choices in the first phase of the race depend on the regime. We term the effect on these equilibrium choices an ex ante incentive effect. The firms can only prefer regime N if the ex ante incentive effect is positive; that is, if the absence of property rights induces more efficient equilibrium choices in the first phase of the race.

3 Analysis

We now turn to a more detailed analysis of our model. Our method of proof is entirely constructive: to prove the possibility result that firms may prefer the regime without patent protection on research tools, we show that there are values of Π that satisfy all restrictions we introduce. In particular, and among other things, we will show that there is a range of values for Π such that at the same time the ex post efficiency effect is negative and the ex ante incentive effect is positive.

3.1 The ex post efficiency effect

Consider first the regime with patent rights on the research tool. To make the analysis non-trivial we assume that the value of the innovation is sufficiently high, so that continuing the research is better than dropping out in any phase. In particular, the value is high enough to make the firm willing to continue its research in phase two, $\Pi > \frac{\underline{c}}{\underline{\lambda}}$. The firm's optimal research intensity solves

$$V_m = \max_{z_2} \frac{\lambda(z_2)\,\Pi - c(z_2)}{r + \lambda(z_2)} \tag{9}$$

where we dropped the firm index i because there only is one of them. The optimum is generically attained at a boundary. The solution is $z_2^P = 0$ for $\Pi \leq \Pi_m$ and $z_2^P = 1$ for $\Pi > \Pi_m$, where

$$\Pi_m \equiv \frac{(r + \underline{\lambda})\,\overline{c} - \left(r + \overline{\lambda}\right)\underline{c}}{r\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{10}$$

Next, consider the regime without intellectual property rights on research tools. In the subgame following the discovery of the research tool, firm $i's$ optimal research intensity is a solution to the problem

$$V_d(z_{j2}) = \max_{z_{i2}} \frac{\lambda(z_{i2})\,\Pi - c(z_{i2})}{r + \lambda(z_{i2}) + \lambda(z_{j2})} \tag{11}$$

The difference to (9) is that the value of firm i drops to zero if firm j innovates first. Depending on the value of Π, the subgame has either multiple equilibria or a unique equilibrium. Manipulating

(11) for $z_{j2} = 0$, we find $z_{12} = z_{22} = z_2^N = 0$ is an equilibrium for $\Pi \leq \Pi_d^0$, where

$$\Pi_d^0 \equiv \frac{(r + 2\underline{\lambda})\,\overline{c} - \left(r + \underline{\lambda} + \overline{\lambda}\right)\underline{c}}{(r + \underline{\lambda})\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{12}$$

Likewise, $z_{12} = z_{22} = z_2^N = 1$ is an equilibrium for $\Pi \geq \Pi_d^1$, where

$$\Pi_d^1 \equiv \frac{\left(r + \underline{\lambda} + \overline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}}{\left(r + \overline{\lambda}\right)\left(\overline{\lambda} - \underline{\lambda}\right)}.$$

We observe that $\Pi_d^0 > \Pi_d^1$. Hence, for $\Pi > \Pi_d^0$, the subgame has a unique Nash-equilibrium, which is $z_{12} = z_{22} = z_2^N = 1$. We will focus on this case. It is easy to verify that $\Pi_m > \Pi_d^0$. For values of Π that satisfy $\Pi_d^0 < \Pi < \Pi_m$, competition induces firms to speed up the innovation process in the sense that each of them invests more than it would in the absence of competition. Since overinvestment is a robust feature of the race environment, we will restrict attention to values of Π in the interval $\left(\Pi_d^0, \Pi_m\right)$.

As we have argued above, it simplifies our analysis if licensing does not occur on equilibrium path, which is the case if $2V_d - V_m < 0$. Using the fact that for $\Pi \in \left(\Pi_d^0, \Pi_m\right)$ the equilibrium in the no property right regime is $z_2^N = 1$ and the equilibrium in the property right regime is $z_2^P = 0$, we can evaluate the equilibrium continuation values in (9) and (11) and find $2V_d - V_m < 0$ if and only if $\Pi < \tilde{\Pi}$, where

$$\tilde{\Pi} \equiv \frac{(2r + 2\underline{\lambda})\,\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}}{r\overline{\lambda} + r\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{13}$$

To complete the proof that the ex post efficiency effect may indeed be negative for a non-empty set of values Π we need to show that the restrictions $\Pi_d^0 < \Pi < \Pi_m$ and $\Pi < \tilde{\Pi}$ are consistent with each other.

