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

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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: i) the competition emerging from imitation is weak; ii) the innovation at hand attracts large investments; and iii) research spill-overs are small. Conversely, weak IP rights best fit those industries where there is a substantial information flow between firms in the prediscovery phase.

Keywords: Kaplow test, research spill-overs, patents and trade secrets.

1 Introduction

For manufacturing products, intellectual property law has traditionally focussed on two polar types of protection: patents and trade secrets. The former provide a strong form of protection, since they grant an exclusive - though temporary - right to the use of patented technology. Trade secret law, by contrast, gives weak (i.e. non-exclusive) protection. That is, it precludes misappropriation of knowledge and know-how (as by espionage or breach of confidentiality duties),

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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 (weak or strong) should be accorded to different intangible assets is a crucial policy issue. Patents are regulated by specific eligibility requirements: any new piece of technical knowledge that fails to meet these patentability requirements will inevitably receive only weaker forms of protection, like trade secrecy or copyright.

Even for those innovations that are patented, the delimitation of the scope of the patent grant remains an important policy issue. The boundaries of the exclusive right of the patentee are set mainly by the breadth of the claims, but also by antitrust law restrictions on licensing practices, settlement agreements and non-disclosure policy. In general terms, the right to exclude should not go beyond the boundaries of the scope of IPR grants ("patent misuse") and should not lead to unreasonable exclusionary practices. The refusal to license proprietary technology, for instance, has in a few exceptional cases been judged grounds for antitrust liability (e.g. in Kodak II, 125 F.3d 1195, 1997).

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. Striking the right balance is the crux of intellectual property law, and is at the center of the constant tensions between IP law and competition law.

We do not intend, here, to attempt a general assessment of this trade-off, but rather to 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 2009), we develop a ratio test that measures the "social cost of incentives" attendant on the different specifications of IP rights. We take the level of innovation incentives as given and investigate which *type* of protection entails the lowest social costs. This approach, originally developed by Kaplow

[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."

[2] Copyright law, for instance, allows for parallel development but is wary of reverse engineering (circumvention of digital locks). In recent decades the traditional dichotomous nature of intellectual property protection has been progressively eroded by the enactment of "hybrid" legal statues, such as the Semiconductor Chip Protection Act of 1984 and the Plant Variety Protection Act of 1970 (amended in 1994). See Reichman (1994).

(1984), allows us to set the complex issue of the optimal *level* of protection aside.

The test we propose balances costs and benefits of exclusive protection in a simple way. In line with Kaplow (1984), the costs of IP protection are equated with the deadweight loss resulting from the lack of competition, the benefits with incentive to innovate.[3] Unlike Kaplow, however, we posit that innovation is the result a race, so we investigate the relationship between the structure of IP rights, the nature of the innovation process, and the incentives to innovate. We argue that incentives cannot be simply equated with first inventor's profits, because they also depend on what reward goes to the loser of the innovation race. Under weak IPRs, in fact, late-comers have the chance to duplicate the innovation and compete on the market, earning positive profits.

Prima facie, it is not obvious how the presence of a second prize affects the incentives to innovate. Most of the literature has focussed on cases where the second prize has a positive effect on innovation.[4] In our model, the effect of the second prize depends on the nature of the innovation process. We show that if firms' research entails no spill-overs, the second prize dilutes the incentive to innovate, since it amounts to a reward for failure. In the presence of spill-overs, however, the second prize may enhance the incentive to innovate, since it makes research non-competitive: 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.

When the spill-over is large enough, the efficient reward structure is likely to be weak property rights.

In practice, a good many factors impact the magnitude of the spill-overs within industries. The most important include 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.

[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).

[4] As when the innovation rate is dictated only by the entry decision of firms, in the classic contribution of La Manna et al. (1989). The relationship between different innovation models is investigated in Denicolò and Franzoni (2009).

To a large extent, spill-overs characterize institutional step-ups which allow for substantial flows 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).[5] Typical examples are found in the software industry (Osterloh and Rota 2007) and in the semiconductor industry (Hall and Ziedonis 2001).

Our analysis suggests that strong IP rights are appropriate in Route 128 but not in Silicon Valley, in the pharmaceutical but not in the software and semiconductors industries.

