Knowledge, competition and appropriability: Is strong IPR protection always needed for more and better innovations?

Giovanni Dosi[1], Luigi Marengo[1], Corrado Pasquali[2], and Marco Valente[3]

[1]*LEM, Scuola Superiore S. Anna, Pisa, <giovanni.dosi; luigi.marengo>@sssup.it*
[2]*Università di Teramo, cpasquali@unite.it*
[3]*Università de L'Aquila, valente@ec.univaq.it*

SECOND INCOMPLETE DRAFT - September 2007

Abstract

The economic theory of intellectual property rights is based on a rather narrow view of both competition (i.e. the perfect competition model of neoclassical microeconomics) and technological knowledge (i.e. knowledge is reduced to free flowing information). In this paper we suggest some ways of enriching this framework with a more realistic and empirically based view of both and, by means of a simulation model, we investigate some consequences that different appropriability regimes could have in such a richer framework. Our main conclusion is that the implications of intellectual property rights for technological and industrial evolution and for social welfare are very much dependent upon specific characteristics of the competition process and of the underlying technological knowledge.

1 Introduction

It is a piece of undisputable evidence that product, process and organizational innovations are key to economic growth and that a major strength of capitalistic free-market systems has been their unrivalled capacity to promote both the growth of technological knowledge and, perhaps even more, its use for economic purposes, i.e. its translation into better marketable products and cheaper production processes. Market capitalism combines decentralization (and therefore multiplicity and diversity of innovative efforts) with strong incentives to producing innovation, as innovators are – most of the times – rewarded by considerable gains.

However, it sounds like a kind of paradox that the prototype of free market, i.e. perfect competition, does not look at all appropriate to provide such incentives, at least in the theoretical elaborations of economists. In perfect competition the competitive advantage acquired by means of an innovation gets quickly eroded as price falls to the industry's marginal cost and profit to its "normal" level. But the industry's marginal cost does not include the innovator's sunk costs of research and development (R&D). Thus forward looking potential innovators would never invest in R&D, knowing that returns to innovation would quickly disappear and that they could never pay back the R&D investment.

At a closer scrutiny this argument rests upon a set of explicit or implicit assumptions, which can be roughly summarized into three items. The first fundamental assumption is that competition in the real world is correctly (albeit in a stylized manner) described by the economists' model and that, in particular, all market mechanisms should be compared to the ideal of static efficiency of perfect competition. The second assumption is that the innovator's advantage quickly vanishes because superior knowledge cannot be effectively appropriated for its nature of quasi public good, that is non rival and hardly excludable. In turn this hypothesis has two corollaries: that innovative knowledge "naturally" tends to diffuse at a relatively fast rate and that IPRs are the only effective way to prevent this diffusion and allow appropriation. The third implicit assumption is that potential innovators must be enough forward looking to anticipate that their advantage will be quickly eroded, if in fact advantages were actually eroded but potential innovators were myopic enough to underestimate such erosion, incentives to innovate would be at least partially preserved.

In this paper we will try and challenge some of the lines of reasoning behind the common wisdom on some of the assumptions in the former two categories. For the time being we will leave aside the third one, though some reasonable doubts could be raised on its validity as well, witness the ample evidence on the so-called over confidence bias that "affects" entrepreneurs.[1] Our main point is that once we take into account that market is not only a static allocation of resources to their most efficient use and that technological knowledge cannot be reduced to freely flowing information, the economic issues at stake with property rights are not just striking a balance between static monopoly deadweight losses and dynamic lack of incentives. Within the broader picture we outline in this paper the links between the strength of IPR protection and the dynamic properties of an industry cannot be univocally determined but are very much dependent upon market

---

[1] For instance, empirical studies show that the vast majority of new firms do not survive more than a few years. This evidence should discourage entrepreneurial entry if the latter was based on a correct estimates of the probability of success. On the contrary, entry remains consistently high also under this regime of weak incentives, probably because entrepreneurs are over-confident, i.e. they believe their entrepreneurial idea is "better" than the others' and that they are therefore located in the survivors' queue of the distribution. It seems quite reasonable to suppose that also innovators are likely to be subject to the same bias.

specific and technology specific factors. In other words we claim that industry matters a lot and probably the incentive problem, which is indeed there, should be solved by means of less universal and more industry specific devices rather than universal legal rights.

The paper is structured as follows: in section 2 we develop the main theoretical arguments. Then in section 3 we provide a very synthetic overview of empirical studies, broadly supporting the view that there is no clear-cut evidence that stronger IPR protection leads to more innovation and more dynamic efficiency and that the effects of patents are very much dependent upon technology specific and market specific factors. In section 4 we outline an evolutionary simulation model in which we try and analyze the dynamic properties of different patent regimes within a formal framework that, albeit still very stylized, tries to account for richer properties of market competition processes and of technological knowledge. The first main feature of the model is that we focus upon product innovation and that the latter is essentially creation of new products which get "experimented" in the market through the creation of ever new sub-markets only loosely competing (or not at all if very innovative) with existing products. We show that IPRs do indeed have an impact not only on the incentives to do research and development but also on the directions in which research moves and that directions induced by a given IPR arrangement might not be dynamically optimal. The second feature is that we give a central role in the model to variables describing technological knowledge, such as knowledge complexity, technological opportunities and cumulativeness and show that IPRs have a very different impact depending on these knowledge dimensions. In section 5 we describe the main results we get from simulating the model and, finally, in section 6 we draw some tentative conclusions and policy implications.

