Rewarding innovation efficiently: the case for exclusive rights

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Abstract

This paper investigates the conditions for the desirability of exclusive property rights for innovators. Strong rights are contrasted with weak rights, which allow for some degree of imitation and ex-post competition. The comparison between the two alternatives boils down to a specific "ratio test," which suggests that strong IP rights are preferable when: i) competition emerging from imitation is weak; ii) the innovation at hand attracts large investments; iii) research spill-overs are small. The analysis provides useful insights on policy issues lying at the intersection between intellectual property law and competition law.

1 Introduction

When should an inventor be granted fully exclusive rights on the use of the innovation? When should these rights be weakened so as to allow for some degree of imitation and product market competition?

With respect to manufactured items, IP law has traditionally focussed on two polar types of protection: patents and trade secrets. The former provide

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a **strong** form of protection, a "property right," since they grant an exclusive - though temporary - right on the use of patented technology. Trade secret law provides instead a **weak** type of protection since it protects the innovator against "misappropriation" of knowledge and know how (e.g. by means of espionage or breach of confidentiality duties), but not against 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]

To determine which type of protection to grant to different types of intangible assets is a crucial policy issue. Regulation of access to the patent system is essentially carried out by lawmakers and administrators (the PTO) by means of the patentability requirements and the patentable subject matters. Inventions that fail to meet these requisites will inevitably benefit from weaker forms of protection (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 exclusion rights of the patentee are demarked in the first place by the breadth of the claims listed in the specification, but also by the restrictions posed by antitrust law to licensing practices, settlement agreements and non-disclosure policy. In general terms, the right to exclude should not trespass the boundaries of the scope of IPR grants and should not lead to "exclusionary" practices. Refusals to license proprietary technology, for instance, have in a few exceptional circumstances given rise to antitrust liability (e.g. in Kodak II, 125 F.3d at 1195).

While strong protection of IPR is ostensibly oriented at providing a large reward to the innovator, weak protection aims at fostering imitation and competition. Policy is thus called upon to solve a difficult trade-off between providing incentives to create the innovation and the need to encourage its diffusion. The proper balancing between these two objectives is the fundamental issue of IP law and is at the center of the constant tensions

[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 weary of reverse engeneeing (circumvention of digital locks). Over the last decades, the traditional dichotomous nature of intellectual property protection has been progressively eroded by the enactment of "hybrid" legal statues, like the Semiconductor Chip Protection Act of 1984 and the Plant Variety Protection Act of 1970 (amended in 1994). See Reichman (1994).

between IP and competition law.[3]

Our purpose is not to attempt a general assessment of this trade-off, but rather to provide some insights on the basic factors that should guide the choice between strong and weak protection. Building on our previous work (Denicolò and Franzoni 2007), we develop a comprehensive test able to capture the combined impact of these factors and to identify the conditions under which strong exclusive rights are desirable. While the test is specific to the model at hand, the insights provided can be applied to all scenarios in which anti-trust concerns and property rights might conflict. In section 5, we identify several important policy issues bearing on our analysis.

In line with much of the previous literature, we recognize that weak IP fosters follow-on imitation and competition, which is generally desirable from an ex-post perspective. Thus, one important element for our test has to do with the degree of competition (and attendant deadweight loss) ensuing from weak IP protection. The second element, not previously considered in the literature, has to do with the adverse effect that non exclusivity has on ex-ante incentives to innovate. Weak IP rights reduce the incentives to innovate for two reasons. By allowing for imitation and competition, they: i) reduce the profits of the innovator, and ii) provide a second prize to the firms that have lost the race for priority. If the industry is not foreclosed by a strong exclusive right, laggard firms can try and catch up with the industry leader either by imitation or duplication. The presence of the second prize tends to deflate incentives to race for priority.

Finally, an additional element that has to be considered in the assessment of weak IP rights is the level of duplicative research they create. Since resources devoted to the replication of an existing innovation are essentially wasteful, strong IP rights tend to be preferable if the "share" of duopoly profits dissipated in duplication costs are larger.

We combine the aforementioned factors in a ratio test that measures the "social cost per level of incentives" attendant with different specifications of

[3] As effectively summarized by the Supreme Courst in the landmark case *Bonito Boats*: "From their inception, the federal patent laws have embodied a careful balance between the need to promote innovation and the recognition that imitation and refinement through imitation are both necessary to invention itself and the very lifeblood of a competitive economy. The novelty and nonobviousness requirements of patentability embody a congressional understanding, implicit in the patent clause itself, that free exploitation of ideas will be the rule, to which the federal protection of a patent is the exception." Bonito Boats v. Thunder Craft Boats, 489, U.S. 141 (1989).

IP rights. On the basis of our test, which refines the test originally proposed by Kaplow (1984), we argue that strong exclusive rights are desirable if: i) the innovation stage is highly rivalrous, ii) follow-on competition (in case of imitation) is weak, and iii) duplication entails large (wasteful) costs.

We will show that the degree of rivalry of the innovation stage depends on the level of the investments that it is able to attract (i.e. on the "importance" of the innovation at hand) and that rivalry tends to decrease - or even vanish - when research entails spill-overs. Since the level of the spill-overs in research essentially depends on the protection measures to which it is subject, our results underscore the connection between the protection of research at different stages (process vs outcome). Strong exclusive rights on the outcome of research are especially desirable for big innovations arising from well protected research. On the other hand, weak IP rights fit best with small innovations stemming from relatively unprotected research. They are therefore particularly recommended for those industries where the link between research effort and priority in discovery is tenuous, and innovations are essentially the outcome of joint collective effort ("collective innovations", in the sense of Allen 1983).