Our results complement a recent body of literature that advocates weak IP rights for sectors where several firms come up with the same innovation.[6] 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 defence to infringement (the "independent inventor defence"). [7] Although this literature deals specifically with the rights of patentees, 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 should be the case of the IT and biotechnology sectors, where the underlying knowledge base is in the public domain and is expanding so rapidly that many incremental

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

[6] 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 (2006).

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

improvements are "in the air" (Shapiro 2008).[8]

We contribute to this literature with our emphasis on the role of spill-overs. In our view, what matters most is not the likelihood of several parties coming up with the same innovation, but the degree of rivalry in the race to discovery. In this sense, our position is more nuanced: as we said before, weak IP rights may be desirable in some industries but not in others.[9]

The test we develop here is specific to the model at hand, but insights it generates can apply to many scenarios in which anti-trust concerns and property rights might conflict. In section 5, we identify several important policy issues on which our analysis bears.

2 The Ratio Test

Our point of departure is the simple observation that strengthening the innovator's market power becomes increasingly costly in terms of deadweight loss.

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

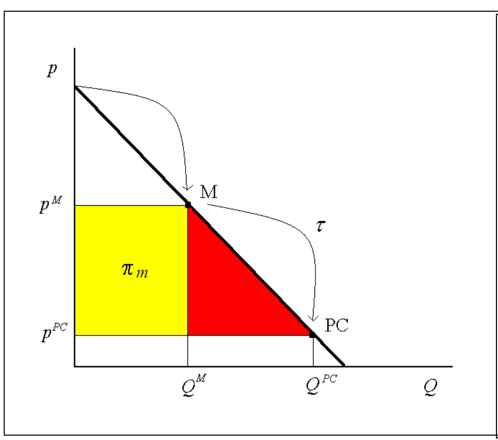

Fig. 1A: Patent

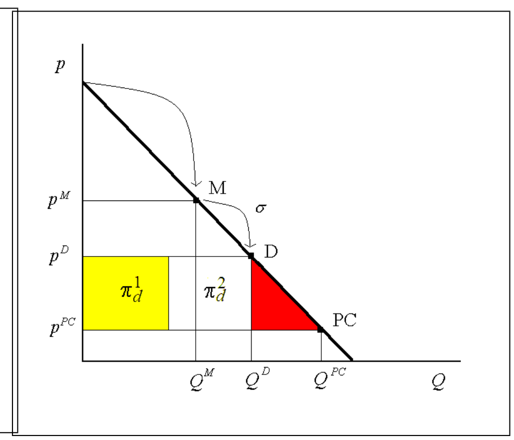

Fig. 1B: Trade secret

[8] 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.

[9] It is remarkable how *eBay Inc. v. MercExchange L.L. M.* (547 U.S. 388, 2006) spurred different reactions in the business world, with the pharmaceutical business association supporting strong property-like remedies for patent infringement, and the electronic and software sectors opposing them.

If the innovation is protected by a patent (Fig. 1A), 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. 1B), the innovator enjoys monopoly profits for a lead time of expected duration σ, and duopoly profits π_d^1 from the time if duplication onwards. For simplicity, we assume that duopoly lasts forever. After the initial-lead time period, the presence of the competitor yields 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). 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 less 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, you can compare the deadweight loss of the outcomes and determine the most efficient solution. So, the question becomes: can a patent yield the same incentive to innovate as a weak system of protection, at a lower social cost?[10]

In the case at hand, where only one firm is able to discover the innovation, this exercise yields a simple solution.

Initially, both regimes entail a monopolistic situation. The comparison between the two regimes therefore hinges on the second period (duopoly vs monopoly), for the relevant time span (until expiration under patent, forever under trade secrecy).[11] So let us compare the two regimes from the time when the innovation is duplicated.

Let h be the discounted value of a stream of 1 dollar from now to infinity, let e be the discounted value of a stream of 1 dollar from now until date E (expiry

[10] The question could also be formulated conversely, assuming that the expected duration of the weak IPR can be affected by the policy-maker.

[11] Trade secrecy may terminate because the secret leaks out or because it becomes technologically obsolete. These possibilities would not alter the analysis significantly.

