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How much should society fuel the greed of innovators? On the relations between appropriability, opportunities and rates of innovation

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Abstract

The paper attempts a critical assessment of both the theory and the empirical evidence on the role of appropriability and in particular of Intellectual Property Rights (IPRs) as incentives for technological innovation. We start with a critical discussion of the standard justification of the attribution of IPR in terms of "market failures" in knowledge generation. Such an approach, we argue, misses important features of technological knowledge and also neglects the importance of non-market institutions in the innovation process. Next, we examine the recent changes in the IPR regimes and their influence upon both rates of patenting and underlying rates of innovation. The evidence broadly suggests that, first, IPRs are not the most important device apt to "profit from innovation"; and second, they have at best no impact, or possibly even a negative impact on the underlying rates of innovation. Rather, we argue, technology- and industry-specific patterns of innovation are primarily driven by the opportunities associated with each technological paradigm. Conversely, firm-specific abilities to seize them and "profit from innovation" depend partly on adequacy of the strategic combinations identified by the taxonomy of [Teece, D., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. Research Policy 15, 285–305.] and partly on idiosyncratic capabilities embodied in the various firms.

Keywords: Innovation; Appropriability; Intellectual property rights; IPR; Teece

1. Introduction

This paper attempts a critical assessment of both theory and empirical evidence on the role and consequences of the various modes of appropriation, with particular emphasis on Intellectual Property Rights (IPRs), as incentives for technological innovation.

That profit-motivated innovators are fundamental drivers of the "unbound Prometheus" of modern capitalism (Landes, 1969) has been well appreciated since Smith, Marx and, later, Schumpeter. For a long time such an acknowledgment has come as an almost self-evident "stylized fact". Finer concerns of the determinants of the propensity to innovate by entrepreneurs and business firms came much later with the identification of a potentially quite general trade-off underlying the economic exploitation of technological knowledge: in so far as the latter is a non-rival and hardly excludable quasi-public good, pure competitive markets are unable to generate a stream of quasi-rents sufficient to motivate profit-seeking firms to invest resources in its production (Arrow, 1962). In order to provide such incentives, a general condition is to depart from pure competition

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(as was indeed quite naturally acknowledged by Smith, Marx and Schumpeter).

Granted that, however, what is empirically the extent of such a departure? And, from a normative point of view, what is the desirable degree of appropriability able to fuel a sustained flow of innovations undertaken by business firms? And through which mechanisms? Moreover, what is the impact of different institutional and technological conditions upon the profitability and competitive success of innovators themselves?

The latter angle is the one tackled in the seminal paper of Teece (1986) who argues that profits from innovation depend upon the interaction of three families of factors, namely, appropriability regimes, complementary assets and the presence or absence of a dominant paradigm. Note that, appropriability conditions, in addition to patent and copyright protection, include secrecy, lead times, costs and time required for duplication, learning, sales and service assets. Moreover, as Teece emphasizes, such appropriability regimes are largely dictated by the nature of technological knowledge (Teece, 1986, p. 287).

These fundamental observations on the mechanisms through which firms "benefit from innovation", however, have been lost in a good deal of contemporary literature on the incentive to innovate, wherein, first, appropriability conditions are reduced almost exclusively to IPR regimes, and, secondly, the award of IPR themselves is theoretically rooted in a framework – in our view deeply misleading – namely that of "market failures".

In what follows we start from a critical assessment of such a perspective and of the related notion of a monotonic relation between IP protection and rates of innovation (Section 2).

Next, after an overview of the recent changes in IPR regimes (Section 3), in Section 4 we review the empirical evidence on the relationship between appropriability in general and IP protection in particular, on the one hand, and rates of innovation on the other. Such evidence, we shall argue, suggests that, first, appropriability conditions are just one of several factors (possibly a second order one) shaping the propensity to innovate. Together, the relative importance of the various factors and their interaction is highly sector and technology specific.

Second, appropriability is likely to display a threshold effect, meaning that a minimum degree of appropriability is necessary to motivate innovative effort, but above such a threshold further strengthening of appropriability conditions will not determine further increases of R&D investments and rates of innovation. Rather, social inefficiencies such as "anti-commons" effects (Heller and Eisenberg, 1998), rent seeking behaviours, dissipation of quasi-rents into litigation etc. are much more likely to emerge.

Third and relatedly, there seems to be no clear evidence of a positive relation between the tightening of IPRs regimes and the rates of innovation. Conversely, there is good evidence on the (perverse) links between IPRs protection and income distribution.

The rates of innovation, we suggest, fundamentally depend on paradigm-specific opportunities rather than on mere appropriability conditions (at least above some threshold) and even less so on the specific subset of appropriability devices represented by legal IPR protection.