Our results suggest that strong, but possibly short, exclusive rights tend to be an efficient reward mechanism for rivalrous innovations. These results stand in contrast with a recent stream of the literature advocating weak IP rights.[4]

An important part of this literature has recently dealt with the rights of patent holders with respect to follow on innovators. Stephen Maurer and Suzanne Scotchmer (2002) and Carl Shapiro (2006) have argued that late innovators who make the same discovery of the patentee by parallel development should be granted a defence to infringement (*independent inventor defence*). This proposal has spurred an interesting debate, which has mostly focused on the practical problems posed by its implementation[5]. Even if the focus of this stream of literature centers mostly on the rights of patentees, its insights have a more general bearing. They suggest that exclusive rights define an inefficient system for rewarding innovation, especially in those cases where multiple parties are likely to discover the same innovation. Since these scenarios are most likely to arise in those industries where the underlying knowledge base in the public domain is advancing rapidly, so

[4] See, among others, Lamanna et alt. (1989), Farrell (1995), Leibovitz (2002), Kultti, Toikka, Takalo (2006), Shapiro (2006) and (2007), Bessen and Maskin (2008), Henry (2006).

[5] See Blair and Cotter (2001), Vermont (2006) and (2007), and Lemley (2007).

that many incremental improvements are “in the air,” the call for a weakening of IP rights is presumably greatest in the information technology and biotechnology sectors (Shapiro 2007).

Perhaps surprisingly, our results point in the opposite direction: precisely in those sectors where the innovation is discovered by multiple parties we know that the innovation process is highly rival and hence most suitable to strong IP protection. We do not contend that in these cases the *absolute* level of the reward to the innovator might be excessive, as suggested by Shapiro, but argue that here (possibly short) strong exclusive rights would provide incentives to innovate in a more efficient way. In Section 5.2 we expand on this issue and further emphasize the difference between Shapiro’s and our arguments.

2 The Ratio Test

One of the problems posed by a reward scheme based on exclusive rights has to do with the social cost of monopoly. Since the deadweight loss generally increases more than proportionally with the price charged, monopoly power turns out to be particularly costly to society. If the reward to the innovator were provided with some lesser degree of market power, social cost to society would accordingly be lower.

These type of "Ramsey pricing" like considerations have driven important results on the optimal patent breadth (Gilbert and Shapiro 1990) and have been at the core to the recent theories of "weak IP rights". The logic of the argument can be easily understood by means of simple diagrams.

Let us compare a regime of strong protection (patent) to a regime of weak protection in which innovators able to replicate the invention can practice it (trade secrecy). Let us focus on the case where two firms race to discover the innovation. The first to discover becomes the "innovator", the second one the "imitator" or "duplicator".

Let us consider the following diagrams.

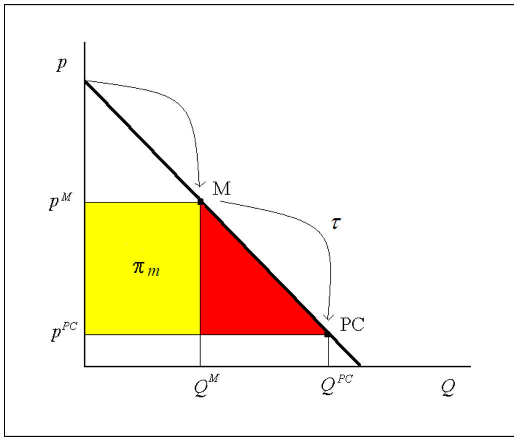

Fig. A: Strong protection

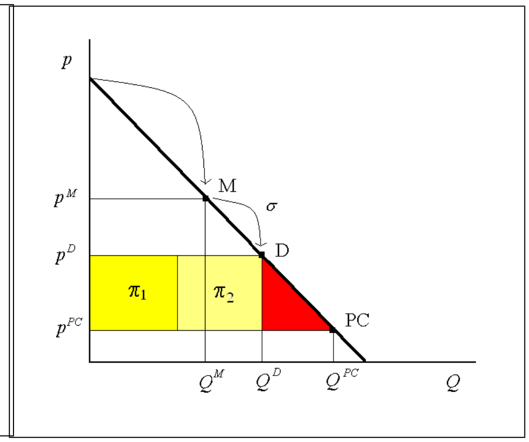

Fig. B: Weak Protection

Under a strong property right (Fig. A), discovery spans a temporary monopoly followed by perfect competition at the end of the term. During the patent term (of duration τ), the innovator earns monopoly profits π_m while society at large bears the deadweight loss Δ_m (shaded area).

Under weak protection (Fig. B), discovery spans a period of monopoly (lead time) of expected duration σ, followed by duopoly (and triopoly and so on if more firms could duplicate the innovation) due to the imitation process. After the initial lead time period, weak protection allows for some competition in the market, which leads to lower prices and greater output. Thus, the reward to the innovator has two components: monopolistic lead time, which entails the same type of social cost of the patent, and duopoly, which entails lower profits ($\pi_1 + \pi_2 \leq \pi_m$) and lower social cost Δ_d (the shaded area).

Note that during the first time period we have a monopolistic situation in both regimes. The comparison between the two regimes hinges therefore on the second period (duopoly vs monopoly), for the relevant time period (until the end of the term for the patent, forever under trade secrecy)[6].

Two observations are in order. First, if we consider the total amount of reward per period available, we notice that the fragmentation of the entitlement entails some profit dissipation. In other words, ex-post competition

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

reduces the total amount of profits available to the firms. This effect plays against fragmentation, as emphasized by Kultti, Toikka, and Takalo (2006).

