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Vincenzo Denicolòyand Luigi A. Franzoni
Indira Gandhi Institute of Development Research (IGIDR)
General Arun Kumar Vaidya Marg
Goregaon (E), Mumbai- 400065, INDIA
Email (corresponding author):

Abstract

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JEL Code:

O34 (Intellectual Property Rights), K21 (Antitrust Law)

Acknowledgements:

Rewarding innovation efficiently: research spill-overs and exclusive IP rights*

Vincenzo Denicolò[†] and Luigi A. Franzoni[‡]

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ABSTRACT: We investigate the conditions for the desirability of exclusive intellectual property rights for innovators, as opposed to weak rights allowing for some degree of imitation and ex-post competition. The comparison between the two alternatives reduces to a specific "ratio test," which suggests that strong, exclusive IP rights are preferable when competition from potential imitators is weak, the innovation attracts large R&D investments, and research spill-overs are small.

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[†]University of Bologna, Italy, and University of Leicester, U.K.

[‡]University of Bologna, Italy. Corresponding author: luigi.franzoni@unibo.it

1 Introduction

For manufacturing products, intellectual property law has traditionally focussed on two polar types of protection: patents and trade secrets. Patents guarantee a strong form of protection, since they grant an exclusive - though temporary - right to the use of patented technology. Trade secret law, by contrast, provides weaker, non-exclusive protection in that it precludes misappropriation of knowledge and know-how (as by espionage or breach of confidentiality duties), but not duplication through reverse engineering or parallel development.[1] Other forms of IP protection lie somewhere in between these two extremes and borrow elements from each of them.[2]

Which form of protection should be accorded to innovators is a crucial policy issue. Where strong exclusive protection of IPRs is ostensibly intended to ensure a large reward for the innovator, weak protection aims to foster imitation and competition. Policy, then, must solve a difficult trade-off between incentives for innovation and the need to encourage diffusion.

The main policy tools that determine the degree of exclusivity are the "patentability requirements": any piece of innovative technological knowledge that fails to meet these requirements cannot be patented and hence can only receive weaker forms of protection, like trade secrecy or copyright. But even the degree of exclusivity guaranteed by patents depends on certain policy choices. The possibility of lawful imitation, and hence the boundaries of the patent holder's exclusive rights, depends on the breadth of the patent

[1] In the words of the Restatement of Unfair Competition, § 43: "[T]he owner of a trade secret does not have an exclusive right to possession or use of the secret information. Protection is available only against a wrongful acquisition, use or disclosure of the trade secret." As a result, if competitors want to gain access to the innovation, they have to discover it at their own expense. They will imitate only if the profit of doing so outweigh the costs: "Where patent law acts as a barrier, trade secret law functions relatively as a sieve" (the Supreme Court in *Kewanee Oil*). From this perspective, trade secrets are not protected by means of a "property rule," but rather by a "quasi-liability rule," which allows for unwanted taking upon payment of duplication costs (Reichman 1994).

[2] Copyright law, for instance, allows for parallel development but is wary of reverse engineering (circumvention of digital locks).

claims. Antitrust policy may also play a role by setting restrictions on licensing practices, settlement agreements and non-disclosure policy. The refusal to license proprietary technology, for instance, has been judged anticompetitive in a few cases (e.g. in Kodak II, 125 F.3d 1195, 1997 and in several European cases, most notably Microsoft). Thus, our analysis may also apply to various scenarios in which anti-trust concerns and property rights might conflict, as discussed in greater detail in section 5.

In this paper, we offer some insights into the basic factors that should guide the choice between strong and weak protection. Building on our previous work (Denicolò and Franzoni 2010), we develop a ratio test that measures the "social cost" of the incentives provided by the different specifications of IP rights. We take the level of innovation incentives as given and investigate which type of protection provides those incentives at the lowest social cost. This approach, originally developed by Kaplow (1984), allows us to sidestep the complex issue of determining the optimal level of protection.

The test we develop balances costs and benefits of exclusive protection in a simple way. As in Kaplow (1984), the cost of IP protection is the deadweight loss resulting from the lack of competition, and the benefit is the incentive to innovate.[3] Unlike Kaplow, however, we posit that a number of firms may race for the innovation. And unlike our previous work, here we allow for the presence of R&D spill-overs. In this richer framework, we investigate the relationship between the structure of IP rights, the nature of the innovation process, and the incentives to innovate.

We argue that the incentives to innovate depend both on the first inventor's profits and on whatever reward is obtained by the losers of the innovation race (which under weak IPRs may still duplicate the innovation

[3] Kaplow (1984) develops his test to assess the impact of patentees' restrictive practices. He cautions, however, that "Factors aiding in the application of this test to specific practices include the extent to which the reward is pure transfer, the portion of the reward that accrues to the patentee, and the degree to which the reward serves as an incentive." We are in fact exploring the latter points. Kaplow does not use his test to compare monopoly and duopoly. For an illustration of the applications of the Kaplow test in the economics of IP, see Scotchmer (2004), ch.4. A legally oriented introduction is provided by Carrier (2002).

and compete on the market, thereby earning positive profits). The way the presence of a second prize affects the incentives to innovate depends on the magnitude of R&D spill-overs. If there are no spill-overs, as in our previous paper, the second prize simply dilutes the incentive to innovate, since it provides a reward for failure. In the presence of spill-overs, however, the second prize may enhance the incentive to innovate. The intuitive reason is that spill-overs turn the innovation race into a more co-operative game, where firms are more interested in bringing forward the date of discovery (regardless of who makes it), than in preempting the rival in the priority race. In this case, the incentives provided by "winner-take-all" are limited, given the imperfect ability of the firms to reverse the finish order. Non-exclusive IP rights, providing prizes also to firms that are not the first to discover, are likely to be preferable.

In practice, a good many factors impact the magnitude of R&D spill-overs within different industries, including industry practice with respect to job mobility of researchers and technical personnel (with their inside information), formal or informal communication between researchers, and technical espionage. R&D spill-overs tend to be more prevalent in institutional step-ups that allow for substantial exchanges of pre-discovery information.

In her pioneering contribution, Saxenian (1994) compares two emblematic districts: Route 128 outside Boston and Silicon Valley in California. Route 128 is dominated by low worker mobility and linear career paths. Know-how tends to be well protected and district spill-overs are small. Silicon Valley is marked by high mobility of workers between firms and a strong bias against vertical integration. Post-employment covenants not to compete are generally not enforced (Gilson 1999). Spill-overs are notoriously large.

More generally, in industries where knowledge flows rapidly between firms, as in the Silicon Valley, innovation can be seen as the outcome of cumulative efforts: each firm contributes a bit to the final result, which can therefore be referred to as a "collective invention" (Allen 1983).[4] Typ-

[4] Von Hippel and von Krogh (2006) and Meyer (2003) provide good overviews of the topic and mention several historical cases.

ical examples are the software industry (Osterloh and Rota 2007) and the semiconductor industry (Hall and Ziedonis 2001). From this viewpoint, our results suggest that strong IP rights are appropriate in Route 128 but not in Silicon Valley, in the pharmaceutical sector but not in the software and semiconductor industries.