Note that observed rates of innovation at the level of an industry or an economy are only remotely related to any 'equilibrium' rate of R&D investment by the "representative" firm, whatever that means. Given whatever incentive profile, one typically observes quite varied search responses (as very roughly measured by R&D investments) and also quite different technological and economic outcomes, well beyond what a statistician would interpret as independent realizations of the same underlying random process. We thus conclude (Section 5) that while the first order determinants of the rates of innovation rest within the technology-specific and sector-specific opportunity conditions, the differential ability of individual firms to economically benefit from them stem from idiosyncratic organizational capabilities.

But if this is the case, the answer to the question we ask in the title of this paper is also straightforward: fuelling the greed of innovators might be at best irrelevant for the ensuing rates of innovation, while of course bad from a social point of view.

2. Some failures of the "market failure" arguments

The economic foundations of both theory and practice of IPR rest upon a standard market failure argument, without any explicit consideration of the characteristics of the knowledge whose appropriation should be granted by patents or other forms of legal monopoly.

The proposition that a positive and uniform relation exists between innovation and intensity of IP protection in the form of legally enforced rights such as patents holds only relative to a specific (and highly disputable) representation of markets, their functioning and their "failures", on the one hand, and of knowledge and its nature on the other.

The argument falls within the realm of standard "Coasian" positive externality problem, which can be briefly stated in the following way. There exists a normative set of efficiency conditions under which markets perfectly fulfil their role of purely allocative mechanisms.

The lack of externalities is one of such conditions because their appearance amounts (as with positive externalities) to under-investment and under-production of those goods involved in the externality itself. Facing any departure from efficiency conditions, a set of policies and institutional devices must be put in place with the aim of re-establishing them in order to achieve social efficiency. Knowledge generation is one of the loci entailing such an externality: since knowledge is (to a good extent) a public good, it will be underproduced and will receive insufficient investments. Hence an artificial scarcity is created to amend non-rivalry and non-excludability in its use, yielding an appropriate degree of appropriability of returns from investments in its production. The core of the matter then becomes one of balancing out the detrimental effect of the deadweight loss implied by a legally enforced monopoly, on the one hand, and the beneficial effect of investments in R&D and more generally in knowledge generation, on the other.

A number of general considerations can be made about this argument.

First, the argument fundamentally rests on the existence of a theoretical (but hardly relevant in terms of empirical and descriptive adequacy) benchmark of efficiency against which policy and institutional interventions should be compared as to their necessity and efficacy.

Second, the efficiency notion employed is a strict notion of static efficiency which brings with it the idea that markets do nothing except (more or less efficiently) allocate resources.

Third, a most clear-cut distinction between market and non-market realms is assumed, together with the idea that non market (policy, institutional) interventions can re-establish perfect competition using purely market-based "tools".

Fourth, it is assumed that the nature of "knowledge" is totally captured by the notion of "information" thus setting the possibility of institutionally treating it in uniform ways, neglecting any dimension of knowledge which relates to its "non public good" features.

According to this perspective, the transformation of the public good "knowledge" in the private good "patent" will perfectly set incentives for its production by way of legally enforced conditions and possibilities of appropriability.

However, if one starts questioning that markets solely allocate resources one may begin to consider them as performing a wider set of activities such as being the places in which "novelty" is (imperfectly) produced, (imperfectly) tested and (imperfectly) selected. In this alternative perspective, it becomes hard to reduce any efficiency consideration to static efficiency so that, for instance, it is not necessarily true that allocative patterns which are efficient from a static perspective have the same property from a dynamical point of view. It thus follows that the institutional attribution of property rights (whether efficient or not in a static allocative perspective) may strongly influence the patterns of technological evolution in directions which are not necessarily optimal or even desirable.

In this sense, any question about the appropriate level of IP protection and degree of appropriability would be better grounded on a theory of innovative opportunities and productive knowledge (issues on which the theory of allocative efficiency is rather silent: cf. Winter (1982) and Stiglitz (1994) from different angles).

In addition, viewing markets as embedded and depending upon a whole ensemble of non-market institutions, allows to appreciate the fact that technological innovation is highly dependent on a variety of complementary institutions (e.g. public agencies, public policies, universities, communities and of course corporate organizations with their rich inner structure) which can hardly be called "markets" and hardly can they be regulated by pure market incentives. Precisely this institutional embeddedness of innovative activities makes it very unlikely that a "market failure" approach such as the one we sketched above could provide any satisfactory account of the relationship between appropriability and propensity to innovate.

Finally, the (misleading) identification of knowledge with information (that is, the deletion of any reference to cognitive and procedural devices whose role is to transform sheer information into "useful knowledge" and which are to a large extent tacit and embedded in organizations) makes one forget that processes through which new knowledge is generated are strongly dependent on the specificities of each technological paradigm (which hardly can be reduced to "information" categories).

One question which seems to be rarely asked (and answered) in precise terms is: what is (if any) the increase in the value of an innovation realized by way of patenting it? A straightforward answer to this question would be: in a perfectly competitive market, any innovation has no value (i.e. its price equals to zero) as its marginal cost of reproduction equals zero. As a consequence, the whole and sole value of an innovation comes from its being patented. Under this perspective, one is forced to conclude that a straightforward positive relation exists between innovative activities and patents: a relation in which patents are the one and only source of value of technological innovations (given perfect competition). That is, in Teece's words, patents would be the only way of "profiting from technological innovation".