From a broader perspective, however, the dissipation argument is not fully compelling: duopoly (under weak protection) and monopoly (under strong protection) have different durations, so that, overall, the discounted amount of profits available to the firms in the different regimes depend on the circumstances and, to a large extent, on policy decisions. Thus, the comparison between the absolute levels of remuneration does not yield a general insight into the problem.

Therefore, more to the point is a second observation, which abstracts from the actual duration of monopoly and duopoly. If we look at the social cost of each unit of profit accruing to the firms, we notice that duopoly entails a more favorable deadweight loss to profits ratio. In other words, if the reward is fragmented, its unit social cost per period decreases. This is the point that needs to be expanded.

Let us suppose that firms can invest up-front a fixed amount of resources in R&D, which dictate the expected time of the discovery. Ex-ante, firms are all the same and all share the same chances to be the first to discover, the second, etc. Thus, from the point of view of each firm, what determines the incentive to enter the innovation race is the total amount of profits available over time in the industry (in Figure B, π_m for the duration of lead time, $\pi_1 + \pi_2$, for the duration of duopoly). [7]

The same amount of profits can be provided by a patent system, where the patent term is suitably adjusted. The difference between the two regimes would then lie in the amount of social losses attendant with the required level of profits. Since both the profits and the social losses are constant over the relevant time period, what matters is the static ratio between the two. Under strong IP rights, each unit of profit brings with it a social cost equal to Δ_m/π_m. Under weak IP rights (after monopolistic lead time has expired), each unit of industry profits brings with it a social loss equal to $\Delta_d/(\pi_1 + \pi_2)$.

Therefore, from a social point of view, the comparison between a system of strong property rights and a system of weak property rights boils down to a comparison of deadweight loss to profits ratios. With two firms, strong property rights are preferable if the so-called "Kaplow test" is met (after

[7] These are the assumptions characterizing the pioneering contribution of La Manna, MacLeod and D. de Meza (1989).

Kaplow 1984):

$$\frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{2\pi_d}, \qquad \text{Kaplow test},$$

where Δ_m signifies the deadweight loss associated with monopoly, Δ_d the deadweight loss associated with duopoly, π_m monopoly profits and $2\pi_d$ industry profits under duopoly.

Under this test, the efficient type of protection is that which minimizes the social costs required to provide incentives to innovate. Since innovation and diffusion of the innovation are conflicting goals, the efficient solution is the one that is able to achieve the best trade-off between the two.[8]

Since the deadweight loss increases more than proportionally with industry profits (as far as demand is not too convex), strong property rights (and attendant monopoly power) turn out to be excessively costly to society. Under Kaplow's test, weak property rights are generally preferable because, by allowing for some degree of competition, they reduce the deadweight loss attendant with industry profits. As such, weak IP rights represent an ideal alternative to the extreme solutions defined by full exclusivity (which provides too little diffusion of the innovation) and prefect competition (which provides too little reward to the innovator).

We contend that the Kaplow test - and the theories that derive from it - miss an important element for the correct evaluation of alternative policy solutions. In particular, we argue that a proper comparison between regimes should also account for the adverse effect that the fragmentation of the reward has on ex-ante incentives. If we move away from the hypothesis that the amount of research of each firm is fixed, as in Lamanna et alt., and assume instead that the amount of research carried out by each firm depends on the reward structure, then it becomes evident that the presence of multiple prizes will have an adverse effect on the inventive to innovate. The purported positive effects of fragmentation will then have to be balanced against their adverse incentive effects and the ratio test will have to be reformulated accordingly.

[8] In his original formulation, Kaplow (1984) adds some caveats: "The ratio test, which compares the patentee's reward to the monopoly loss imposed on society, should guide the evaluation of restrictive practices. Practices with [lower] ratios generally should be preferred. 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 Kaplow test in the economics of IP, see Scotchmer (2004), ch.4.

Let us consider again duopoly profits upon imitation/duplication (Fig. B). The first inventor earns π_1, the second inventor earns π_2. We argue that the allocation of profits according to priority in time importantly affects the incentives to innovate. While the incentives to innovate depend positively on π_1 - the reward for the firm that has won the innovation race,- they are likely to depend negatively on π_2, - the reward for the firm that has lost the innovation race (and has caught up by means of imitation or parallel development). A proper computation of the incentives to innovate has to account for the combined impact of π_1 and π_2.

Closer scrutiny shows that the impact of π_2, the reward to the laggard, essentially depends on the nature of the innovation process. If research entails little or no spill-overs, then the impact of π_2 on the incentives to innovate is clearly negative. Furthermore, the negative impact is greater if the race is more intense. If the rival spends a large amount of resources and is likely to discover soon, then the presence of the second prize for the loser is likely to have larger adverse consequences on the incentives to invest. If the rival is not likely to discover soon, then the presence of a second prize has very little impact on the incentives to innovate.

If research entails very large spill-overs (in the sense that an increase in research of Firm 1 impacts positively the chances of discovery of Firm 2, and vice versa), then firms turn their attention more to the total amount of reward available, rather than to the division between first and second prize. In fact, when the spill-over is extremely strong, individual firms might not even be able to invert the arrival order: their research effort advances the probability of discovery at industry level (one of the firms innovates), but has no impact on priority. When this occurs, research investments are said to be "cooperative" in nature.[9] Here, an increase in the second prize has a positive impact on the incentives to innovate: the adverse priority effect (consolation prize for the loser) is outweighed by the direct positive effect (the firm is able to bring the second prize forward in time).

Depending on the nature of the innovation process (rival or cooperative), π_2 may either spur innovation or slow it down. Our task is to develop a simple way to account for this effect on the incentives to innovate and to include this into the ratio test. For this purpose, we need to sketch a simple dynamic model of innovation.