Our research complements a recent body of literature that advocates weak IP rights for sectors where several firms come up with the same innovation.[5] One of the main issues investigated by this literature is what rights the first patentee should have with respect to other inventors. Stephen Maurer and Suzanne Scotchmer (2002) and Carl Shapiro (2006), in particular, have argued that late innovators who make the same discovery by parallel development should be granted a defense to infringement (the "independent invention defense").[6] Although this literature deals specifically with the rights of patent holders, its insights have a more general bearing. They suggest that exclusive rights may be an inefficient system for rewarding innovation, especially where multiple parties are likely to make the same discovery. Shapiro (2008) argues that this is particularly true of the IT and biotechnology sectors, where the underlying knowledge base in the public domain is expanding so rapidly that many incremental improvements are "in the air" (Shapiro 2008).[7]

Our contribution to this literature is to emphasize the role of R&D spillovers. In our model, the key factor is the degree of rivalry in the innovation race, not the mere fact that several firms may come up with the same innovation. In this sense, our position is more cautious: a move to weak IP rights may be desirable only in special industries.

[5] See, among others, La Manna et alt. (1989), Farrell (1995), Ayres and Klemperer (1999), Leibovitz (2002), Kultti, Toikka, and Takalo (2007), Shapiro (2006) and (2008), Bessen and Maskin (2009), Henry (2010).

[6] These proposals has prompted an interesting debate. See, among others, Blair and Cotter (2001), Vermont (2006) and (2007), and Lemley (2007).

[7] Vermont (2006) further emphasises that an innovator who is able to get to the discovery shortly before his rivals adds little to social welfare, and should thus be denied a full-term patent.

2 The Ratio Test

Let us compare strong protection (patent) to weak protection (trade secrecy). In Figure 1 and 2, Firm 1 discovers a new product and Firm 2, possibly, replicates it.

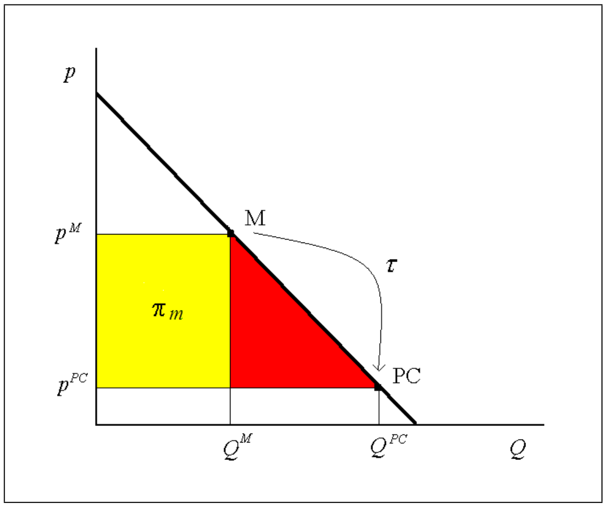

Fig. 1. Patent

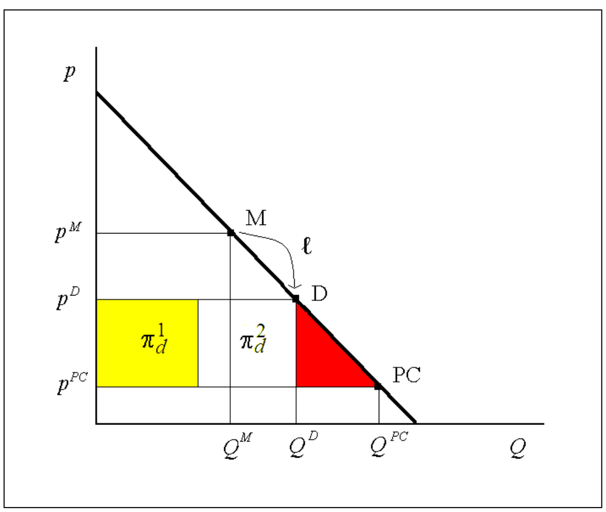

Fig. 2. Trade secret

If the innovation is protected by a patent (Fig. 1), Firm 1 enjoys monopoly power until it expires. At that time, thanks to disclosure, perfect competition prevails. During the life of the patent (of duration τ), the innovator earns monopoly profits π_m and society bears the deadweight loss Δ_m (shaded area).

If the innovation is protected only by trade secrecy (Fig. 2), the innovator enjoys monopoly profits for a lead time of expected duration ℓ, and duopoly profits π_d^1 form the time of duplication onwards. For simplicity, we assume that duopoly lasts forever. After the initial lead-time period, the presence of the competitor entails lower prices and greater output. Here, the reward to the innovator has two components: lead-time profit, with the same social cost as the patent, and duopoly profit, which a smaller deadweight loss Δ_d (the shaded area in Fig. 2). The total profit of the innovator under weak protection depends on the lead time and the duration of duopoly. In general, it may be greater or lower than under strong protection, and no direct comparison between the two regimes can be made.

For more general insight, we should look at the problem from a broader perspective and assume that the policy-maker controls also the duration of the patent. The comparison can then be carried out on a pair-wise basis: take the level of innovation provided by weak property rights as given (it can vary across industries), and ask what patent length would provide exactly the same incentive to innovate. At that point, one can compare the deadweight loss of the two outcomes and determine the most efficient solution. Because patents provide the pre-specified reward faster than trade secrecy, under patents the pain (deadweight loss) is sharper but briefer.

In this simple example with one innovator and one duplicator, that exercise yields a clear-cut solution. Initially, before the innovation is duplicated, both regimes generate a monopoly, yielding the same profit and the same deadweight loss. The comparison therefore hinges on the subsequent period (duopoly vs monopoly), for the relevant time span (until expiry under patents, forever under trade secrecy).[8] So let us compare the two regimes from the time when the innovation is duplicated.

[8] One can easily allow for a finite duration of the duopoly period as well. Trade secrecy

Let h be the discounted value of a stream of 1 dollar from now to infinity, and let e be the discounted value of a stream of 1 dollar from now until date E (expiry of patent), with: $e \leq h$. Then, in order to have the same amount of profit for the innovator in the two regimes, we must have: $e\, \pi_m = h\, \pi_d$, that is $e = h\, \pi_d / \pi_m$.

Patents entail a lower social cost than trade secrecy if the discounted flow of monopoly deadweight loss for E years is less than the discounted flow of duopoly deadweight loss forever: $e\, \Delta_m < h\, \Delta_d$. Using the definition of e, we get:

$$\text{BASIC RATIO TEST:} \qquad \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d}. \tag{1}$$

Strong IPRs are therefore preferable if the deadweight loss per unit of monopoly profit is less than the deadweight loss per unit of duopoly profit.

Depending on the nature of duopoly competition, inequality (1) may or may not be satisfied. Intuitively, there are two relevant factors. On the one hand, duopoly tends to produce a substantially lower deadweight loss per unit of *industry* profits than monopoly because of the Ramsey effect (as price increases, deadweight loss increases at a faster rate than profits). At the limit, if the duopoly price is very low, Δ_d / π_d converges to zero, and inequality (1) cannot be satisfied. On the other hand, under duopoly only half of industry profits are captured by the innovator; and the part captured by the duplicator does not contribute to the incentive to innovate. This factor works against weak IPRs.