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: $e\,\pi_m = h\,\pi_d$, i.e. $e = h\,\pi_d/\pi_m$.

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 preferable if the deadweight loss per unit of monopoly profit is less than that 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 half captured by the duplicator does not contribute to the incentive to innovate. This factor works against weak IPRs. By concentrating all profit on the innovator, patents provide the reward faster than duopoly. Figuratively, under monopoly the pain (deadweight loss) is sharper but briefer.

The second effect dominates and inequality (1) is satisfied when the duopoly price is relatively high. With a linear demand function, 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, the actual deadweight loss is somewhat greater than that depicted in the diagram, and lead-time profit somewhat less. This effect tilts the balance against weak IPRs.[12]

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,

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

who 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, and the 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 entails 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 industry level than about its division between first and second discoverer. Here, an increase in the second prize has 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 with the case where firms conduct their research in isolation. Discovery follows a Poisson process.[13] The probability of Firm 1 making the discovery in a unit of time is x_1, that of the discovery being made by Firm 2 is x_2. Let P_W be the reward for the winner of the race, and P_L the reward for the loser upon the winner's discovery. Under a system of full exclusivity P_L is zero, while under a system of weak IP rights P_L includes the net expected profit from successful duplication.

Under these assumptions, 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.

[13] 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 discovery remains the same.

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

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

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, in that 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.[14] 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.[15]

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 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.[16]

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

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

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* $\delta\left(x\right)$*-dollar reduction in the reward to the winner (with* $0\leq\delta\left(x\right)<1$).

[14] 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 (2009).

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

[16] 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.

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 patents are socially preferable if

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

The Modified test compares the social cost "per unit of incentive" to innovate under the two regimes. In the numerator we find the dissemination costs of exclusive rights, measured by standard deadweight loss. In the denominator, the incentive to innovate is measured taking into account any reward 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 proportional to the duopoly profit of the innovator *suitably deflated by the consolation prize*. Hence, the incentive is proportional to: $\pi_d^1 - \delta\left(x\right)\pi_d^2 = \left[1 - \delta\left(x\right)\right]\pi_d$.

This modified ratio test accounts for the degree of rivalry in the innovation race. If there is no rivalry ($\delta\left(x\right) \to 0$), 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 test is easier to pass: short-lived exclusive rights - no consolation prize to the loser - are able to provide the same incentives to innovate as a long-lasting duopoly, at less social cost.

Note that the variable $\delta\left(x\right) = \frac{x_2}{x_2+r}$ can be interpreted as the rival's "discounting-adjusted probability" of success in the innovation race.[17] If rivals are likely to discover "soon", 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 $\delta\left(x\right) \to 0$ - firms will care more about bringing the date of discovery forward than about preempting rivals.

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How can we get a sense of the magnitude of $\delta\left(x\right)$?

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

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 $\delta(x) = \frac{0.5}{0.5+0.05} = 0.90$.

If the expected time to rivals' discovery is 5 years (so that $x = 0.2$), then $\delta(x) = \frac{0.2}{0.2+0.05} = 0.80$.

If the expected time of discovery of the rivals is 10 years (so that $x = 0.1$), then $\delta(x) = \frac{0.1}{0.1+0.05} = 0.66$.

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The "discounting-adjusted probability" of discovery of rivals is large and innovation is more competitive when the innovation attracts a lot of investments (because it will command a high price or because the cost of research is low), and the interest rate is high.

In view of equation (3), we concluded in Denicolò and Franzoni (2009) 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.

4 Innovation without rivalry

In many industries, research does not take place in isolation; instead, that done by each firm spills over to the others, allowing them to advance towards the discovery.

We capture the impact of research spill-overs by assuming that the probability of discovery of each firm depends positively on its own research effort and also on that of the rival. More specifically, let the probability of Firm 1 making the discovery in the unit time period be:

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

where the parameter $\sigma \in [0, 1)$ measures the amount of spill-over, x_1 the research effort of Firm 1 and x_2 the research effort of Firm 2. Symmetrically, the probability of Firm 2 making the discovery 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):

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

As before, an increase in the research effort of Firm 1 has two positive effects on its payoff: it brings forward its gain from the discovery (first prize or second prize through the spill-over) and it increases its chances of preempting Firms 2.