[9] The concept of "cooperative" innovation is adapted from the literature on contractual investments (e.g. Che and Hausch 1999), and is not related to cooperative joint ventures.

3 Rewarding rivalry

Let us consider the case where two firms independently pursue the same innovation and assume that discovery follows a Poisson process.[10] The probability that firm 1 makes the discovery in a unit time period is x_1, while the probability that the discovery is 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 discovery by the rival. P_L is zero under a system of full exclusivity, while it includes the expected profits from successful duplication under a system of weak IP rights.

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.

We leave the details of the analysis to the appendix (see also Denicolò and Franzoni 2007). To gain some insight, however, let us consider the problem of Firm 1. In order to maximize its payoff, Firm 1 will set x_1 so as to equate marginal benefits and costs:

$$\underbrace{\frac{P_W \ r}{(x_1 + x_2 + r)^2}}_{\text{earlier discovery}} + \underbrace{\frac{x_2 (P_W - P_L)}{(x_1 + x_2 + r)^2}}_{\text{priority effect}} = \underbrace{\frac{c'(x_1)(x_1 + x_2 + r) - c(x_1)}{(x_1 + x_2 + r)^2}}_{\text{marginal costs}} \tag{1}$$

Eq. (1) is central to understand the impact of multiple prizes.

Marginal benefits include two terms. The first term, denoted "earlier discovery" effect, captures the fact that an increase in the research effort brings the expected discovery date forward (with attendant prize). The second term - the "priority effect" - represents the gain of preempting firm 2 in the priority race: by increasing its probability of discovery, Firm 1 increases its chances of preventing Firm 2 from discovering in the following period (with probability x_2). Discovery by Firm 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 research costs per period and the reduction in costs due to earlier termination of the race.

[10] Memoryless Poisson processes are commonly employed in innovation theory since they display a very simple dynamic path: in each time interval, the equilibrium probability of discovery remains the same.

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

The "priority effect" is at the center of our analysis. It captures the intensity of the *rivalry* in innovation: each firm has greater incentives to invest in research if it believes that the other one has good chances to make the discovery. This effect is the outcome of a "common pool" problem in innovation races: opportunities to discover are finite and firms contest to grasp them. By making a discovery, a firm terminates the race and deprives the other ones of the chance to make the same discovery.[12]

From eq. (1) one can easily see that the second prize P_L impacts negatively the incentives to innovate, since it reduces the priority effect. If we compute the *relative* disincentive power of $P_{L,}$ we get

$$\frac{-\frac{\partial x}{\partial P_L}}{\frac{\partial x}{\partial P_W}} = \frac{\partial P_W}{\partial P_L} = \frac{x_2}{x_2 + r} = \delta(x).$$

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

This is the key information for our reformulation of the Kaplow test. In the numerator of our ratio test we keep the dissemination costs of exclusive rights, measured by the standard deadweight loss. In the denominator, we measure the incentives to innovate. For strong IP rights, incentives to innovate are proportional to monopoly profits. For weak IP rights (after the initial lead time has elapsed and monopoly has terminated), incentives to innovate are proportional to the duopoly profits of the innovator *suitably deflated by the presence of the consolation prize* (that is, including $-\delta(x)\pi_2$)

Hence, strong IP rights turn out to be socially preferable if (see the appendix for the proof)

$$\text{Modified Ratio Test: } \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d \, [1 - \delta(x)]} \tag{2}$$

Our modified ratio test has two distinguishing features.

First, for the case where the race displays very little rivalry ($\delta(x) \to 0$), what matters for the assessment of the weak IP regime is the ratio of deadweight loss to individual profits, rather than industry profits. As opposed to the Kaplow test, here we recognize that only duopoly profits

[12] The "common pool" problem has been 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.

accruing to the first inventor foster innovation (profits accruing to the second inventor foster instead imitation).

Second, our ratio test accounts for the degree of rivalry of the innovation race. If the rival is closer to discovery, then the presence of the consolation prize has a larger adverse effect on the incentives to innovate (large $\delta(x)$). Clearly, the more rivalrous the innovation race, the less desirable is the fragmentation of the entitlement.

Note that $\delta(x)$ has a simple interpretation: it is the "discounted probability" of success of the rivals in the innovation race.[13] In intuitive terms, $\delta(x)$ tells us how likely it is that the rivals will complete the project and claim priority. More precisely, $\delta(x)$ measures how far away in time is the expected discovery date of the rivals. If rivals are to discover "soon", then the race is very intense and the presence of exclusive rights matters a lot (firms are afraid of losing the priority). If rivals are to discover "late", the race for priority is less intense and the presence of exclusive rights is less important. In the latter case, firms care more about bringing the date of discovery forward rather than preempting rivals.

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How do we get a feeling of the magnitude of $\delta(x)$?

Note that $\frac{1}{x}$ is the expected time until discovery by the rivals.

If the expected time of discovery of the rivals is 2 years (so that $x = 0.5$) and the interest rate is $r = 5\%$, then $\delta(x) = \frac{0.5}{0.5+0.05} = 0.90$.

If the expected time of discovery of the rivals is 5 years (so that $x = 0.02$) and the interest rate is $r = 5\%$, then $\delta(x) = \frac{0.02}{0.02+0.05} = 0.80$.

If the expected time of discovery of the rivals is 10 years (so that $x = 0.1$) and the interest rate is $r = 5\%$, then $\delta(x) = \frac{0.1}{0.1+0.05} = 0.66$.

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In this basic model, the discounted probability of discovery of rivals is large and innovation is more rivalrous when*:* i) the innovation attracts a lot of investments (say because the innovation at hand is "big" or the marginal costs are low), ii) the interest rate is large (future payoffs have lower value).