Under more careful scrutiny, however, this argument is subject to a series of limitations and counter-examples. A first class of counter-arguments does arise from the many instances of innovations that in spite of not being patented (or patented under very weak patent regimes) have most definitely produced considerable streams of economic value.

Relevant examples can be drawn from those technologies forming the core of ICT. For instance, the transistor, while being patented from Bell Labs, was liberally licensed also as a consequence of antitrust litigation and pressure from the US Justice Department: its early producers nonetheless obtained enough revenue to be the seeds of the emergence of a whole industry (Grandstrand, 2005). The early growth of the semiconductor industry had been driven to a good extent by public procurement in a weak IP regime. The software industry, certainly a quite profitable one, similarly emerged under a weak IP regime. The telecom industry was largely operated by national monopolies until the 90s who were undertaking also a good deal of research, and IPRs played little role in the rapid advance of technology in this industry. Mobile telephony also emerged under a weak IP regime (until the late 1980s).

We suggest indeed that strong IPR did not play a pivotal role neither in the emergence of ICT nor as a means of value generation. Quite on the contrary, in the early stage of those sectors it might have been the very weakness of the patent regime that spurred their rapid growth. Conversely, the strengthening of the IP regime in recent years (soon after the ICT boom in the late 80s) might well have been (in terms of political influence) a consequence rather than a cause of the fast pace at which the ICT sector expanded.

Back to our opening question, it is worth noting how (some) economists have been at least cautious with respect to the adoption of the patent system as the only means to foster innovative activity and to its uniform effectiveness. As Machlup (1958) put it: "If we did not have a patent system, it would be irresponsible, on the basis of our present knowledge of its economic consequences, to recommend instituting one. But since we have had a patent system for a long time, it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it." Similar doubts are expressed in David (1993) and David (2002) who argues that IPR are not necessary for new technologies and suggests that different institutional mechanisms more similar to open science might work more efficiently.

Of course, the cautious economist is well aware that even from a purely theoretical point of view, the innovation/patent relation is by no means a simple one. And similarly tricky from a policy point of view is the identification of a balance between gains and losses of any system of intellectual property protection.

As a matter of fact, on the one hand it may be argued that intellectual property monopolies afforded by patents or copyright raise prices above unit production costs thus diminishing the benefits that consumers derive from using protected innovations. On the other hand, the standard argument claims that the same rights provide a significant incentive at producing new knowledge through costly investments in innovative research.

However, such a purported trade-off might well apply also at the micro level. Whether or not a firm has the profitability of its own innovations secured by IP rights, its R&D behaviour and its IPR enforcement strategies cannot be unaffected by the actions of other firms acquiring and exploiting their own IP rights. The effect of firms exploiting IP rights invariably raises the costs that other firms incur when trying to access and utilize existing knowledge. Similar dilemmas apply to the effects of a strong IP system on competition process. Static measures of competition may decrease when a monopoly right is granted but dynamic measures could possibly increase if this right facilitates entry into an industry by new and innovative firms.

Are these trade-offs general features of the relationship between static allocative efficiency and dynamic/innovative efficiency? There are good reasons to think that such trade-offs might not theoretically even appear in an evolutionary world, as Winter (1993) shows.

On the grounds of a simple evolutionary model of innovation and imitation, Winter (1993) compares the properties of the dynamics of a simulated industry with and without patent protection to the innovators. The results show that, first, under the patent regime the total surplus (that is the total discovered present value of consumers' and producers' surplus) is lower than under the non-patent one. Second and even more interestingly, the non-patent regime yields significantly higher total investment in R&D and displays higher best practice productivity.

More generally, an evolutionary interpretation of the relation between appropriability and innovation is based on the premise that no model of invention and innovation and no answer to patent policy questions is possible without a reasonable account of inventive and innovative opportunities and their nature. The notion of technological paradigm (Dosi, 1982), in this respect, is precisely an attempt to account for the nature of innovative activities. There are few ideas associated with the notion of paradigm worth recalling here.

First, note that any satisfactory description of "what technology is" and how it changes must also embody the representation of the specific forms of knowledge on which a particular activity is based and cannot be reduced to a set of well-defined blueprints. It primarily concerns problem-solving activities involving – to varying degrees – also tacit forms of knowledge embodied in individuals and in organizational procedures. Second, paradigms entail specific heuristics and visions on "how to do things" and how to improve them, often shared by the community of practitioners in each particular activity (engineers, firms, technical societies, etc.), i.e. they entail collectively shared cognitive frames.