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

The relative disincentive effect of the second prize is now

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

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.*

As the spill-over gets larger, 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 ranges from $\hat{\delta}(x)$ to -1.

If there is no spill-over, then the second prize has a clearly negative effect on the incentive to innovate: $\rho(x) = \hat{\delta}(x) > 0$, as in Section 3.

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 ($\rho(x) < 0$).

For environments with maximum spill-over, $\sigma \to 1$, the first and the second prize become perfect substitutes ($\rho(x) \to -1$): they have the same effect on the incentive to innovate (a 1-dollar increase in the second prize is equivalent to a 1-dollar increase in the first prize).

The new ratio test, in the presence of spill-overs, is (substituting $\rho(x)$ for $\delta(x)$ 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 2A and 2B illustrate.

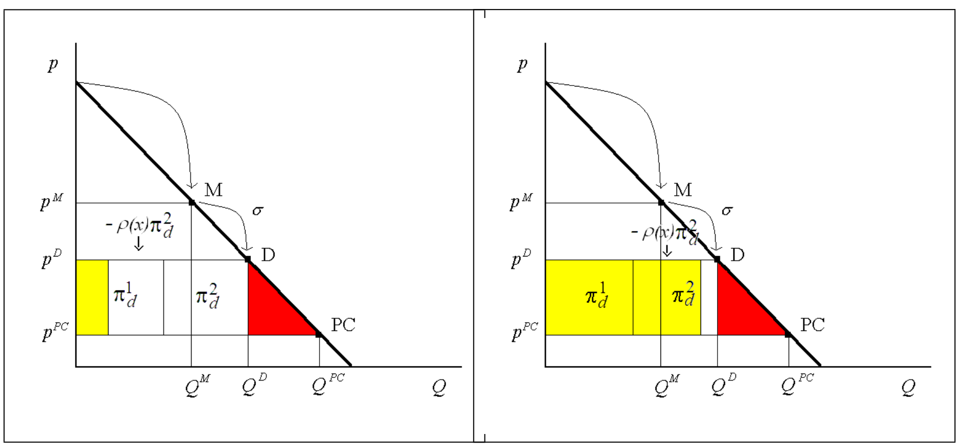

Fig. 2A. Competitive innovation. Fig. 2B. Non-competitive innovation.

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 $\rho(x) = \frac{0.80-0.33}{1-0.80 \text{ x } 0.33} = 0.64$. In the ratio test, industry profits need to be discounted by a factor equal to 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.[18]

As a final caveat, we should recall that weak property rights entail an additional distortion. Let us look again at Figure 2. After one 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-sides impact. They increase the social costs of the weak IPRs regime,[19] but also reduce the second prize. Hence, they may increase the incentives to innovate. As a rule, however, duplication costs tend to favour strong IP rights (see Appendix 7.1).

5 Policy discussion

In this section we discuss several issues that have come to the forefront of the policy debate, pertaining to the desirability of strong exclusive rights for inno-

[18] 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.

[19] 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."

vators.

5.1 Patents and trade secrets

Not all innovations can be patented.[20] Innovations that do not meet the patentability requirements can only be protected by trade secrecy or, in certain fields, copyright. These types of IP protection differ on many accounts. Patent protection is commonly considered the strongest (a "property rule" in the sense of Calabresi and Melamed), since it grants the right to exclude others from making, using, or selling the protected invention during the term of the patent. In other words, once the innovation is patented, any unauthorized duplication costituts an infringement, even if it is derived independently.[21]

Other forms of IP protection are definitely weaker. Trade secrecy protects the innovator against "misappropriation" of intellectual property (e.g. by espionage or breach of confidentiality duties), but not against duplication through reverse engineering or parallel development. 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 takings upon payment of duplication costs (Reichman 1994).

In the case of copyright, inadvertent replication of work does not generally constitute an infringement.[22] 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,

[20] Survey evidence collected by Cohen, Nelson and Walsh (2000) suggests that, on average, US manufaturers apply for patents on 49% of their product innovations and 31% of their process innovations. There are large cross-industry differences in the propensity to patent.