The second effect dominates and inequality (1) is satisfied when the duopoly price is relatively high. With a linear demand function, for instance, strong IP rights are preferable if duopoly price is not less than the Cournot equilibrium price.

To complete the picture, consider that both duplication and the effort to prevent duplication consume resources. This implies that under weak IPRs,

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protection may terminate, for instance, because the secret leaks out, or because it becomes technologically obsolete. These possibilities would not alter the analysis significantly.

the actual deadweight loss is somewhat greater than that depicted in the diagram, and lead-time profit somewhat less. These effect tilt the balance against weak IPRs.[9]

The case where only one firm can obtain the innovation is simple, since incentive to innovate can be equated with the innovator's expected profit. In most circumstances, however, innovations can be achieved by different firms, which race to be first. In this case, the incentive depends not only on the prize to the winner but also on the prize to the loser.

In the model developed below, the prize to the loser decreases the incentive to innovate if the innovation race has no spill-overs. The magnitude of this adverse impact increases with the intensity of the race: if the rival is spending substantial resources and is likely to make the discovery soon, then the availability of a second prize is likely to provide a strong incentive to wait (that is, not invest).

However, when research does entail spill-overs, in the sense that an increase in research at one firms positively affects the other's chance of discovery, then firms care more about the total reward at the industry level than its division among first and second discoverer. Here, an increase in the second prize may have a *positive* impact on the incentive to innovate: the adverse priority effect (reduced incentive to preempt the rival in the race) is outweighed by the direct positive effect (by investing in research, a firm increases its chances of getting the second prize).

To formally identify these effects, we now sketch a simple dynamic model of innovation.

3 Rewarding rivalry

Let us begin from the case where firms conduct their research in isolation (no R&D spillovers). Discovery follows a Poisson process.[10] The probability

[9] Wasteful duplication under weak IPRs is the focus of the papers of Gallini (1992) and Denicolò and Franzoni (2008).

[10] Memoryless Poisson processes are commonly employed in innovation theory because they have a very simple dynamic path: in each time interval, the equilibrium probability

of Firm 1 making the discovery in a small period of time Δt (conditional on no previous success) is $x_1 \Delta t$, that of the discovery being made by Firm 2 is $x_2 \Delta t$. Let P_W be the reward for the winner of the race, and P_L the reward for the loser at the time of first discovery. P_L is zero under a system of full exclusivity, while under a system of weak IP rights it equals the net expected profit from successful duplication.

Under these assumptions, it can be shown that Firm 1's expected payoff from the race is

$$V_1(x_1) = \frac{x_1 P_W + x_2 \ P_L - c(x_1)}{x_1 + x_2 + r},$$

where $c(x_1)$ represents the cost of carrying out research with intensity x_1 and r is the interest rate. A similar expression holds for Firm 2.

In order to maximize its payoff, Firm 1 will set x_1 so as to equate the marginal benefits and costs of research:

$$\underbrace{\frac{P_W \ r}{(x_1 + x_2 + r)^2}}_{\text{earlier discovery}} + \underbrace{\frac{x_2 (P_W - P_L)}{(x_1 + x_2 + r)^2}}_{\text{priority effect}} = \underbrace{\frac{c'(x_1)(x_1 + x_2 + r) - c(x_1)}{(x_1 + x_2 + r)^2}}_{\text{marginal costs}} \qquad (2)$$

The marginal benefit includes two terms: the "earlier discovery effect," which captures the fact that an increase in research effort allows the firm to get to the first prize earlier, and the "priority effect," which represents the gain of preempting Firm 2. This term is proportional to $(P_W - P_L)$, since discovery by Firm 2 (which occurs with instantaneous probability x_2) would deprive Firm 1 of the difference between the first and the second prize.[11] The marginal cost term accounts both for the increase in expected research costs per period and for the reduction in costs due to earlier termination of the race.[12]

The priority effect is at the center of our analysis. Its magnitude increases with the degree of *rivalry* in the innovation race: each firm has a greater

of discovery remains the same.

[11] In the industrial organization literature these effects are called the "profit incentive" and the "competitive threat." See Beath, Katsoulacos, and Ulph (1989) and Denicolò and Franzoni (2010).

[12] Eq. (2) can also be written as $P_W - V_1(x_1) = c'(x_1)$: in each moment, the capital gain from discovery should equal the marginal cost of research (Mortensen 1982).

incentive to preempt the other when it believes that the rival is more likely to make the discovery. This effect is the outcome of a common pool problem in innovation races: the opportunities to discover are finite and firms vie for them. By making a discovery, a firm ends the race and deprives the other of the chance to claim priority.[13]

From eq. (2) one can easily see that the second prize P_L diminishes the incentive to innovate, by reducing the priority effect. If we compute the *relative* disincentive power of P_L, we get

$$\left.\frac{\partial P_W}{\partial P_L}\right|_{x_1 \text{ cost}} = \frac{\frac{\partial x_1}{\partial P_L}}{\frac{\partial x_1}{\partial P_W}} = -\frac{x_2}{x_2 + r} = -\,\delta\,(x)\,.$$

This expression tells us that in terms of the incentive to innovate: *a 1-dollar increase in the reward to the loser of the race is equivalent to a* $\delta\,(x)$*-dollar reduction in the reward to the winner (with* $0 \leq \delta\,(x) < 1$).

This is the key information for our reformulation of the basic ratio test. Using a procedure analogous to that of Section 2, in the appendix we show that strong IPRs are socially preferable if

$$\text{Modified Ratio Test:} \qquad \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d\ [1 - \delta\,(x)]} \tag{3}$$

To interpret this formula, recollect that any ratio test compares the social cost of protection "per unit of incentive" to innovate. The social costs are the deadweight losses, as discussed above. The denominator of the ratios is the incentive to innovate. In our Modified test, this takes into account both the reward to the winner and to the loser of the race. For strong IP rights, there is no reward for the loser. Hence, the incentive to innovate is proportional to monopoly profit. For weak IP rights (after the initial lead time has elapsed and the monopoly ends), the incentive to innovate is

[13] The "common pool" problem was first studied by Gordon (1954). See Luek and Miceli (2007) for an interesting account of the relationship between common pool discovery and rules of first possession.

proportional to the duopoly profit of the innovator *suitably deflated by the consolation prize.* The deflation factor is $[1 - \delta(x)]$.

This modified ratio test accounts for the degree of rivalry in the innovation race. If there is no rivalry ($\delta(x) \to 0$), than all that matters is the ratio between deadweight loss and individual profit (as in eq. 1). If the race is more sharply contested, so that firms care about preempting their rivals, then the Modified test is easier to pass than the Basic test. That is, short-lived exclusive rights - with no consolation prize to the loser - provide the same incentives to innovate as a long-lasting duopoly at lower social cost.

Note that the variable $\delta(x) = \frac{x_2}{x_2+r}$ can be interpreted as the rival's "discounting-adjusted probability" of success in the innovation race.[14] If rivals are likely to discover early, then the race is very intense and the presence/absence of a second prize matters greatly, since the risk of losing priority is high. If rivals are likely to discover late - or possibly never, for $\delta(x) \to 0$ - firms will care more about bringing the date of discovery forward than about preempting rivals.