Third, paradigms often also define basic templates of artefacts and systems, which over time are progressively modified and improved. These basic artefacts can also be described in terms of some fundamental technological and economic characteristics. For example, in the case of an airplane, their basic attributes are described not only and obviously in terms of inputs and production costs, but also on the basis of some salient technological features such as wing-load, take-off weight, speed, distance it can cover, etc. What is interesting here is that technical progress seems to display patterns and invariances in terms of these product characteristics. Hence the notion of technological trajectories associated with the progressive realization of the innovative opportunities underlying each paradigm. In turn one of the fundamental implications of the existence of such trajectories is that each particular body of knowledge (each paradigm) shapes and constraints the rates and direction of technical change, in a first rough approximation, irrespectively of market inducements, and thus also irrespectively of appropriability conditions.

3. The growth in patenting rates and the (mis-)uses of patent protection

Needless to say, such a lack of any robust theory-backed relation between appropriability (and even less IPR forms of appropriability) and rates of innovation, puts the burden of proof upon the actual empirical record.

Indeed, the past two decades have witnessed the broadening the patenting domain including the application of "property" to scientific research and its results. This has been associated with an unprecedented increase in patenting rates. Between 1988 and 2000, patent applications from US corporations have more than doubled.

The relation between the two phenomena, however, and – even more important – their economic implications are subject to significant controversy (see Kortum and Lerner, 1998, Hall, 2005, Lerner, 2002, Jaffe and Lerner, 2004 and Jaffe, 2000).

A first hypothesis is that the observed "patent explosion" has been linked to an analogously unprecedented explosion in the amount and quality of scientific and technological progress. A "hard" version of that hypothesis would claim that the increase of patents has actually spurred the acceleration of innovation, which otherwise would have not taken place. A "softer" version would instead maintain that the increase of patents has been an effect rather than a cause of increased innovation, as the latter would have taken place also with weaker protection.

The symmetrically opposite hypothesis is that the patent explosion is due to changes both in the legal and institutional framework and in firms' strategy with little relation to the underlying innovative activities.

While it is difficult to come to sharp conclusions in absence of counterfactual experiments, some circumstantial evidence does lend some support to the latter hypothesis.

Certainly, part of the growth in the number of patents is simply due to the expansion of the patentability domain to new types of objects such as software, research tools, business methods, genes and artificially engineered organisms (see also Tirole, 2002 on the European case). Moreover, new actors have entered the patenting game, most notably universities and public agencies (more on it in Mowery et al., 2001). Finally also corporate strategies *vis-à-vis* the legal claim of IPR appear to have significantly changed.

First, patents have acquired importance among the non physical assets of firms as means to signal the enterprise's value to potential investors, even well before the patented knowledge has been embodied in any marketable good. Under this respect, the most relevant institutional change is to be found in the so called "Alternative 2" under the Nasdaq regulation (1984). This allowed "market entry and listing of firms operating at a deficit on the condition that they had considerable intangible capital composed of IPRs".

At the same time, patents seems to have acquired a strategic value, quite independently from any embodiment in profitable goods and even in those industries in which they were considered nothing more than a minor by-product of R&D: extensive portfolios of legal rights are considered means for entry deterrence (Hall and Ziedonis, 2001) and for infringement and counter infringement suits against rivals. Texas Instruments, for instance, is estimated to have gained almost one billion dollars from patent licenses and settlements resulting from its aggressive enforcement policy. It is interesting to note that this practice has generated a new commercial strategy called "defensive publishing".

According to this practice, firms who find too expensive to build an extensive portfolio of patents tend to openly describe an invention in order to place it in the "prior art" domain, thus preserving the option to employ that invention free from the interference of anyone who might eventually patent the same idea.

Kortum and Lerner (1998) present a careful account of different explanations of recent massive increases in patenting rates, comparing different interpretative hypothesis.

First, according to the "friendly court hypothesis", the balance between costs related to the patenting process (in terms, e.g. of loss of secrecy) and the value of the protection that a patent affords to the innovator had been altered by an increase in the probability of successful application granted by the establishment in the USA of the Court of Appeals for the Federal Circuit (CAFC) specialized in patent cases—regarded by most observers as a strongly pro-patent institution (cf. Merges, 1996)

Second, the "regulatory capture" tries to explain the surge of US patent applications tracking it back to the fact that business firms in general and in particular larger corporations (whose propensity to patent has traditionally been higher than average) succeeded in inducing the US government to change patent policy in their favour by adopting a stronger patent regime.

The third hypothesis grounds the interpretation into a general increase in "technological opportunities" related, in particular, to the emergence of new technological paradigms such as those concerning information technologies and biotechnologies.

Remarkably, Kortum and Lerner (1998) do not find any overwhelming support neither for the political/institutional explanations nor for the latter one drawing the surge in patenting to changes in the underlying technological opportunities. At the same time there is a good evidence that the cost related to IP enforcement has gone up together with the firms' propensity to litigate: the number of patents suits instituted in the US Federal Courts has increased from 795 in 1981 to 2573 in 2001. Quite naturally, this has lead to significative increases in litigation expenditures. It has been estimated by the US Department of Commerce that patent litigation begun in 1991 led to total legal expenditures by US firms that were at least 25% of the amount of basic research by these firms in that year.