[21] In this sense, patent infringement resembles a strict liability offence. However, the analogy is not perfect, since the determination of damages depends on whether the violator was put on notice or not (see Blair and Cotter 2001).

[22] 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).

as is the distribution of circumvention technologies.[23]

Our analysis does not treat the optimal degree of reverse engineering. We focus instead on the optimality of exclusivity rules from an ex-ante perspective, given ease of duplication. Our results are relevant to the issue of which class of innovations, or industries, should have access to patent protection[24].

We contend that strong exclusive rights should apply to highly innovative sectors where firms race neck-and-neck for major innovations, where research knowledge is jealously guarded, and where product competition (in case of imitation) is weak.

5.2 The independent inventor 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 (Meucci, Bell and Gray), and the integrated circuit (Kilby and Noyce).

Simultaneous discoveries of this type put some strain on the patent system, which must determine who was the true first-inventor.[25]

The thesis that only the first inventor (whether he is first to invent or the first to file) 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 (2006). These authors advocate a defense that would allow the second inventor to practice the innovation if he can prove that he developed it independently.

The arguments in favour of weak patents strongly resemble those for trade secrecy (weak IP). Leaving aside the many practical problems (see Lemley 2007),

[23] On the protection of software and the economics of reverse engineering, see the insightful work of Samuelson and Scotchmer (2002).

[24] For complex innovations, firms sometimes resort to a combination of patent and trade secrecy protection. This raises interesting policy issues, analyzed by Ottoz and Cugno (2008) .

[25] 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 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).

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 ratio test also applies to this special set up.

The general recommendation deriving from our results differs markedly from that of Shapiro (2006) and (2008). Accordingly, let us examine his arguments more closely.

Shapiro (2008) notes that in presence of multiple nearly simultaneous innovations, there is a likely discrepancy between the private reward and the social contribution of the first innovator. Say a firm makes the discovery one day before its rival: in this case, the marginal social contribution is the social value of the innovation (net of deadweight loss) for a day, while the private reward is monopoly profits for the full patent term. That is, there is a gross disproportion between reward and contribution. On the basis of this observation, Shapiro argues that, to align private with social benefits, one should reduce the reward to the winner by forcing him to share the market with the second inventor, if and when one materializes.

We agree that when the innovation race is tight, and many firms independently pursue the same invention, the marginal contribution of each is small.[26] However, this does not mean that - *on average* - firms are overcompensated: while the reward for the first inventor is relatively large, that for all the others is nil.

When races are tight, the incentive to invest in research is amplified by the desire of each firm to preempt its rivals. From the firm's point of view, the marginal benefit of bringing the innovation date forward by one day is not just the value of earlier discovery, but also, and perhaps more importantly, that of preempting rivals. Since, from a social point of view, it does not matter who makes the discovery, expenditures aimed only at "redistributing" the prize across contestants could be regarded as unproductive. Hence, the disalignment between social and private benefits.

Still, we argue that society can gain a net benefit from these "rivalrous" expenditures. In fact, when competition for priority is strong, the incentive to innovate can effectively be obtained by means of a limited prize. Since the prize - monopoly profits - is costly to society, it should be handed out parsimoniously.

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

Strong IPRs may be desirable precisely because they reduce the total amount of profits necessary to stimulate innovation. In the appendix we show that, for any given level of the incentive to innovate, the expected profits for the firms are lower if incentives are provided through strong IP rights. Thus, if firms could choose the way in which incentives are provided, they would opt for tranquillity ("everybody wins"). From a social point of view, though, firms' life should be made hard (at least as long as the spill-over is small).

For innovations characterized by large spill-overs, weak property rights are likely to be the best solution. In this case, the priority effect is small and society benefits from the reduction in deadweight loss induced by product market competition.

5.3 Intellectual property and antitrust

Under some circumstances, the right to exclude provided by patents and other IP rights may run counter to antitrust law. Take, for example, a firm holding monopolistic power that refuses to licence 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.[27] 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 licensing. Assuming that patent duration can be appropriately fixed, we compare strong

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

IPRs and weak one (with mandatory licences).

The comparison clearly depends on the size of the mandated royalty: if it is symbolic (close to zero), 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.