Weak IP rights are socially desirable when they are able to effectively reduce the obstacles to the diffusion of innovation (low deadweight loss) and when the race to discovery is not too rivalrous. More specifically, weak IP rights are desirable when ex-post competition between firms tends to be

[13] The result does not change if there are many rivals.

intense and the innovation does not attract large investments (in this case, it would become rivalrous).

4 Cooperative innovation

In this section, we extend our results to the case where research activities within an industry have non-rivalrous nature. More precisely, we consider the case where research by one firm entails positive spill-overs on the innovation activity of the other firms.

Innovations produced in industries characterized by large spill-overs are the result of the efforts of all firms of the industry. In this sense, they can be assimilated to the "collective innovations" first analyzed by Allen (1983).[14] Recent cases where research takes the shape of a collective enterprise are found in the software industry with respect to the development of open source software (Orsteloh and Rota 2007) and in the semiconductors industry in the Silicon Valley district (Hall Ziedonis 2001).

Different factors can impact the degree of "research sharing" within each industry. Among the most important, we should list industry practice with respect to: i) formal or informal communication between researchers (say at professional and academic conferences), ii) job mobility of researchers and technical personnel (taking with them inside information), iii) ease of technical espionage.

Note that by and large, these features denote a scant protection of technological information. Thus, large spill-overs are likely to be themselves the result of a regime of weak protection of technological know-how (see, for instance, Saxenian 1994 and Gilson 1999).

Let us consider the impact of research spill-overs on the degree of rivalry of innovation. Let us assume that the probability of discovery of each firm depends on its own research effort and on the research effort of the rival. More specifically, let the probability that Firm 1 makes the discovery in the unit time period be:

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

where $\sigma \in [0, 1)$ 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 that Firm 2 makes the discovery in the unit time period is equal to

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

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

Firm 1's expected profits are now

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

and the optimal choice of x_1 must satisfy (omitting arguments):

$$\underbrace{\frac{(P_W + \sigma P_L)\, r}{\left(\lambda^1 + \lambda^2 + r\right)^2}}_{\text{earlier discovery}} + \underbrace{\frac{\left(\lambda^2 - \sigma\lambda^1\right)(P_W - P_L)}{\left(\lambda^1 + \lambda^2 + r\right)^2}}_{\text{priority effect}} = \underbrace{\frac{c'\ \left(\lambda^1 + \lambda^2 + r\right) - c\ \left(\lambda_1^1 + \lambda_1^2\right)}{\left(\lambda^1 + \lambda^2 + r\right)^2}}_{\text{marginal costs}}, \tag{3}$$

An increase in the research effort of Firm 1 brings forward the payoff from discovery (discovery by Firm 1 or, through the spill-over, discovery by Firm 2) and prevents itself from being relegated to the second place.

Note that the priority effect is smaller if the spill-over is larger: when research of Firm 1 affects the probability of discovery of Firm 2, the ability of each firm to "reverse" the order of arrival is blunted. In the extreme case in which research effort of each firm affects in the same way the probability of discovery of all firms, the priority effect vanishes: firms are not able to affect the order of arrival.

The relative (dis)incentive effect of the second prize is now

$$\frac{-\frac{\partial x}{\partial P_L}}{\frac{\partial x}{\partial P_W}} = \frac{\partial P_W}{\partial P_L} = \frac{\lambda^2 - \sigma\lambda^1 - \sigma r}{\lambda^2 - \sigma\lambda^1 + r}, \tag{4}$$

which can also be written as (see appendix)

$$\frac{\partial P_W}{\partial P_L} = \frac{\delta(x) - \sigma}{1 - \sigma\ \delta(x)} = \rho(x),$$

where $\delta(x) = \frac{\lambda(x_2)}{\lambda(x_2) + r}$ is the discounted probability of innovation of the rival.

A one dollar increase in the reward to the loser of the priority race is equivalent to a reduction in the reward to the winner by $\rho(x)$ dollars.

As the spill-over gets larger, the innovation race becomes less rivalrous: 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 $\delta(x)$ to -1.

For σ sufficiently large ($\sigma > \delta(x)$), an increase in the second prize has a positive impact on the incentives to innovate. Here, the incentives to innovate are driven mostly by the earlier discovery effect and firms carry out research in the attempt to bring forward the date in which they will collect one of the prizes, be it the first or the second. The priority effect is blunted by the spill-over (the link between the firm's research and priority is weakened). Here, the innovation process is "cooperative" in nature: the positive externality due to the spill-over outweighs the negative externality due to the common pool effect.

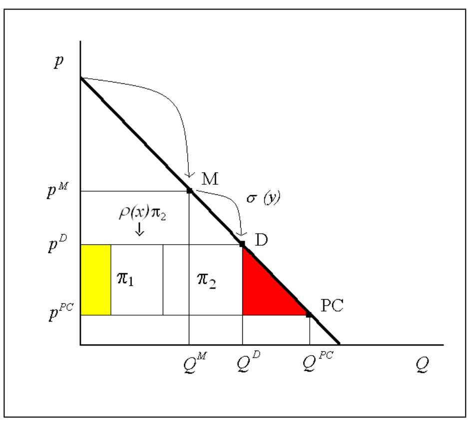
For environments characterized by maximum spill-over, $\sigma \to 1$, the first and the second prize become perfect substitutes: they have the same effect on the incentives to innovate (an increase in the second prize by 1 dollar is equivalent to an increase in the first prize by 1 dollar).