4. The blurred relations between appropriability and innovation rates: some evidence

What is the effect of the increase in patent protection on R&D and technical advance? Interestingly, also in this domain the evidence is far from conclusive. This is due at least to two reasons. First, innovative environments are concurrently influenced by a variety of different factors which makes it difficult (both for the scholar and the policy-maker) to single out patent policy effects from effects due to other factors. Indeed, as we shall argue below, a first order influence is likely to be exerted by the richness of opportunities irrespectively of appropriability regimes. Second, as patents are just one of the means to appropriate returns from innovative activity, changes in patent policy might often be of limited effect.

At the same time also the influence of IPR regimes upon knowledge dissemination appears to be ambiguous. Hortsmann et al. (1985) highlight the cases in which, on the one hand, the legally enforced monopoly rents should induce firms to patent a large part of their innovations, while, on the other hand, the costs related to disclosure might well be greater than the gains eventually attainable from patenting.

In this respect, to our knowledge, not enough attention has been devoted to question whether the diffusion of technical information embodied in inventions is enhanced or not by the patent system.

The somewhat symmetric opposite issue concerns the costs involved in the imitation of patent-protected innovations. In this respect, Mansfield et al. (1981) find, first, that patents do indeed entail some significant imitation costs. Second, there are remarkable intersectoral differences. For example, their data show a 30% in drugs, 20% in chemicals and only 7% in electronics. In addition, they show that patent protection is not essential for the development of at least three out of four patented innovations. Innovators introduce new products notwithstanding the fact that other firms will be able to imitate those products at a fraction of the costs faced by the innovator. This happens both because there are other barriers to entry and because innovations are felt to be profitable in any case. Both Mansfield et al. (1981) and Mansfield (1986) suggest that the absence of patent protection would have little impact on the innovative efforts of firms in most sectors. The effects of IPR regimes on the propensity to innovate are also likely to depend upon the nature of innovations themselves and in particular whether they are, so to speak, discrete "stand alone" events or "cumulative". So it is widely recognized that the effect of patenting might turn out to be a deleterious one on innovation in the case of strongly cumulative technologies in which each innovation builds on previous ones. As Merges and Nelson (1994) and Scotchmer (1991) suggest, in this realm stronger patents may represent an obstacle to valuable but potentially infringing research rather than an incentive.

Historical examples, such as those quoted by Merges and Nelson on the Selden patent of a light gasoline in an internal combustion engine to power an automobile and the Wright brothers patent on an efficient stabilizing and steering system for flying machines are good cases to the point, showing how the IPR regime probably slowed down considerably the subsequent development of automobiles and aircrafts. The current debate on property rights in biotechnology suggests similar problems, whereby granting very broad claims on patents might have a detrimental effect on the rate of innovation, insofar as they preclude the exploration of alternative applications of the patented invention. This is particularly the case with inventions concerning fundamental pieces of knowledge: good examples are genes or the Leder and Stewart patent on a genetically engineered mouse that develops cancer. To the extent that such techniques and knowledge are critical for further research that proceeds cumulatively on the basis of the original invention, the attribution of broad property rights might severely hamper further developments. Even more so if the patent protects non only the product the inventors have achieved (the "onco-mouse") but all the class of products that could be produced through that principle ("all transgenic non-human mammals") or all the possible uses of a patented invention (say, a gene sequence), even though they are not named in the application.

More generally, the evidence suggests that the patents/innovation relation depends on the very nature of industry-specific knowledge bases, on industry stages in their life-cycles and on the forms of corporate organizations.

Different surveys highlight, first, such intersectoral differences and second, on average, the limited effectiveness of patents as an appropriability device for purpose of "profiting from innovation". Levin et al. (1987), for instance, reports that patents are by and large viewed as less important than learning curve advantages and lead time in order to protect product innovation and the least effective among appropriability means as far as process innovations are concerned (see Table 1).

Cohen et al. (2000) present a follow-up to Levin et al. (1987) just cited addressing also the impact of patenting on the incentive to undertake R&D. Again, they report on the relative importance of the variety of mechanisms used by firms to protect their innovations – including secrecy, lead time, complementary capabilities and patents (cf., again, Table 1).

The percentage of innovations for which a factor is effective in protecting competitive advantage deriving from them is thus measured. The main finding is that, as far as product innovations are concerned, the most effective mechanisms are secrecy and lead time while patents are the least effective, with the partial exception of drugs and medical equipment. Moreover the reasons for the "not patenting" choice are reported to be (i) demonstration of novelty (32%), (ii) information disclosure (24%) and (iii) ease of inventing around (25%).