Proposition 1 *For r sufficiently small there is a non-empty interval $\left(\Pi_d^0, \tilde{\Pi}\right)$ such that for $\Pi \in \left(\Pi_d^0, \tilde{\Pi}\right)$, the ex post efficiency effect is negative, $2V_d - V_m < 0$.*

The proof in the appendix is constructive. We show that for small enough values of r, the relevant boundary values satisfy $\Pi_d^0 < \tilde{\Pi} < \Pi_m$. The intuition for this result is that the Nash equilibrium in our race features excessive investments. Overinvestment occurs when $z_2^N = 1$ and $z_2^P = 0$ and in addition, a cooperative investment choice of firms in the regime without property rights would feature $z = 0$; this is precisely the case for $\Pi \in \left(\Pi_d^0, \tilde{\Pi}\right)$.

Proposition 1 has two implications. From a positive perspective, it implies that licensing will not occur on equilibrium path if the inventor of the research tool has patent rights on the research tool. From a normative perspective, Proposition 1 says that the absence of property rights on the research tool implies a loss of value ex post, because too many firms enter the second phase of the race.

3.2 The ex ante incentive effect

We consider next the ex ante incentive effect. Given a negative ex post efficiency effect, we need to show that the ex ante incentive effect can be positive for the values of Π that satisfy our restrictions. That is we want to find values of r and $\Pi \in \left(\Pi_d^0, \tilde{\Pi}\right)$ such that

$$\frac{\lambda_1^N V_m - c_1^N}{r + 2\lambda_1^N} > \frac{\lambda_1^P V_m - c_1^P}{r + 2\lambda_1^P}. \tag{14}$$

The expression on the right-hand side of (14) is the ex ante value of a firm in the regime featuring property right protection for the research tool. Obviously, this value is computed using the true, symmetric equilibrium choice in this regime, z_1^P. The value on the left–hand side of (14) is a hypothetical value computed using the symmetric equilibrium choice z_1^N but still the continuation value V_m. Thus, the ex ante efficiency effect is positive if the firms in the property rights regime would prefer the equilibrium induced in the regime without property rights. Intuitively, we expect this to occur if $z_1^N < z_1^P$, that is when the property rights regime induces inefficiently high equilibrium investments.

We begin demonstrating that for small enough values of r and $\Pi \in \left(\Pi_d^0, \tilde{\Pi}\right)$, the first stage equilibrium choices in the no-property right regime are $z_1^N = 0$. Manipulating (3) for $z_{1j} = 0$ and $V_N^+ = V_N^- = V_d$, we find $z_1^N = 0$ is a Nash-equilibrium if

$$V_d \leq V_d^0 \equiv \frac{(r + 2\underline{\lambda})\,\overline{c} - \left(r + \underline{\lambda} + \overline{\lambda}\right)\underline{c}}{r\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{15}$$

Indeed, this equilibrium is unique if $z_1^N = 1$ is not a Nash-equilibrium (as this also implies that there is no mixed strategy equilibrium and no asymmetric equilibrium in pure strategies); $z_1^N = 1$ is not a Nash-equilibrium if

$$V_d \leq V_d^1 \equiv \frac{\left(r + \underline{\lambda} + \overline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}}{r\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{16}$$

It is easy to see that $V_d^0 < V_d^1$. Hence, it suffices to check whether the inequality is satisfied at the highest possible value of V_d that is consistent with Proposition 1. Indeed using (13) and (15) , one can verify that $V_d = \frac{\overline{\lambda}\tilde{\Pi} - \overline{c}}{r + 2\overline{\lambda}} \leq V_d^0$.

Consider now the first stage equilibrium choices in the regime featuring patent rights for research tools. We obtain the firms' objective functions by substituting $V_P^+ = V_m$ and $V_P^- = 0$ into (3) .