Our modified test becomes now (replacing $\rho(x)$ for $\delta(x)$ in ineq. 2):

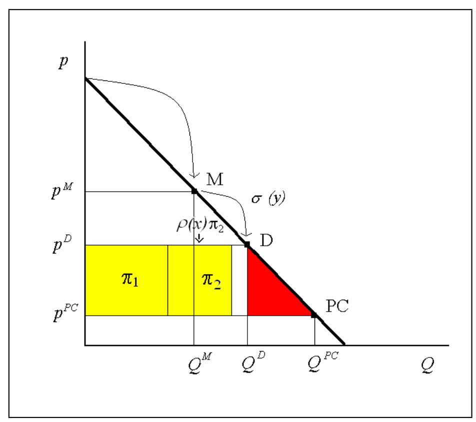
$$\text{MODIFIED RATIO TEST: } \frac{\Delta_m}{\pi_m} < \frac{\Delta_d}{\pi_d \ [1 - \rho(x)]},$$

where $\rho(x)$ is positive if the innovation process is rivalrous, and negative if it is cooperative.

As the innovation race becomes less rivalrous and more cooperative, the test gets harder to pass. Figures illustrate.



Rivalrous innovation.



Cooperative innovation.

The incentive to innovate is proportional to $\pi_1 - \rho(x)\pi_2$, where -$\rho(x)$ is negative for rivalrous innovations and positive for cooperative innovations.

From the definition of $\rho(x)$ we find that strong IP protection is preferable if

i) competition emerging from imitation is weak (large $\frac{\Delta_d}{\pi_d}$);

ii) the innovation at hand attracts large investments (large x_2);

iii) the spill-over is small.[15]

If there are no spill-overs, then what matters is the degree of rivalry, as in Section 3.

Note that for any level of the spillover ($\sigma < 1$), innovation remains rivalrous if the level of investment in research is sufficiently large.

However, if the spill-overs is extremely large, $\sigma- > 1$, then strong IPRs are preferable if

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

which is the standard Kaplow test. Remarkably, *the standard Kaplow test applies if firm's research has no impact on priority.*

To sum up, our results suggest that property fragmentation might represent an efficient reward system for those environments characterized by strong research spill-overs ("collective research") and small research investments.

As a final caveat, we should recall that weak property rights entail an additional distortion. Let us look again at Figure 2. After one of the firms has made the discovery, the other engages in catching up. The costs borne by the laggard partially dissipate the expected profits accruing from successful duplication. These costs, which are borne only in the weak IP regime, have a double impact. They increase the social costs of the weak IP regime, but also reduce the second prize and hence increase the incentives to innovate. Overall, however, duplication costs tend to favour strong IP rights (see the Appendix 7.1).

5 Policy discussion

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

[15] Note that we are working with implicit functions, since x is endogenously determined. With quadratic research costs, x depends negatively on σ. Our interpretation of the results is thus consistent with this more general view.

5.1 Patents and trade secrets

Not all innovations can be patented.[16] Innovation that do not meet the patentability requirements can only be protected by trade secrecy or, in some specific fields, copyright. These types of IP protection differ on many accounts. Patent protection is commonly regarded as the most strong form of protection (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 has been patented, any unauthorized duplication infringes on the patent right, even if the duplication has taken place by means of independent rediscovery.[17]

Other forms of IP protection are definitely weaker on this account. Trade secret law protects the innovator against "misappropriation" of IP (e.g. by means of 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 imitation profits outweigh imitation 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 secret protection does not provide a "property right" in the standard sense. Rather, it defines a "quasi-liability regime", 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.[18] Copyright is said to protect expression rather than ideas, which should freely circulate in the public arena. Reverse engineering of copyright material, however, is subject to specific restrictions. Decompilation or disassembly of object code for the sake of developing interoperable software, for instance, is generally deemed as legal (after Sega v Accolade, 977 F.2d 1510, 9th Cir. 1992). Under the Digital Millennium

[16] 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 differences in the propensity to patent across industries.

[17] 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 infringer was put on notice or not (see Blair and Cotter 2001).

[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 songwriter copyright (see Landes and Posner 2003, p. 88).

Copyright Act, however, circumvention of technical measures used to protect copyrighted works (so called "digital locks"), as well as the distribution of circumvention technologies, is forbidden[19].

Our analysis is not about the optimal degree of reverse engineering. We focus instead on the optimality of exclusivity rules from an ex-ante perspective, given the ease of duplication.

Our results shed light on the issue of which class of innovations, or industries, should have access to patent protection. In very broad terms, we are offering insights on both the issue of the patentable subject matter and the patentability requirements.

We contend that strong exclusive rights should apply to competitive (read rivalrous) innovation sectors where firms race neck and neck for major innovations, where research knowledge is jealously held , and where product competition (in case of imitation) is weak.

5.2 Independent inventor defense

It is not unusual that the same discovery is made nearly simultaneously by different parties. Classic examples of such discoveries 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).[20]

Simultaneous discoveries of this type put some strain on the patent system, which is called upon to determine who is the true and first inventor.[21]

The idea that only the first inventor (be it the first to invent or the first to file) should be allowed to practice the innovation has been recently put into question by an influential stream of the literature, originating from the pioneering contribution of Lamanna et alt. (1989) and further developed by

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

[20] Examples are taken from Shapiro (2007), with the exception of Meucci, whose contribution has been overlooked for a long time. In June 2002, however, the House of Representatives has passed a reparatory resolution: "If Meucci had been able to pay the $10 fee to maintain the caveat after 1874, no patent could have been issued to Bell" (H. Res. 269).

[21] Evidence of nearly simultaneous innovations can be obtained by looking at 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 big corporations with large patent portfolios - Cohen and Ishii (2006).

Leibovitz (2002), Maurer and Scotchmer (2002), Kultti and Takalo (2008), Shapiro (2006) and (2007) and Vermont (2007) and (2008) and Henry (2007).