The uses of patents differ also relative to "complex" and "discrete" product industries. Complex products industries are those in which a product is protected by a big number of patents while discrete product industries are those in which a product is relatively sim-

Table 1
Effectiveness of appropriability mechanism in product and process innovations, 1983 and 1994, Surveys, USA, 33 manufacturing industries

Mechanism	1st		2nd		3rd		4th	
	1983	1994	1983	1994	1983	1994	1983	1994
Product innovation								
Patents	4	7	3	5	17	7	9	4
Secrecy	0	13	0	11	11	2	22	5
Lead time	14	10	14	8	5	7	0	7
Sales & service	16	4	16	4	1	7	0	10
Manufacturing	n.a.	3	n.a.	3	n.a.	14	n.a.	7
Process innovation								
Patents	2	1	4	5	3	3	24	16
Secrecy	2	21	10	10	19	1	2	0
Lead time	26	3	5	7	2	16	0	3
Sales & service	4	0	16	0	7	3	6	11
Manufacturing	n.a.	10	n.a.	12	n.a.	10	n.a.	0

Sources: Levin et al. (1987) and Cohen et al. (2000) as presented in Winter (2002), n.a.: for observations not available.

ple and therefore associated with a small number of patents. In complex product industries, patents are used to block rival use of components and acquire bargaining strength in cross-licensing negotiations. In discrete product industries, patents are used to block substitutes by creating patent "fences" (cf. Gallini, 2002, Ziedonis, 2003).

It is interesting also to compare Cohen et al. (2000) with the old Levin et al. (1987) which came before the changes in the IPR regime and before the massive increase in patenting rates. Still, also in Cohen et al. (2000) patents are not reported to be the key means to appropriate returns from innovations in most industries. Secrecy, lead time and complementary capabilities are often perceived more important appropriability mechanisms.

It could well be that a good deal of the increasing patenting activities over the last two decades might have gone into "building fences" around some key invention thus possibly raising the private rate of return to patenting itself (Jaffe, 2000) without however bearing any significant relation with the underlying rates of innovation. This is consistent also with the evidence discussed in Lerner (2002) who shows that the growth in (real) R&D spending predates the strengthening of the IP regime.

The apparent lack of effects of different IPR regimes upon the rates of innovation appears also from broad historical comparisons. So for example, based on the analysis of data from the catalogues of two 19th century world fairs: the Crystal Palace Exhibition in London in 1851, and the Centennial Exhibition in Philadelphia in 1876, Moser (2003) finds no evidence that countries with stronger IP protection produced more innovations than those with weaker IP protection and a strong evidence of the influence of IP law on sectoral distribution of innovations. In weak IP countries firms did innovate in sectors in which other forms of appropriation (e.g. secrecy and lead time) were more effective, whereas in countries with strong IP protection significantly more innovative effort went to the sectors in which these other forms were less effective. Hence, the interesting conclusion that can be drawn from Moser's study that patents' main effect could well be on the directions rather than on the rates of innovative activity.

The relationship between investment in search and innovative outcomes is explored at length in Hall and Ziedonis (2001) in the case of the semiconductor industry. In this sector, the little role and effectiveness of patents – related to short product life-cycles and fast-paced innovation which make secrecy and lead time much more effective appropriability mechanisms – also makes the surge in patenting (dating back to the 80s) particularly striking. As Hall and Ziedonis report, in the semiconductor industry patenting per R&D dollar doubled over the period 1982–1992. (Incidentally note that, over the same period, patenting rates in the US were stable in manufacturing as a whole and did decline in pharmaceuticals.)

Semiconductors are indeed a high-opportunity sector whose relatively low propensity to patent is fundamentally due to the characteristic of the knowledge base of the industry.

Thus, it could well be that the growth in patents might have been associated with the use of patents as "bargaining chips" in the exchanges of technology among different firms.

Such a use of (low quality) patents – as Winter (2002) suggests – might be a rather diffused phenomenon: when patents are used as "bargaining chips", i.e. as "the currency of technology deals" all the "standard requirements" about such issues as non obviousness, usefulness, novelty, articulability (you can't patent an intuition), reducibility to practice (you can't patent an idea per se), observability in use, turn out to be much less relevant.

In Winter's terms, "if the relevant test of a patent's value is what it is worth in exchange, then it is worth about what people think it is worth' – like any paper currency". "Wildcat patents" work reasonably well to facilitate exchanges of technology.[1] So, why should we worry?" One of the worries, concerns the "tragedy of anti-commons". While the quality of patents lowers and their use bear very little link with the requirements of stimulating the production and diffusion of knowledge, the costs devoted to untie conflicting and overlapping claims on IP are likely to increase together with the uncertainty about the extent of legal liability in using knowledge inputs. Hence, as convincingly argued by Heller and Eisenberg (1998) and Heller (1998) a "tragedy of anti-commons" is likely to emerge wherein the IP regime gives too many subjects the right to exclude others from using fragmented and overlapping pieces of knowledge with no one having ultimately the effective privilege of use.