We observe that the structure of the firm's problem is identical to (11) with Π replaced by V_m. Hence, the structure of the equilibrium set is the same as well. We state without further proof that unique equilibrium is $z_1^P = 1$ for $V_m > V_m^0$ where

$$V_m^0 \equiv \frac{(r + 2\underline{\lambda})\,\overline{c} - \left(r + \underline{\lambda} + \overline{\lambda}\right)\underline{c}}{(r + \underline{\lambda})\left(\overline{\lambda} - \underline{\lambda}\right)}.$$

For consistency we have to ensure that there are values of Π such that at the same time $V_m = \frac{\underline{\lambda}\Pi - \underline{c}}{r + \underline{\lambda}} > V_m^0$, which puts a lower bound on Π, and $\Pi < \tilde{\Pi}$, for consistency with Proposition 1. $V_m = \frac{\underline{\lambda}\Pi - \underline{c}}{r + \underline{\lambda}} > V_m^0$ is equivalent to $\Pi > \Pi^*$, where

$$\Pi^* \equiv \frac{(r + 2\underline{\lambda})\left(\overline{c} - \underline{c}\right)}{\underline{\lambda}\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{17}$$

And indeed for small enough values of r, we have $\Pi^* < \tilde{\Pi}$.

Proposition 2 *For r sufficiently small, there is a non-empty interval $\left(\Pi^*, \tilde{\Pi}\right)$ such that for $\Pi \in \left(\Pi^*, \tilde{\Pi}\right)$, the ex ante incentive effect is positive.*

The intuition for the result is straightforward. Firms in the regime with property rights protection play an equilibrium with high investments into innovations. But, as we show in detail in the proof of the proposition, this corresponds to overinvestment for the values of the innovation we focus on. Hence, firms have (collectively) a preference for the action profile $z_1 = 0$, but this is not a Nash-equilibrium. Economically, Proposition 2 states that property rights for the research tool create too much incentives for research in the first phase of the race.

3.3 Comparison of Regimes

We can now substitute for all equilibrium values in (8) to prove the following Proposition:

Proposition 3 *For small enough values of r and $\Pi \in \left(\Pi^*, \tilde{\Pi}\right)$, firms prefer to have no patent protection for research tools.*

Property rights on research tools induce wasteful overinvestment into finding the research tool. On the other hand, the absence of property rights induces an inefficient race structure in the second phase of the race. However, the former effect outweighs the latter, so firms have a preference to share research results obtained during the first phase of the innovation.

4 Extensions and Discussion

4.1 Welfare

It is easy to incorporate welfare considerations into our analysis. Since the final innovation is protected by a patent in both regimes, market prices for consumers are the same in both regimes. Hence, what matters to them is only how fast the final innovation is found. In the regime without patent protection, the expected length of the first phase of the race is $\frac{1}{2\underline{\lambda}}$ as firms free ride on the other firm's effort to find the research tool. The expected length of the second phase is $\frac{1}{2\bar{\lambda}}$ as firms invest inefficiently high amounts into research for the final innovation. In contrast, in the regime with patent protection, the expected length of the first phase is $\frac{1}{2\bar{\lambda}}$, while the expected length of the second phase is $\frac{1}{\underline{\lambda}}$. Adding the expected length of the entire two step innovation, shows that the final innovation is found faster when there are no property rights on the research tool. We state this result in the following Proposition:

Proposition 4 *For small enough values of r and $\Pi \in \left(\Pi^{*}, \tilde{\Pi}\right)$, consumers are better off without patent protection for research tools.*

4.2 Ex Post Licensing

We have chosen parameters the way that licensing does not occur on equilibrium path. Clearly this captures only a subset of cases of interest. However, it clearly captures the example of Myriad Genetics we started out with. Moreover, we merely want to demonstrate that firms *may* prefer to have no property rights on research tools. Hence, we can just as well restrict attention to the case where no ex post licensing occurs, given that it is analytically convenient to do so. However, one may still wonder how our analysis is affected by this restriction. Allowing for ex post licensing to occur - that is to analyze our game for a different set of parameters - makes the effects we discussed less pronounced, but conceptually the analysis remains valid. Interestingly, the trade-off can be reversed. That is, the sign of the ex ante and ex post effect may be reversed. In cases where this reversal occurs, patent protection for research tools is optimal.[6]

[6] Discussing all cases results in a rather tedious case distinction, which we have done, but chose to not expose here. The interested reader can obtain results from the authors upon request.