The discounting-adjusted probability of discovery is large, and hence innovation is more competitive, when the race attracts a lot of investments and the interest rate is high.

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How can we get a sense of the magnitude of the deflation factor $[1 - \delta(x)]$?

Let us set the interest rate at 5%. Note that $1/x$ is the expected time until discovery by the rivals (not discounted).

If the expected time to rivals' discovery is 2 years (so that $x = 0.5$), then $1 - \delta(x) = 1 - \frac{0.5}{0.5+0.05} = 0.10$.

If the expected time to rivals' discovery is 5 years (so that $x = 0.2$), then $1 - \delta(x) = 1 - \frac{0.2}{0.2+0.05} = 0.20$.

[14] Technically: $\delta(x) = \int_0^\infty e^{-rt}\ x\ e^{-t\ x}\ x\ dt$, where x is the instantaneous probability of discovery of the rivals (one or many) and e^{-rx} the probability that they have not yet discovered by time t. Thus, $\delta(x)$ is the expected discounted value of a dollar that can arrive with the same probability x at any moment from now to infinity.

If the expected time of discovery of the rivals is 10 years (so that $x = 0.1$), then $1 - \delta(x) = 1 - \frac{0.1}{0.1+0.05} = 0.33$.

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In view of equation (3), we concluded in Denicolò and Franzoni (2010) that weak IP rights are unlikely to be optimal when research does not entail spill-overs. They provide a second prize to the loser and tend to have a strong adverse effect on the incentive to innovate. This applies in particular to industries in which R&D attracts substantial investment and product market competition is not very strong.[15] However, in the next section we show that this conclusion may be reversed when R&D spillovers are large.

4 Innovation without rivalry

In many industries, the research done by each firm spills over to the others, allowing them to increase their probability of success. We capture these research spill-overs by assuming that the probability of discovery of each firm depends positively not only on its own research effort but also on that of the rival. More specifically, the instantaneous probability of Firm 1 making the discovery is now:

$$\lambda^1(x_1, x_2) = x_1 + \sigma x_2,$$

where the parameter $\sigma \in [0, 1)$ measures the magnitude of the spill-overs. Symmetrically, the probability of success of Firm 2 is equal to

$$\lambda^2(x_2, x_1) = x_2 + \sigma x_1.$$

Firm 1's expected profits are now

$$V_1(x_1) = \frac{\lambda^1(x_1, x_2)\ P_W + \lambda^2(x_1, x_2)\ P_L - c(x_1)}{\lambda^1(x_1, x_2) + \lambda^2(x_1, x_2) + r}.$$

The optimal choice of x_1 must satisfy (omitting arguments):

[15] In Denicolò and Franzoni (2010) we also address the issues of differentiated innovations and competitive technology licensing. Conversely, all the results reported in the Appendix of this paper are new.

$$\underbrace{\frac{(P_W+\sigma P_L)\, r}{\left(\lambda^1+\lambda^2+r\right)^2}}_{\text{earlier discovery}}+\underbrace{\frac{\left(\lambda^2-\sigma\lambda^1\right)(P_W-P_L)}{\left(\lambda^1+\lambda^2+r\right)^2}}_{\text{priority effect}}=\underbrace{\frac{c' \ \left(\lambda^1+\lambda^2+r\right)-c\ \left(\lambda_1^1+\lambda_1^2\right)}{\left(\lambda^1+\lambda^2+r\right)^2}}_{\text{marginal costs}}. \tag{4}$$

As before, an increase in the research effort of Firm 1 has two positive effects on its payoff: it brings forward the discovery, and it increases Firm 1's chances of preempting Firm 2.

Note that the priority effect is smaller when the spill-over is larger. When a firm's research affects the probability of discovery of the other, the ability of each firm to "reverse" the order of arrival of the race is weakened. In the extreme case in which the research effort of one firm affects the probability of discovery of both firms in the same way $(\sigma \to 1)$, the priority effect vanishes. Firms cannot affect priority at all, and each has a 50% chance of being the first to invent irrespective of how much it invests in R&D.

The relative disincentive effect of the second prize is now

$$\left.\frac{\partial P_W}{\partial P_L}\right|_{x_1 \text{ cost}}=\frac{\frac{\partial x_1}{\partial P_L}}{\frac{\partial x_1}{\partial P_W}}=-\frac{\lambda^2-\sigma\lambda^1-\sigma r}{\lambda^2-\sigma\lambda^1+r}, \tag{5}$$

which can also be written as (see appendix)

$$\left.\frac{\partial P_W}{\partial P_L}\right|_{x_1}=-\frac{\hat{\delta}\,(x)-\sigma}{1-\sigma\ \hat{\delta}\,(x)}=-\rho\,(x)\,,$$

where $\hat{\delta}\,(x)=\frac{\lambda(x_2)}{\lambda(x_2)+r}$ is the rival's discounted probability of innovation. *A 1-dollar increase in the reward to the loser of the priority race is equivalent to a reduction of* $\rho\,(x)$*-dollars in the winner's reward.*

When $\sigma=0$, we are back to the case of the previous section. As the spill-over gets larger, however, the innovation race becomes less competitive: an increase in the second prize is equivalent to a smaller reduction in the first prize. As σ ranges from 0 to 1, the rate of substitution between the second and the first prize $\rho\,(x)$ ranges from $\hat{\delta}\,(x)$ to -1. For σ sufficiently large, $\sigma > \hat{\delta}\,(x)$, the incentive to innovate is driven mostly by the earlier discovery effect, and the second prize has a *positive* impact on the incentives to innovate ($\rho(x) < 0$). In the exteme case of maximum spill-over, $\sigma \to 1$, the first and the second prize become perfect substitutes ($\rho(x) \to -1$): a 1-dollar increase in the second prize is equivalent to a 1-dollar increase in the first prize.

In the presence of spill-overs, the new ratio test is (substituting $\rho(x)$ for $\hat{\delta}(x)$ in ineq. 3):

$$\text{MODIFIED RATIO TEST:} \quad \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d \; [1 - \rho(x)]}, \tag{6}$$

where $\rho(x)$ is *positive* if the innovation process is competitive (i.e. $\sigma < \hat{\delta}(x)$), and *negative* if it is not (i.e. $\sigma > \hat{\delta}(x)$).

As the innovation race gets less competitive, the test is harder to pass (the social cost per unit of incentive under duopoly gets smaller). Figures 3 and 4 illustrate.