In these circumstances, the proliferation of patents might turn out to have the effect of discouraging innovation. One of the by products of the recent surge in patenting is that, in several domains, knowledge has been so finely sub-divided into separate property claims (on essentially complementary pieces of information) that the cost of reassembling constituent parts/properties in

[1] Winter here is pursuing an analogy between patents and "wildcat banknotes" in the US free banking period (1837–1865).

order to engage in further research charges a heavy burden on technological advance. This means that a large number of costly negotiations might be needed in order to secure critical licenses, with the effect of discouraging the pursue of certain classes of research projects (e.g. high risk exploratory projects). Ironically, Barton (2000) notes that "the number of intellectual property lawyers is growing faster than the amount of research".

While it is not yet clear how widespread are the foregoing phenomena of a negative influence of strengthened IPR protection upon the rates of innovation, a good deal of evidences does suggest that, at the very least, no monotonic relation is there between IPR protection and propensity to innovate. So, for example, Bessen and Maskin (2000) observe that computers and semiconductors while having been among the most innovative industries in the last 40 years, have historically had weak patent protection and rapid imitation of their products. It is well known that the software industry in the US experienced a rapid strengthening of patent protection in the 80s. Bessen and Maskin (2000) suggest that "far from unleashing a flurry of new innovative activity, these stronger rights ushered in a period in which R&D spending levelled off, if not declined, in the most patent-intensive industries and firms". The idea is that in industries like software, imitation might be promoting innovation and that, on the other hand, strong patents might inhibit it. Bessen and Maskin (2000) argue that this phenomenon is likely to occur in those industries characterized by a relevant degree of sequentiality (each innovation builds on a previous one) and complementarity (the simultaneous existence of different research lines enhances the probability that a goal might be eventually reached). A patent, in this perspective, actually prevents non-holders from the use of the idea (or of similar ideas) protected by the patent itself and in a sequential world full of complementarities this turns out to slowdown innovation rates. Conversely, it might well happen that firms would be better off in an environment characterized by easy imitation, whereby it would be true that imitation would reduce current profits but it would be also true that easy imitation would raise the probability of further innovation to take place and of further profitable innovations to be realized.

A related but distinct question concerns the relationship between IPRs, the existence of markets for technologies and the rates of innovation and diffusion (see Arora et al., 2001 for a detailed analysis of the developments). While it is certainly true that some IPR protection is often a necessary condition for the development of markets for technologies, no clear evidence is there suggesting that more protection means more market. And neither there is general evidence that more market drives higher rates of innovation. Rather, the degree to which technological diffusion occurs via market exchange depend to a great extent on the nature of technological knowledge itself, e.g. its degree of codifiability (Arora et al., 2001).

So far we have primarily discussed the relations between the regimes of IPR protection and rates of innovations, basically concluding that either the relation is not there, or, if it is there it might be a perverse one, with strong IPR enforcement actually deterring innovative efforts. However we know also that IPR protection is only one of the mechanisms for appropriating returns from innovation, and certainly not the most important one.

What about then the impact of appropriability in general? Considering together the evidence on appropriability from survey data and (cf. Cohen et al., 2000 and Levin et al., 1987), the cross-sectoral evidence on technological opportunities (cf. Klevorick et al., 1995) and the evidence from multiple sources on the modes, rates and directions of innovation (for two surveys, cf. Dosi, 1988 and Dosi et al., 2005), the broadbrush conclusion is that also appropriability conditions in general have only a limited effects on the pattern of innovation, if any. This clearly applies above a minimum threshold: with perfectly zero appropriability, the incentive to innovate for private actors would vanish, but with few exceptions such strict zero condition is hardly ever encountered. And the threshold, as the open source software shows might be indeed very low.

5. Opportunities, capabilities, and greed: some conclusions on the drivers of innovation and its private appropriation

There are some basic messages from the foregoing discussion of the theory and empirical evidence on the relationship between degrees of IPR protection and rates of innovation. The obvious premise is that some private expectation of "profiting from innovation" is and has been throughout the history of modern capitalism a necessary condition for entrepreneurs and business firms in order to undertake expensive and time-consuming search for innovations themselves. That was already well clear to classical economists and has been quite uncontroversial since.

However, having acknowledged that, there are neither strong theoretical reasons nor any strong empirical evidence suggesting that tuning up or down appropriability mechanisms of innovations, in general, and appropriability by means of IPR in particular, has any robust effect upon the resources which private self-seeking agents devote to innovative search and upon the rates at which they discover new products and new production processes. As pointed out by the already mentioned survey by Jaffe (2000) on the effects of the changes in IPR regimes in recent years "there is little empirical evidence that what is widely perceived to be a significant strengthening of intellectual property protection had significant impact on the innovation process" (Jaffe, 2000, p. 540).

Note that any tightening of IPR is bound to come together with a fall in "consumer surplus": making use somewhat uneasily of such static tool for welfare analysis, it is straightforward that as producers' rents and prices on innovation grow, the former must fall. Conversely, on the producers' side, "to the extent that firms' attention and resources are, at the margin, diverted from innovation itself toward the acquisition, defense and assertion against others of property rights, the social return to the endeavor as a whole is likely to fall. While the evidence on all sides is scant, it is fair to say that there is at least much evidence of these effects of patent policy changes as there is evidence of stimulation of research" (Jaffe, 2000, p. 555).