The arguments in favour of weak patents closely resemble those in favour of trade secrecy (weak IP). Apart from the many practical problems that a system of weak patents would pose (see Lemley 2007), a system of weak patents would differ from a regime of trade secrecy in the temporal length of the "oligopolistic" regime. Under secrecy, oligopoly terminates when the secret somehow leaks out (possibly never); under weak patents, oligopoly terminates when the patent of the first inventor expires.

In appendix 7.2, we show that our ratio test also applies to this special set up.

The general recommendation arising from our results markedly differs from that put forward by Shapiro (2006) and (2007). We should therefore look at his arguments more closely.

Shapiro (2007) underscores the fact that in presence of multiple nearly simultaneous innovations, a wedge is likely to arise between the private reward to the first innovator and his social contribution. Take the case of a firm that is able to make the discovery one day before the rival: in this case, the marginal social contribution is equal to 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. There is in this case a gross disproportion between reward and contribution. On the basis of this observation, Shapiro argues that, in order to bring private and social benefits in line, one should reduce the reward to the winner by forcing him to share the market with the second inventor, if and when it materializes.

In our model, this conclusion is not warranted.

We agree that when the innovation race is tight, and many firms independently pursue the same invention, then the marginal contribution of each firm is small.[22] This does not mean, however, that firms - in average - are overcompensated. In fact, for a firm that gets a relatively big reward, there are many others that get no reward at all.

It is also true that when races are tight, the incentive to invest in research is amplified by the desire of each firm to preempt the rivals in the priority race. In the eyes of the firms, the marginal benefit of bringing the innovation date forward by one day is not just the value of earlier discovery but also, and more importantly, the value of preempting rivals and "take away from

[22] The marginal contribution to discovey is proportional to the "earlier discovery" term of eqs. 1 and 3.

them" the winner's prize. From a social point of view, however, who makes the discovery is not relevant. Hence, expenditures borne with the purpose of "redistributing" the prize across contestants tend to be essentially non productive.

We argue however that society can net a benefit from these "rivalrous" expenditures. In fact, when competition for priority is strong, incentives to innovate can effectively be obtained by means of a limited prize. Since the prize is costly to society - monopoly profits come with a social cost - it should be handed out parsimoniously. Devises able to reduce the total amount of profits to be relinquished to firms are socially valuable.[23]

This is the essence of our argument. We do not contest that the *absolute* level of the reward accruing to innovators in the presence of multiple discovery might be too large. However, a proper evaluation of the right level of the remuneration of innovation is a complex endeavour, which should take into account all "distortions" of the IP regime, including the fact that total private benefits only entail a small fraction of total social benefits available and that the supply of innovations may be more or less sensitive to the level of the reward.[24] In the historical examples mentioned above (e.g. the invention of the telegraph, the light bulb, etc.), the impact of the innovations on people's daily life was so deep that one can hardly claim that they were invented too early or that too much effort was devoted to their discovery.

Suppose however that we can prove that, for some industries characterized by frequent simultaneous discoveries, research expenditure is excessive and that it should decrease. In order to advocate for property fragmentation, one would still have to prove that there are no other policy tools able to achieve the same goal at a lower social cost. In fact, as we have shown, for rivalrous innovations a simple reduction of the patent term can do the same job in a better way.

For industries with large spill-overs and low research expenditures, weak property rights might instead provide the efficient solution. Remarkably, this suggests that fragmented entitlements are recommended in situations characterized by strong *under-compensation* of innovators rather than over-compensation, as argued by Shapiro and Vermont.

[23] It can be proved that, given the same incentives to innovate, the expected profits made by firms are lower if IP rights are strong.

[24] Denicolò (2007) argues that, as a general rule, the elasticity of supply of the number of innovations should be the main criterion to establish the "right" level of compensation of innovators.

5.3 Intellectual property and antitrust

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

The stance taken by courts and antitrust authorities on this issue varies over time and differs across countries (see for instance Schweizer 2007). In the US there is a general consensus - reinforced by the recent *Trinko* decision (540 U.S. 398, 2004) - that competition rules should not trump IP law.[25] In Europe, anti-trust authorities and courts follow a different approach, which tends to set a closer boundary to IPRs. A refusal to licence an IPR by a dominant undertaking constitutes an abuse if certain conditions hold, outlined by the European Court of Justice in the *Magill* case. The EU antitrust authorities seem to support a "balancing of interests" approach, where the positive effect of competition should be weighted against the adverse impacts on innovation on a case by case basis (DG Competition 2005).

Our analysis provides a broad framework for the assessment of such practices, highlighting the tension between competition and innovation. We argue that most of the times the impact of policy decisions on the innovation process is not straightforward, and that profits at firm or industry level cannot be taken as a proxy of the incentives to innovate. In order to assess the impact of such decisions, one should consider how they alter the "reward structure" for successful innovation. Policies aimed at improving ex-post competition can have a huge adverse impact on the incentives to innovate, especially in industries where innovation is fast and research is well protected. In such industries, it is generally not a good idea to use competition as a means to decrease the reward to the innovator.

6 Conclusions

This paper contributes to the analysis of the optimal scope of IP protection. We have shown that the trade-off between the broad goals of creation and diffusion of the innovation can be addressed by means of a simple ratio test.

[25] See, for instance, the recent report by the U.S. Dept. of Justice and Fed. Trade Commission (2007).

Admittedly, our analysis abstracts away from a number of important issues, concerning administrative and enforcement costs, the effectivenss of patent disclosure, the impact of IPRs on technology licensing, and so on. We are also aware that practical implementation of the test requires a large amount of information, that courts and lawmakers may not be able to get.[26]

These difficulties notwithstanding, we believe that our analysis is able to provide a framework broad enough to shed some light on the complex implications of exclusivity in innovation industries.