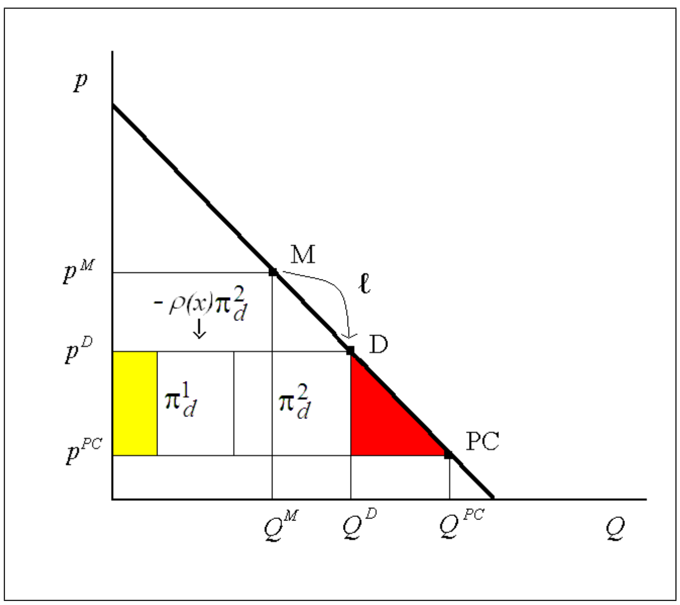

Fig. 3. Competitive innovation.

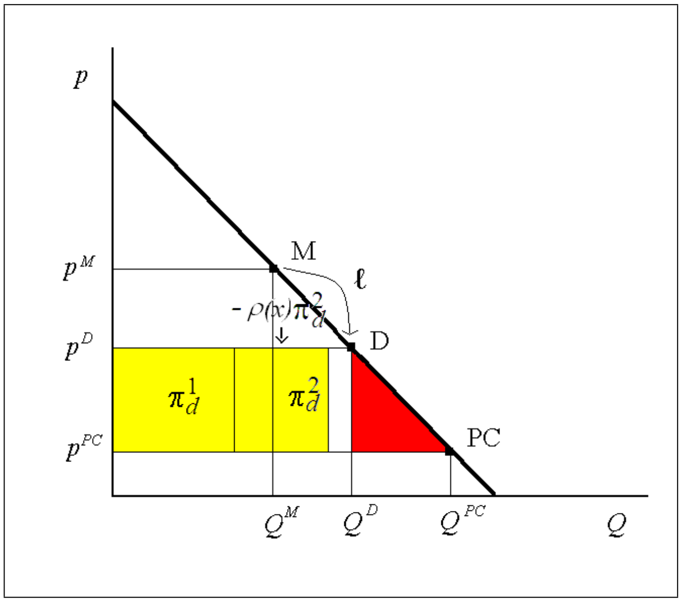

Fig. 4. Non-competitive innovation. The incentive to innovate is proportional to $\pi_d^1 - \rho(x)\,\pi_d^2$, where $\rho(x)$ is positive for competitive and negative for non-competitive innovations.

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Example. Let us consider a case where 25% of each firm's probability of discovery is due to spill-over: $\frac{\sigma x}{x+\sigma x} = \frac{\sigma}{1+\sigma} = 25\%$, so that $\sigma = 0.33\%$. The interest rate is 5%. If the expected time to rival's discovery is 5 years, we have $\hat{\delta}(x) = 0.80$ and $[1-\rho(x)] = 1 - \frac{0.80-0.33}{1-0.80 \text{ x } 0.33} = 0.36$.

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Note that if the spill-overs is maximal, $\sigma \to 1$, strong IPRs are preferable if

$$\frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{2\pi_d}, \tag{7}$$

which is the ratio test obtained by Shapiro (2006). Here, the incentive to innovate is proxied by industry profits. Remarkably, *the latter test is appropriate if firm's research has no impact on priority.*

From (6), we find that strong IP protection is preferable if

i) the competition arising from imitation is weak (large Δ_d/π_d);

ii) the innovation involved attracts large investment (large $\hat{\delta}(x)$);
iii) the spill-over is small.[16]

As a final caveat, we should recall that weak property rights entail an additional distortion. Let us look again at Figure 2. After a firm has made the discovery, the other tries and catches up. The costs to the pursuer partially dissipate the expected profits from successful duplication. These costs, which are sustained only under weak IPRs, have a two-sided impact. They increase the social costs of the weak IPRs regime,[17] but also reduce the second prize. Typically, duplication costs tend to favor strong IP rights, although in special circumstances they may increase the incentives to innovate, which tends to favor the weak IP regime (see Appendix 7.1).

5 Policy discussion

While we have presented our model in terms of a comparison between patents and trade secrets, the insights we have obtained are more general. In this section we discuss several other issues that have recently come to the forefront of the policy debate, and which pertain to the desirability of strong exclusive rights for innovators.

5.1 Patents and copyrights

A long debated issue is whether software should be protected by the patent or the copyright system. Our results are relevant to the issue of which

[16] The result on spill-over obtains when the level of the research incentive is given. With quadratic research costs, x depends negatively on σ. Thus an increase in σ would make weak IP protection preferable both because research is more cooperative, and because research intensity is smaller.

[17] Duffie (2007) notes: "Once an invention has been created — once a technical insight such as Bell's has been discovered — it is a waste of resources for others to continue working in an attempt to achieve that insight a second time. If independent invention were a defense, firms would have an incentive to wall off their researchers from the knowledge of new discoveries and to continue funding their researchers' attempts to discover independently what has already been discovered."

class of innovations, or industries, should have access to patent protection and which to copyright. Indeed, copyright is similar to trade secret in that independent duplication of copyrighted work does not generally constitute an infringement.[18] Copyright is said to protect expression rather than ideas, which should circulate freely. Reverse engineering of copyright material, however, is subject to specific restrictions. Decompilation or disassembly of object codes in order to develop interoperable software, for instance, is generally deemed legal (after Sega v Accolade, 977 F.2d 1510, 9th Cir. 1992). Under the Digital Millennium Copyright Act, however, circumvention of technical measures used to protect copyrighted works (so called "digital locks") is forbidden, as is the distribution of circumvention technologies.[19]

We contend that the large spill-overs characterising the software industry - open source software being paradigmatic - make it suitable for protection by means of non-exclusive rights. Research is also generally dispersed and not targeting big blockbuster innovations: the research process is thus better depicted as a cooperative enterprise than a competitive race.

5.2 The independent invention defense

It is not unusual for the same invention to be made virtually simultaneously by different parties. Classic examples include the telegraph (Morse and Alter), the light bulb (Edison and Swan), the telephone (Bell, Gray and Meucci), and the integrated circuit (Kilby and Noyce).

Simultaneous discoveries of this type put some strain on the patent system, which must determine who is the true first-inventor.[20] However, the

[18] There are, however, exceptions. For instance, if a song has been widely performed, inadvertent duplication of the melody constitutes an infringement of the original writer's copyright (see Landes and Posner 2003, p. 88).

[19] Our analysis does not treat the optimal degree of reverse engineering. On the protection of software and the economics of reverse engineering, see the insightful work of Samuelson and Scotchmer (2002).

[20] Evidence on nearly simultaneous innovations can be obtained from the cases where the priority of the innovation is disputed (interference cases). These are relatively rare, typically less than 3 out of 1000 patent applications per year (Mossinghoff, 2002 and Lemley and Chien, 2003), but highly instructive. Simultaneous discovery is shown to be

assumption that only the first inventor should be allowed to practice the innovation has been called into question by an influential body of literature, originating from the pioneering contribution of La Manna et al. (1989) and developed by Leibovitz (2002), Maurer and Scotchmer (2002), Kultti and Takalo (2008), Shapiro (2006, 2008), Vermont (2007 and 2008) and Henry (2010). These authors advocate “multiple patents”, or at least an “independent invention defense” that would allow the second inventor to practice the innovation - if only he can prove that he developed it independently.