But if IPR regimes have at best second order effects upon the rates of innovation what are the main determinants of the rates and directions of innovation?

Our basic answer, as argued above and elsewhere (cf. Dosi, 1988, Dosi, 1997, Dosi et al., 2005) is the following. The fundamental determinants of observed rates of innovation in individual industries/technologies appear to be nested in levels of opportunities which each industry faces. "Opportunities" capture, so to speak, the width, depth and richness of the sea in which incumbents and entrants go fishing for innovation. In turn, such opportunities are partly generated by research institutions outside the business sector, partly stem from the very search efforts undertaken by incumbent firms in the past and partly flow through the economic system via suppliers/users relationships (see the detailed intersectoral comparisons in Pavitt, 1984 and in Klevorick et al., 1995). Given whatever level of innovative opportunities typically associated with particular technological paradigms, there seem to be no general lack of appropriability conditions deterring firms from going out and fishing in the sea. Simply, appropriability conditions vary a lot across sectors and across technologies, precisely as highlighted by the paper by David Teece which this special issue of Research Policy celebrates. Indeed, one of the major contributions of that work is to build a taxonomy of strategies and organizational forms and map them into the characteristics of knowledge bases, production technologies and markets of the particular activity in which the innovative/imitative firms operates.

As these "dominant" modes of appropriation of the returns from innovation vary across activities, so should also vary the "packets" of winning strategies and organizational forms: in fact, Teece's challenging conjecture still awaits a thorough statistical validation on a relatively large sample of statistical successes and failures.

Note also that Teece's taxonomy runs counter any standard "IPR-leads-to-profitability" model according to which turning the tap of IPR ought to change returns up or down rather uniformly for all firms (except for noise), at least within single sectors. Thus, the theory is totally mute with respect to the enormous variability across firms even within the same sector and under identical IPR regimes, in terms of rates of innovation, production efficiencies and profitabilities (a discussion of such evidence is in Dosi et al. (2005)).

The descriptive side – as distinguished from the normative "strategic" one – of the interpretation by Teece (1986) puts forward a promising candidate in order to begin to account for the patterns of successes and failures in terms of suitability of different strategies/organizational arrangements to knowledge and market conditions. However, Teece himself would certainly agree that such interpretation could go only part of the way in accounting for the enormous inter-firm variability in innovative and economic performances and their persistence over time.

A priori, good candidates for an explanation of the striking differences across firms even within the same line of business in their ability to both innovate and profit from innovation ought to include firm-specific features which are sufficiently inertial over time and only limitedly "plastic" to strategic manipulation so that they can be considered, at least in the short term, "state variables" rather than "control variables" for the firm (Winter, 1987). In fact, an emerging capability-based theory of the firm to which Teece himself powerfully contributed (cf. Teece et al., 1990 and Teece et al., 1997), identifies a fundamental source of differentiation across firms in their distinct problem-solving knowledge yielding different abilities of "doing things"—searching, developing new products, manufacturing, etc. (see Dosi et al., 2000 among many distinguished others). Successful corporations, as one argues at more detail in the introduction to the Dosi et al. (2000), derive competitive strength from their above-average performance in a small number of capability clusters where they can sustain leadership. Symmetrically, laggard firms often find hard the imitation of perceived best-practice production technologies because of the difficulty of identifying the combination of routines and organizational traits which make company x good at doing z.

Such barriers to learning and imitation, it must be emphasized, have very little to do with any legal regime governing the access to the use of supposedly publicly disclosed but legally restricted knowledge such as that associated with patent-related information.

Much more fundamentally, it relates to collective practices which in every organization guide innovative search, production and so on. In fact, in our view, given the opportunities for innovation associated with a particular paradigm – which approximately determine also the ensuing industry-specific rates of innovation – who wins and who looses amongst the firms operating within that industry depends on both the adequacy of their strategic choices – along the lines of the taxonomy of Teece (1986) – and on the type of idiosyncratic capabilities that they embody. In our earlier metaphor, while the "rates of fishing" depend essentially on the size and richness of the sea, idiosyncratic differences in the rates of success in the fishing activity itself, depend to a large extent on firm-specific capabilities.

Moreover, the latter, jointly with complementary assets fundamentally affects also the ability to "profit from innovation". Conversely, if we are right, this whole story has very little to do with any change in the degrees to which society feeds the greed of the fishermen, in terms of prices they are allowed to charge for their catch. That is, out of metaphor, the tuning of IPR-related incentives is likely to have only second order effects, if any, while opportunities together with the capabilities of seeing them are likely to be the major drivers of the collective "unbound Prometheus" of modern capitalism and also to shape the ability of individual innovators to benefit from it.

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