Again, it is worth emphasizing that the relative merits of the strong and weak rights turn on the features of the innovation process: competitive innovation calls for strong IPRs, non-competitive 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 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.[28]

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.

[28]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 probability of discovery in the unit time period 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.[29]

The optimal research effort x_1 must satisfy (omitting arguments)

$$\frac{(P_W+\sigma P_L)\, r}{\left(\lambda^1+\lambda^2+r\right)^2} + \frac{\left(\lambda^2-\sigma\lambda^1\right)(P_W-P_L)}{\left(\lambda^1+\lambda^2+r\right)^2} = \frac{c'(x_1)\left(\lambda^1+\lambda^2+r\right) - c(x_1)\left(\lambda^1_1+\lambda^2_1\right)}{\left(\lambda^1+\lambda^2+r\right)^2}.$$

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).

[29] One can easily see that $\frac{\partial V_1(x_1)}{\partial P_L} > 0$, and $\frac{\partial V_1(x_1)}{\partial x_2} < 0$.

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

$$\frac{\lambda\ P_W + \lambda\ P_L - c\,(x_1)}{2\ \lambda + r} > \frac{\lambda\ \hat{P}_W - c\,(x_1)}{2\ \lambda + r},$$

that is

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

Remark: *Since* $\hat{P}_W = P_W - \rho\,(x)\ \ P_L$*, weak IP rights provide larger expected profits for any level of* $\rho\,(x) > -1$.

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:

$$P_L = (1 - \ell\ )\,\frac{\pi_d}{r} - \ell\ \frac{s\,(y)}{r}, \tag{8}$$

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:[30]

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

Under strong IP rights,

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

where $\frac{\tau}{r}$ 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

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

[30] 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.

which simplifies to

$$\tau = \ell + (1-\ell)\,\frac{\pi_d}{\pi_m} - \rho(x)\,\left[(1-\ell)\,\frac{\pi_d}{\pi_m} - \ell\,\frac{s(y)}{\pi_m}\right]. \tag{9}$$

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

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

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 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. 9, we have that strong IP rights 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.8).

Then, upon simplification, we get:

$$\textbf{General ratio test:} \quad \frac{\Delta_m}{\pi_m}\left(1-\rho\left(x\right)\right) < \frac{\Delta_d}{\pi_d} + \Sigma\left(1-\rho\left(x\right)\frac{\Delta_m}{\pi_m}\right). \quad (10)$$

As long as $\left(1-\rho\left(x\right)\frac{\Delta_m}{\pi_m}\right) > 0$, 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 $\rho\left(x\right)\frac{\Delta_m}{\pi_m} < 1$, which is an extremely mild condition.

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

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

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 inventor defense

Let us now compare strong patents with weak patents, which allow for an independent inventor 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. For our purposes, there is no need to find the explicit solution to this problem. Let $y\left(t\right)$ be the loser's optimal investment in R&D, with $y\left(t\right) > 0$ for $t > t_0$ (where t_0 is the time of the first discovery) and $y\left(t\right) = 0$ 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:

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

where $y\left(t\right)$ 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 $\omega\left(t\right) = e^{-\int_0^t y(\xi)d\xi}$ 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 loser during the patent term, θ ranges from nil (no duplication effort throughout) to τ_1 (infinite duplication effort just after discovery by the winner).

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

$$\hat{\tau} = \tau_1 - \theta + \theta \frac{\pi_d}{\pi_m} - \rho(x) \left[\theta \frac{\pi_d}{r} - E(s) \right]. \tag{11}$$

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 (11), 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

$$\tau_0 = \tau \frac{\pi_d}{\pi_m}\left[1 - \rho(x) + f \ \ (1+\rho(x))\right]. \tag{12}$$

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 (12), the previous inequality can be rewritten as

$$\frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d\left[1 - \rho(x) + f \ \ (1+\rho(x))\right]}. \tag{13}$$

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.

If the royalty is negligible ($f \to 0$), then we turn again to our modified ratio test.

If the royalty takes all the profits of the licensee ($f \to 1$), strong patents are preferable if Shapiro's test applies:

$$\frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{2\pi_d}.$$

In this case, the incentive to innovate is proxied by industry profits, since the latter are all reaped by the first inventor.

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