The case for multiple patents strongly resembles that for trade secrecy (weak IP). Leaving aside the many practical problems of distinguishing genuinely independent inventors from mere imitators (see Lemley 2007), weak patents would differ from trade secrecy in the duration of the oligopolistic regime. Under secrecy, oligopoly ends when the secret somehow leaks out (possibly never); under weak patents, oligopoly terminates when the first inventor’s patent expires. In appendix 7.2, we show that our Modified test also applies to this particular set up.

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One point raised by the multiple patents literature is that, when the innovation race is tight and many firms independently pursue the same invention, the social marginal contribution of each is small.[21] The (private) incentive to invest in research, instead, can be large since it is amplified by the desire of each firm to preempt its rivals. From a social point of view, expenditures aimed only at "redistributing" the prize across contestants could be regarded as unproductive, and thus undesirable. Prima facie, weak IPRs seem preferable becasue, by providing multiple prizes to competing innovators, they deflate precisely this type of expenditures, aligning social and private benefits. However, this is not the whole story, since also the social costs have to be taken into account. Since profits entail a deadweight loss,

particularly concentrated in the chemical and pharmaceutical industries, where research is carried out in structured programmes and mainly directed towards precise technical, mostly demand-driven, targets - see Kingston (2004). Also, interference cases usually involve large corporations with substantial patent portfolios - Cohen and Ishii (2006).

[21] The marginal contribution to discovey is proportional to the "earlier discovery" term of eqs. 2 and 4.

they should be handed out parsimonously. On this account, strong IPRs are preferable, becasue they yield the largest effort with the least amount of expected profits (see Remark in the appendix).[22] From this perspective, the disalignement between private and social benefits turns out to be a blessing.

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5.3 Mandatory licensing

Under some circumstances, the right to exclude provided by patents and other strong IP rights may run counter to antitrust law. Take, for example, a firm holding monopolistic power that refuses to license its proprietary know-how to a competitor or to a downstream firm. This practice may fall under the scrutiny of anti-trust agencies, which will try to ascertain whether the firm is engaging in an anti-competitive exclusionary conduct. If the practice were deemed illegal, the scope of IP rights would clearly be reduced.

The stance on this issue taken by courts and antitrust authorities varies between countries and over time (see for instance Schweizer 2007). In the US there is a broad consensus - reinforced by the recent *Trinko* decision (540 U.S. 398, 2004) - that competition rules should not outweigh IP law.[23] In Europe, anti-trust authorities and courts follow a different approach that tends to be more restrictive of intellectual property rights. A refusal to licence an IPR by a dominant undertaking constitutes an abuse if certain "exceptional" conditions hold, specified by the European Court of Justice in the *Magill* case. The EU antitrust authorities seem to advocate a "balancing of interests," weighing the positive effect of competition against its adverse impacts on innovation case-by-case (DG Competition 2008).

Our analysis provides a basic, preliminary framework for assessing such practices that highlights the tension between competition and innovation. In the appendix, we extend our generalized ratio test to the case of compulsory

[22] Thus, if firms could choose the way in which incentives are provided, they would opt for tranquillity ("everybody wins").

[23] See, for instance, the recent report by the U.S. Department of Justice and the Federal Trade Commission (2007).

licensing. Assuming that patent duration can be appropriately fixed, we compare standard patens (strong IPR) and patents with mandatory licensing (weak IPR).

Let the royalty amount to a share f of the licensee's duopoly profits. Strong IPRs turn out to be preferable if

$$\text{RATIO TEST WITH LICENSING: } \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d \left[1 - \rho(x) + f \ \ (1 + \rho(x))\right]}. \quad (8)$$

Thanks to the license, the loser of the race is able to get a positive reward. Yet, the license also shifts some of the loser's profits to the first inventor. Incentive-wise, mandatory licensing is worse that a normal patent, but is better than trade secrecy (where no transfer of profits takes place).

The test is more easily passed if the royalty is small. If the royalty is symbolic ($f \to 0$), then the Modified ratio test applies. If the royalty captures all the profits of the licensee, then industry profits proxy the incentive to innovate and the test derived by Shapiro [eq. 7] applies.[24]

Again, it is worth emphasizing that the relative merits of the strong and weak rights turn on the magnitude of R&D spillovers: non-cooperative innovation calls for strong IPRs, co-operative innovation for weak. In industries where innovation is rapid and there is little research spill-over, it is generally not a good idea to use competition as a way of decreasing the reward to the innovator.

6 Conclusions

This paper contributes to the analysis of the optimal scope of intellectual protection. We show that, at least at first cut, the choice between strong and weak protection can be addressed by means of a simple ratio test.

Admittedly, our analysis abstracts from a number of important issues, such as administrative and enforcement costs, the effectiveness of patent disclosure, the impact of IPRs on cumulative innovation, and others. We

[24] This is also the test obtained by Maurer and Scotchmer (2002), on the assumption that the first inventor is able to fully extract the profits of potential duplicators.

are also aware that the practical implementation of the test requires a mass of information that courts and lawmakers may not be able to get.[25]

These caveats notwithstanding, we believe that our analysis provides a framework that sheds light on the basic implications of exclusivity in the fruits of innovative activity.

[25] See Maurer and Scotchmer (2006), section 6, for a discussion of the difficulties in the application of ratio tests.

7 Appendix

7.1 The General ratio test.

Let the instantanesou probability of discovery be: $\lambda^1(x_1, x_2) = x_1 + \sigma x_2$, for Firm 1 and $\lambda^2(x_2, x_1) = x_2 + \sigma x_1$ for Firm 2, with $\sigma \in [0, 1)$.

Firm 1's expected profit is

$$V_1(x_1) = \frac{\lambda^1(x_1, x_2)\ P_W + \lambda^2(x_1, x_2)\ P_L - c(x_1)}{\lambda^1(x_1, x_2) + \lambda^2(x_1, x_2) + r},$$

where P_W denotes the reward to the winner of the innovation race, P_L the reward to the loser, $c(x)$ the research costs. One can easily see that $\frac{\partial V_1(x_1)}{\partial P_L} > 0$, and $\frac{\partial V_1(x_1)}{\partial y} < 0$.

The optimal research effort x_1 must satisfy (omitting arguments)

$$\frac{(P_W + \sigma P_L)\, r}{\left(\lambda^1 + \lambda^2 + r\right)^2} + \frac{\left(\lambda^2 - \sigma\lambda^1\right)(P_W - P_L)}{\left(\lambda^1 + \lambda^2 + r\right)^2} = \frac{c'(x_1)\left(\lambda^1 + \lambda^2 + r\right) - c(x_1)\left(\lambda_1^1 + \lambda_1^2\right)}{\left(\lambda^1 + \lambda^2 + r\right)^2}.$$

If IP rights are strong, there is no reward for the loser.

Let P_W and P_L be the rewards under weak IP rights, and let $\hat{P}_W$ be the reward for the first innovator under strong IP rights.