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. P_W and P_L depend on the strength of IP rights.

The optimal research effort x_1 must satisfy

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

Weak and strong IP rights provide therefore the same incentives to innovate if

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

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

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

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

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

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

Let us consider now the rewards to the firms.

Under patenting, the winner takes all: $\hat{P}_L = 0$ and

$$\hat{P}_W = \tau\frac{\pi_m}{r} \tag{5}$$

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

Under weak IP rights, the loser of the race invests in duplication effort until he is able to replicate the innovation. From that time on, it gets duopoly profits:

$$P_L = (1-\ell\ )\frac{\pi_d}{r} - \ell\ \frac{s(y)}{r}, \tag{6}$$

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

The winner of the race gets instead monopoly profits during the lead time and duopoly profits thereafter:

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

In order to get the same incentives 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

$$\tau = \ell \ + (1-\ell\ )\, \frac{\pi_d}{\pi_m} - \rho\,(x)\ \left[(1-\ell\ )\, \frac{\pi_d}{\pi_m} - \ell\ \frac{s\,(y)}{\pi_m} \right]. \tag{7}$$

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

Under patenting, expected social welfare is

$$\hat{W} = (1-z) \left[\tau \frac{v-\Delta_m}{r} + (1-\tau)\frac{v}{r} \right] - z\ \ 2\ c(x), \tag{8}$$

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 minus 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 minus monopoly deadweight loss Δ_m, minus duplication costs $-s(y)$ borne by the laggard; for the remaining period, the full social value minus duopoly deadweight loss Δ_d.

Since the discovery time is the same by assumption, strong IP provide higher 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. 7, we get 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 imitation profits dissipated in imitation costs (see eq.6).

Then, upon simplification, we get:

$$\text{GENERAL RATIO TEST:} \qquad \frac{\Delta_m}{\pi_m}(1-\rho(x)) < \frac{\Delta_d}{\pi_d} + \Sigma\left(1-\rho(x)\frac{\Delta_m}{\pi_m}\right). \quad (9)$$

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

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

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

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 inventor defense

Let us now compare weak and strong patents. Weak patents allow for an independent inventor defence.

Under weak patents, the loser of the race keeps investing until he is able to replicate the innovation. This happens after an expected discounted time period equal to $\widetilde{\ell}$[27] From that time one, it gets duopoly profits until the

[27] For simplicity, we assume here that discovery by the first inventor is public knowledge. What is not known by the second inventor is the content of the discovery, and that is why he is forced to continue in the research. We make no assumption on the relationship between research costs before and after discovery by the rival.

patent of the first inventor expires (the patent term is T_1, the discounted duration of the patent is t_1):

$$\begin{aligned}\widetilde{P}_L &= \int_0^{T_1} e^{-rt}\ e^{-yt}\ y\ \left[\int_t^{T_1} e^{-(s-t)r} ds\right]\ \pi_d\ dt \\ &\qquad\qquad - \int_0^{T_1} e^{-rt}\ e^{-yt}\ s\,(y)\ dt \\ &= \left(t_1 - \widetilde{\ell}\right) \tfrac{\pi_d}{r} - \widetilde{\ell}\ \tfrac{s(y)}{r},\end{aligned}$$

where

$$\widetilde{\ell} = \frac{e^{-T_1(r+y)}\left(r - e^{T_1 y}\left(r + y - e^{T_1 r} y\right)\right)}{(r+y)}$$

is the expected discounted time until duplication. y is the intensity of the duplication effort and is decided by the duplicator so as to maximize P_L.

The reward for the winner of the innovation race is instead:

$$\widetilde{P}_W = \widetilde{\ell}\ \frac{\pi_m}{r} - \left(t_1 - \widetilde{\ell}\right) \frac{\pi_d}{r}. \tag{10}$$

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

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

Strong and weak patents provide the same incentives to innovate if

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

that is

$$\tau \frac{\pi_m}{r} = \widetilde{\ell}\ \frac{\pi_m}{r} - \left(t_1 - \widetilde{\ell}\right) \frac{\pi_d}{r} - \rho\,(x)\ \left[\left(t_1 - \widetilde{\ell}\right) \frac{\pi_d}{r} - \widetilde{\ell}\ \frac{s\,(y)}{r}\right],$$

or

$$\tau = \widetilde{\ell}\ + \left(t_1 - \widetilde{\ell}\ \right) \frac{\pi_d}{\pi_m} - \rho\,(x)\ \left[\left(t_1 - \widetilde{\ell}\ \right) \frac{\pi_d}{\pi_m} - \widetilde{\ell}\ \frac{s\,(y)}{\pi_m}\right]. \tag{11}$$

For the same incentives to innovate, strong patents yield a higher social welfare if

$$\left[\tau \frac{v - \Delta_m}{r} + (1-\tau)\frac{v}{r}\right] > \left[\widetilde{\ell}\ \frac{v - \Delta_m - s(y)}{r} + \left(t_1 - \widetilde{\ell}\right) \frac{v - \Delta_d}{r}\right].$$

Using 11, the previous inequality can be rewritten as

$$\frac{\Delta_m}{\pi_m}\left(1 - \rho\,(x)\right) < \frac{\Delta_d}{\pi_d} + \widetilde{\Sigma}\left(1 - \rho\,(x)\ \frac{\Delta_m}{\pi_m}\right). \tag{12}$$

where

$$\widetilde{\Sigma} = \frac{\widetilde{\ell}}{\left(t_1 - \widetilde{\ell}\right)} \frac{s(y)}{\pi_d},$$

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

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