4.3 Discussion

We have shown that a weakening of patent protection for research tools may enhance welfare. This is in contrast to the common wisdom that patent protection is welfare enhancing because it generates positive incentives to engage in research in the first place. Our findings are in agreement with those of other recent studies that also emphasize the benefits of weak intellectual property rights, notably Denicolò (2000), Anton and Yao (2008), and Bessen and Maskin (2008). These results seem surprising from the viewpoint of the property rights and incomplete contracting literature (Grossman and Hart (1986)), where property rights are used to increase ex ante investment incentives that are generally suboptimally low. In contrast, no property rights are preferable in our context, precisely because firms are induced to waste less resources this way.

We do not view our results as supportive of a major redesign of current patent policies. First, because there are parameter values in our model where the regime with patent protection is preferable. Second, even if patent protection is in place and enforced, firms can find ways to contract around it. In particular, firms can and do sign in practice ex ante licensing agreements. E.g., Anand and Khanna (2000) find that in the chemicals industry 23% of licensing contracts are signed before the development of the technology. In general, we expect ex ante licensing agreements to work well if the set of potential users is known ex ante and reasonably small. However, for research tools that are likely to be used widely, our results shed doubts on the optimality of patent protection.

5 Appendix

Proof of proposition 1. Substituting for the equilibrium choices, we have

$$2V_d - V_m = 2\frac{\overline{\lambda}\Pi - \overline{c}}{r + 2\overline{\lambda}} - \frac{\underline{\lambda}\Pi - \underline{c}}{r + \underline{\lambda}}.$$

We observe that $2V_d - V_m < 0$ if and only if $\Pi < \tilde{\Pi}$, where $\tilde{\Pi}$ is defined in (13).

For consistency with our equilibrium construction, we also require $\Pi > \Pi_d^0$, as defined in (12). These restrictions define a non-empty set only if $\tilde{\Pi} > \Pi_d^0$, that is, if

$$\frac{\overline{c}\left(2r + 2\underline{\lambda}\right) - \left(r + 2\overline{\lambda}\right)\underline{c}}{r\overline{\lambda} + r\left(\overline{\lambda} - \underline{\lambda}\right)} > \frac{\left(r + 2\underline{\lambda}\right)\overline{c} - \left(r + \underline{\lambda} + \overline{\lambda}\right)\underline{c}}{\left(r + \underline{\lambda}\right)\left(\overline{\lambda} - \underline{\lambda}\right)}.$$

This is equivalent to

$$\left(\overline{\lambda}\underline{c} - \underline{\lambda}\overline{c}\right)\left(r^2 + 2r\underline{\lambda} - 2\underline{\lambda}\overline{\lambda} + 2\underline{\lambda}^2\right) > 0,$$

which is satisfied for $r < \tilde{r}$, where $\tilde{r}$ is the non negative solution to $\tilde{r}^2 + 2\underline{\lambda}\tilde{r} - 2\underline{\lambda}\overline{\lambda} + 2\underline{\lambda}^2 = 0$. ■

Proof of Proposition 2. We show that our conditions are met by a non-empty set of values Π. Comparing the values $\Pi_d^0 \equiv \frac{(r+2\underline{\lambda})\overline{c} - (r+\underline{\lambda}+\overline{\lambda})\underline{c}}{(r+\underline{\lambda})(\overline{\lambda}-\underline{\lambda})}$ and $\Pi^* = \frac{(r+2\underline{\lambda})(\overline{c}-\underline{c})}{\underline{\lambda}(\overline{\lambda}-\underline{\lambda})}$, it is easy to see that $\Pi^* > \Pi_d^0$. We next show that $\tilde{\Pi} > \Pi^*$ for r sufficiently small. Indeed,

$$\Pi^* = \frac{\left(r + 2\underline{\lambda}\right)\left(\overline{c} - \underline{c}\right)}{\underline{\lambda}\left(\overline{\lambda} - \underline{\lambda}\right)} < \frac{\left(2r + 2\underline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}}{r\overline{\lambda} + r\left(\overline{\lambda} - \underline{\lambda}\right)} = \tilde{\Pi}$$

if and only if $r < r^*$, where r^* is defined as the nonnegative solution to

$$r^2 + \frac{\left[2\overline{\lambda}\underline{\lambda}\left(\overline{c} - \underline{c}\right) - \underline{\lambda}\underline{c}\left(\overline{\lambda} - \underline{\lambda}\right)\right]}{\left(\overline{c} - \underline{c}\right)\left(2\overline{\lambda} - \underline{\lambda}\right)} r - \frac{\left(\overline{\lambda} - \underline{\lambda}\right)\left(\underline{\lambda}\overline{c} - \overline{\lambda}\underline{c}\right)2\underline{\lambda}}{\left(\overline{c} - \underline{c}\right)\left(2\overline{\lambda} - \underline{\lambda}\right)} = 0.$$