Weak and strong rights provide the same incentives to innovate if

$$\hat{P}_W r + \left(\lambda^2 - \sigma\lambda^1\right)\hat{P}_W = (P_W + \sigma P_L)\, r + \left(\lambda^2 - \sigma\lambda^1\right)(P_W - P_L).$$

that is

$$\begin{aligned} \hat{P}_W &= P_W - \frac{\lambda^2 - \sigma\lambda^1 - \sigma r}{\lambda^2 - \sigma\lambda^1 + r} P_L \\ &= P_W - \rho(x)\ P_L \end{aligned}$$

where $\rho(x) = \frac{\lambda^2 - \sigma\lambda^1 - \sigma r}{\lambda^2 - \sigma\lambda^1 + r} = \frac{\left(1-\sigma^2\right)x_2 - \sigma r}{\left(1-\sigma^2\right)x_2 + r}$.

In a symmetric equilibrium, $\lambda^2 = \lambda^1 = \lambda$, and $\rho(x)$ can be written as

$$\begin{aligned} \rho(x) &= \frac{\lambda(1-\sigma) - \sigma r}{\lambda(1-\sigma) + r} = \frac{(1-\sigma)\frac{\lambda}{\lambda+r} - \sigma\frac{r}{\lambda+r}}{(1-\sigma)\frac{\lambda}{\lambda+r} + \frac{r}{\lambda+r}} = \\ &= \frac{(1-\sigma)\hat{\delta}(x) - \sigma\left(1 - \hat{\delta}(x)\right)}{(1-\sigma)\hat{\delta}(x) + \left(1 - \hat{\delta}(x)\right)} = \frac{\hat{\delta}(x) - \sigma}{1 - \sigma\ \hat{\delta}(x)}, \end{aligned}$$

where $\hat{\delta}(x) = \frac{\lambda}{\lambda + r}$ is the rival's discounted probability of discovery (in the innovation race).

Under weak IP rights, the loser of the race invests in duplication until replication is achieved. From that time on, the loser gets duopoly profits:

$$P_L = (1 - \ell\ ) \frac{\pi_d}{r} - \ell\ \frac{s(y)}{r}, \tag{9}$$

where $\ell\ = \frac{r}{r+y}$ is the lead-time of the first inventor (the discounted expected time until duplication), $s(y)$ are the duplication costs, y is the intensity of the duplication effort,which is decided by the duplicator so as to maximize P_L.

The winner of the race gets monopoly profits during the lead time and duopoly profits thereafter:[26]

$$P_W = \ell\ \frac{\pi_m}{r} + (1 - \ell\ ) \frac{\pi_d}{r}$$

Under strong IP rights,

$$\hat{P}_W = \tau \frac{\pi_m}{r}$$

where τ / r is the discounted duration of the patent ($\tau = \left(1 - e^{-rT}\right)$, T is the patent term).

In order to get the same incentive to innovate, we must have: $\hat{P}_W = P_W - \rho(x)\ P_L$, that is

$$\tau \frac{\pi_m}{r} = \ell\ \frac{\pi_m}{r} + (1 - \ell\ ) \frac{\pi_d}{r} - \rho(x)\ \left[(1 - \ell\ ) \frac{\pi_d}{r} - \ell\ \frac{s(y)}{r}\right]$$

which simplifies to

$$\tau = \ell\ + (1 - \ell\ ) \frac{\pi_d}{\pi_m} - \rho(x)\ \left[(1 - \ell\ ) \frac{\pi_d}{\pi_m} - \ell\ \frac{s(y)}{\pi_m}\right]. \tag{10}$$

[26] Here, we ignore the costs borne by the first inventor to protect the innovation from duplication. These costs would tilt the ratio test against weak IPRs: they reduce the reward to the innovator and at the same time increase the deadweight loss.

Note, incidentally, that - in view of (10) - $\tau > \ell$. Thus, if the trade secrecy option were available together with the patent, the innovator would go for the patent, so as to avoid the risk of being excluded from the market by the pursuer.[27]

Let us consider the point of view of the firms. Given the same incentive to innovate, weak IP rights provide greater expected profits if

$$\frac{\lambda\ P_W + \lambda\ P_L - c\,(x)}{2\ \lambda + r} > \frac{\lambda\ \hat{P}_W - c\,(x)}{2\ \lambda + r},$$

that is

$$P_W + P_L > \hat{P}_W,$$

with $P_W - \rho\,(x)\ \ P_L$ and $\rho\,(x) = \frac{\hat{\delta}(x) - \sigma}{1 - \sigma\ \ \hat{\delta}(x)} \geq -1$. Thus,
Remark: *Weak IP rights require a larger amount of expected profits to yield any given level of incentives to innovate.*

In fact, they require exactly the same amount of profits only in the limit case where research spill-over is maximal $(\sigma = 1)$, and the first and the second prize are perfect substitutes $(\rho\,(x) = -1)$.

Let us now consider the welfare levels associated with the two IP regimes.

Under strong IP rights, expected social welfare is

$$\hat{W} = (1 - z)\left[\tau \frac{v - \Delta_m}{r} + (1 - \tau)\frac{v}{r}\right] - z\ 2\ c(x),$$

where $z = \frac{r}{2\lambda + r}$ is the expected discounted time until innovation.

Upon discovery, social welfare includes: for a discounted time period τ, the social value of the innovation v less the monopoly deadweight loss Δ_m; for the remaining period, the full social value. Before the innovation is achieved, society bears the research costs of the two firms.

Under weak IP rights, expected social welfare is

$$W = (1 - z)\left[\ell\ \frac{v - \Delta_m - s(y)}{r} + (1 - \ell)\ \frac{v - \Delta_d}{r}\right] - z\ \ 2c(x).$$

[27] In some countries, however, late patentees cannot exclude prior users. In that case, the first innovator might resort to secrecy. See Denicolò and Franzoni (2004) and Shapiro (2006).

Upon discovery, social welfare includes: for a discounted time equal to monopolistic lead-time, the social value of the innovation v less the monopoly deadweight loss Δ_m, less duplication costs $s(y)$ borne by the laggard; for the remaining period, the full social value less the duopoly deadweight loss Δ_d.

Since the expected discovery time is the same by assumption, strong IP protection provides greater welfare if

$$\left[\tau\frac{v-\Delta_m}{r}+(1-\tau)\frac{v}{r}\right]>\left[\ell\ \frac{v-\Delta_m-s(y)}{r}+(1-\ell)\ \frac{v-\Delta_d}{r}\right],$$

that is

$$\tau\Delta_m<\ell\ \Delta_m+\ell\ s(y)+(1-\ell)\,\Delta_d$$

Plugging in eq. (10), we have that strong IPRs are preferable if

$$\ell\ +(1-\ell\ )\,\frac{\pi_d}{\pi_m}-\rho\,(x)\ \left[(1-\ell\ )\,\frac{\pi_d}{\pi_m}-\ell\ \frac{s\,(y)}{\pi_m}\right]<\ell+\ell\ \frac{s(y)}{\Delta_m}+(1-\ell)\,\frac{\Delta_d}{\Delta_m}.$$

Let

$$\Sigma=\frac{\ell}{(1-\ell)}\frac{s(y)}{\pi_d}$$

be the share of expected duplication profits dissipated in duplication costs (see eq.9).

Then, upon simplification, strong IPRs are preferable if

General ratio test: $$\frac{\Delta_m}{\pi_m}\,(1-\rho\,(x))<\frac{\Delta_d}{\pi_d}+\Sigma\left(1-\rho\,(x)\,\frac{\Delta_m}{\pi_m}\right). \quad (11)$$

As long as $\left(1-\rho\,(x)\,\frac{\Delta_m}{\pi_m}\right)>0$, the dissipation of duplication profits Σ tilts the balance in favour of strong IP rights. From a social point of view, duplication costs represent a waste of resources. However, they also reduce the prize to the second innovator (which increases social welfare, if innovation is competitive). The net impact is negative if $\rho\,(x)\,\frac{\Delta_m}{\pi_m}<1$, which is an extremely mild condition.

If we ignore duplication costs and set $\Sigma=0$, the test simplifies to

$$\frac{\Delta_m}{\pi_m}<\frac{\Delta_d}{\pi_d}\ \ \frac{\left(1-\sigma^2\right)x_2+r}{r\,(1+\sigma)}.$$

Thus, strong IP rights are preferable if: i) competition emerging from imitation is weak (large $\frac{\Delta_d}{\pi_d}$); ii) the innovation race is intense (large x_2); iii) the spill-over is small.

7.2 Independent invention defense

Let us now compare strong patents with weak patents, which allow for an independent invention defence.

The loser of the race can practice the invention if she is able to make it independently. In that case, the second inventor reaps duopoly profits until the patent of the first inventor expires. This implies that the reward for duplicating the invention decreases with time (it eventually goes to zero at the expiry of the first patent). The optimal R&D investment of the loser is obtained by dynamic optimization. Let $y(t)$ be the loser's optimal investment in R&D, with $y(t) > 0$ for $t > t_0$ (where t_0 is the time of the first discovery) and $y(t) = 0$ for $t \geq t_0 + T_1$ (where T_1 is the duration of the patent).

At the time of the first discovery, the expected payoff of the pursuer is equal to expected discounted duopoly profits net of duplication costs:

$$\widetilde{P}_L = \int_0^{T_1} e^{-rt}\ \omega(t) \left[y(t) \int_t^{T_1} e^{-(\xi - t)r} \pi_d \ d\xi - s(y(t)) \right] \ dt$$

where $y(t)$ is the the probability that the loser will make the discovery between t and $t + dt$, conditional on not having done so by t, and $\omega(t) = e^{-\int_0^t y(\xi) d\xi}$ is the probability that the loser has not yet made the discovery.

$\widetilde{P}_L$ can also be written as

$$\widetilde{P}_L = \theta \frac{\pi_d}{r} - E(s),$$

where θ is the expected discounted duopoly duration and $E(s)$ the expected discounted duplication costs.

The winner of the race gets

$$\begin{aligned} \widetilde{P}_L &= \int_0^{T_1} e^{-rt}\ \pi_m - e^{-rt}\ \omega(t)\ y(t) \left(\int_t^{T_1} e^{-(\xi - t)r} (\pi_m - \pi_d)\ d\xi \right) \ dt = \\ &= \tau_1 \frac{\pi_m}{r} - \theta \left(\frac{\pi_m}{r} - \frac{\pi_d}{r} \right) = (\tau_1 - \theta) \frac{\pi_m}{r} + \theta \frac{\pi_d}{r}, \end{aligned}$$

where

$$\frac{\tau_1}{r} = \int_0^{T_1} e^{-rt}\ dt = \frac{1 - e^{-rT_1}}{r}$$

is the expected discounted term of the weak patent. Depending on the duplication effort exerted by the pursuer during the patent term, θ ranges from nil (no duplication effort throughout) to τ_1 (infinite duplication effort).

Under strong patents, the payoff to the loser of the race is zero, and the payoff to the winner is:

$$\hat{P}_W = \hat{\tau}\frac{\pi_m}{r}.$$

Strong and weak patents provide the same incentive to innovate if

$$\hat{P}_W = \widetilde{P}_W - \rho(x)\ \widetilde{P}_L,$$

that is

$$\hat{\tau}\frac{\pi_m}{r} = (\tau_1 - \theta)\,\frac{\pi_m}{r} - \theta\frac{\pi_d}{r} - \rho(x)\ \left[\theta\frac{\pi_d}{r} - E(s)\right],$$

or

$$\hat{\tau} = \tau_1 - \theta + \theta\frac{\pi_d}{\pi_m} - \rho(x)\ \left[\theta\frac{\pi_d}{r} - E(s)\right]. \tag{12}$$

Given the same incentive to innovate, strong patents yield higher social welfare if

$$\left[\hat{\tau}\frac{v-\Delta_m}{r} + (1-\hat{\tau})\frac{v}{r}\right] > \left[(\tau_1 - \theta)\ \frac{v-\Delta_m}{r} - E(s) + \theta\ \frac{v-\Delta_d}{r} + (1-\tau_1)\frac{v}{r}\right].$$

Using (12), the previous inequality can be written as

$$\frac{\Delta_m}{\pi_m}(1 - \rho(x)) < \frac{\Delta_d}{\pi_d} + \Sigma\left(1 - \rho(x)\,\frac{\Delta_m}{\pi_m}\right),$$

where

$$\Sigma = \frac{E(s)}{\theta\ \ \pi_d},$$

is, again, the share of expected duopoly profits dissipated through duplication. Thus, the general ratio test applies.

7.3 Mandatory licensing

Let us consider the case where the innovator is obliged to license the invention to the other firm on payment of a royalty. The royalty amounts to a share f of duopoly profits until the patent expires. The technology is transferred immediately after discovery.

We have:

$$\begin{aligned} P_L &= \tau \frac{\pi_d}{r}(1-f), \text{ and} \\ P_W &= \tau \frac{\pi_d}{r}(1+f). \end{aligned}$$

We compare the mandatory licensing regime to a regime with no licensing, but shorter patent life. Again, we compare the social costs required to provide a fixed level of incentive to innovate.

Let τ_0 be the expected patent duration (with no licensing) that meets our conditions:

$$\tau_0 \frac{\pi_m}{r} = \tau \frac{\pi_d}{r}(1+f) - \rho(x)\ \tau \frac{\pi_d}{r}(1-f),$$

that is

$$\tau_0 = \tau \frac{\pi_d}{\pi_m}\left[1-\rho(x)+f\ (1+\rho(x))\right]. \tag{13}$$

Social welfare is greatest under the strong patent regime if

$$\tau_0 \frac{v-\Delta_m}{r} + (1-\tau_0)\frac{v}{r} > \tau \frac{v-\Delta_d}{r} + (1-\tau)\frac{v}{r}.$$

Using (13), the previous inequality can be rewritten as

$$\frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d\left[1-\rho(x)+f\ (1+\rho(x))\right]}. \tag{14}$$

If f is large, the test is harder to pass. *Ceteris paribus*, the royalty shifts profits from the second to the first inventor, thereby enhancing the incentive to innovate.

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