We can now verify that inequality (14) is true by construction. Substituting for $z_1^N = 0$, $z_1^P = 1$, and $V_m = \frac{\underline{\lambda}\Pi - \underline{c}}{r + \underline{\lambda}}$, (14) becomes

$$\frac{\underline{\lambda}\left(\frac{\underline{\lambda}\Pi - \underline{c}}{r+\underline{\lambda}}\right) - \underline{c}}{r + 2\underline{\lambda}} - \frac{\overline{\lambda}\left(\frac{\underline{\lambda}\Pi - \underline{c}}{r+\underline{\lambda}}\right) - \overline{c}}{r + 2\overline{\lambda}} > 0,$$

which is equivalent to $\Pi < \Pi^{**}$, where

$$\Pi^{**} \equiv \frac{\left(r + 2\underline{\lambda}\right)\left[\left(r + \overline{\lambda} + \underline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}\right]}{r\underline{\lambda}\left(\overline{\lambda} - \underline{\lambda}\right)}. \tag{18}$$

To complete the proof, we show that $\Pi^{**} > \tilde{\Pi}$. Recall that $\Pi_m > \tilde{\Pi}$, where Π_m is defined in (10). Hence, it suffices to show that $\Pi^{**} > \Pi_m$. Substituting from (10) and (18), we find $\Pi^{**} > \Pi_m$ iff

$$\left(r + 2\underline{\lambda}\right)\left[\left(r + \overline{\lambda} + \underline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}\right] > \underline{\lambda}\left[\left(r + \underline{\lambda}\right)\overline{c} - \left(r + \overline{\lambda}\right)\underline{c}\right].$$

Since $\left(r + 2\underline{\lambda}\right) > \underline{\lambda}$ and $\left[\left(r + \overline{\lambda} + \underline{\lambda}\right)\overline{c} - \left(r + 2\overline{\lambda}\right)\underline{c}\right] > \left(r + \underline{\lambda}\right)\overline{c} - \left(r + \overline{\lambda}\right)\underline{c}$ by the fact that $\underline{\lambda}\overline{c} - \overline{\lambda}\underline{c} > 0$, this condition is indeed met. ■

Proof or proposition 3. Substituting for the equilibrium choices we have for $\Pi \in \left(\Pi^*, \tilde{\Pi}\right)$

$$W_N - W_P = \frac{2\underline{\lambda}\left[\frac{\overline{\lambda}\Pi - \overline{c}}{r+2\overline{\lambda}}\right] - \underline{c}}{r + 2\underline{\lambda}} - \frac{\overline{\lambda}\left[\frac{\underline{\lambda}\Pi - \underline{c}}{r+\underline{\lambda}}\right] - \overline{c}}{r + 2\overline{\lambda}}.$$

We observe that $W_N - W_P > 0$ if and only if $\Pi > \hat{\Pi}$, where

$$\hat{\Pi} \equiv \frac{\overline{\lambda}\underline{c} - (r + \underline{\lambda})(\overline{c} - \underline{c})}{\underline{\lambda}\overline{\lambda}}. \tag{19}$$

To complete the proof, it suffices to show that

$$\hat{\Pi} = \frac{\overline{\lambda}\underline{c} - (r + \underline{\lambda})(\overline{c} - \underline{c})}{\underline{\lambda}\overline{\lambda}} < \frac{(r + 2\underline{\lambda})(\overline{c} - \underline{c})}{\underline{\lambda}\left(\overline{\lambda} - \underline{\lambda}\right)} = \Pi^*. \tag{20}$$

Using the fact that $\underline{\lambda}\overline{c} - \overline{\lambda}\underline{c} > 0$, it is easy to show that condition (20) is indeed met. ■

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