2 Knowledge, competition and innovation: the failure of market failure.

The economic foundations of both theory and practice of IPRs rest upon a standard market failure argument. The proposition that a positive and uniform relation exists between innovation and intensity of intellectual property 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 (Coase 1960), which can be briefly stated in the following way. There exists a normative set of efficiency conditions under which markets perfectly fulfill their role of efficient allocative mechanisms. The lack of externalities is one of such conditions because their appearance amounts (e.g. 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[2], it will be underproduced and will receive insufficient investment. 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. As usual in a Coasian perspective, the attribution and enforcement of well-defined private property rights is viewed as the key to the solution of an externality problem. But in this case there is an additional problem that the object of property rights is by definition a resource that is unique and does not have close substitutes. Property therefore generates monopoly of a resource which otherwise could enjoy the heavenly condition of non-scarcity. 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 which concern both the idea of market and the idea of knowledge implicit in this it. Let us elaborate on both starting from the market.

First, the argument fundamentally rests upon 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”.

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. In particular, there are two issues we want to focus upon. First, IPRs in a Coasian perspective are only a way to internalize externalities and solve a misallocation problem and in this respect, Coase himself has shown, the allocation of IPRs is in prin-

---

[2] Non rivarly of technological knowledge and its commonly understood implications have sometimes been questioned. For instance Boldrin and Levine (2002) claim that non rivarly is not the appropriate category, and that knowledge and information are rather characterized by (infinite) expansibility (David 1992), that is they are not jointly consumed like pure public goods but can indeed be replicated. Replication requires some (though possibly very short) time and involves some (though possibly very low) costs and this is enough to ensure, they show, that competitive markets price innovation positively and provide incentives to innovators.

ciple immaterial to the efficiency of the final allocation as they only provide the correct incentives to induce agents to achieve it. The implicit underlying assumption is that a whole range of *independent* technological opportunities are given and are available to be harvested and the only issue is to provide firms with the correct cost benefit structure to induce them to reap good ones and discard bad ones.

However if we consider a richer picture in which technological opportunities have to be constructed by firms and, in general, are not independent but present complementarities, interdependencies and dynamic path-dependence, then – we will argue in this paper – IPRs are no longer immaterial to the direction of technological progress. They in fact do not only provide incentives, but also set opportunities and constraints for the directions of technological advances and market testing. In particular if technological opportunities are not mutually independent then by foreclosing some firms' research in some directions, patents may on the whole hinder research rather then stimulate it. The issue has been already tackled in the literature in the case of cumulative, sequential or complementary technological advances showing that in these cases patents can in the long run deter innovation and give rise to such hold-up phenomena as the so-called patent thickets and tragedy of the anti-commons (Bessen and Maskin 2000, Shapiro 2000, Heller and Eisenberg 1998, Scotchmer 1991, O'Donoghue 1998). In this paper we analyze the more general case of interdependencies in technological knowledge. We show, also building upon some previous work of ours (Marengo and Dosi 2005, Marengo, Pasquali, and Valente 2005), that the definition of IPRs are not immaterial to determining which kind of innovation undergo the market testing and selection process. One issue which appears crucial in our analysis is what we call the "coarseness" of patents (cf. the related phenomenon of the tragedy of the anti-commons), i.e. whether IPRs are defined on product systems in their entirety or on components, sub-components, and so on with finer and finer IPRs. In a Coasian perspective the latter solution (i.e. very finely defined property rights) should in principle – if it wasn't for transaction costs – increase efficiency, in our framework instead it decreases the number of technological opportunities which can be created and exploited.

A second point we investigate about the function of markets is that nowadays a growing share of innovations are product innovations whose main purpose and effect are to create sub-markets (Sutton 1998, Klette and Kortum 1984, Klepper and Thompson 2007) which only loosely compete with existing submarkets. The perfect competition benchmark seems therefore more and more inappropriate as a description of the actual mechanisms of technological competition as it describes a hardly relevant steady state of processes which in reality are ever upset by pushing competition elsewhere. Again, the pace and directions of the creation of submarkets may be highly influenced by the definition and attributions of IPRs and this effect – we will argue – might be more important than their effect upon an hard to reach static efficiency.

All in all, 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), Stiglitz (1994) from different angles).

Finally, 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.

Concerning now technological knowledge, the standard implicit assumption is 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. Two important questions arise in this respect: first, the transformation of information into useful productive knowledge involves an ensemble of fundamental cognitive and procedural devices which are to a large extent tacit and embedded in organizations and are in any case strongly dependent on the specificities of each technological paradigm (which hardly can be reduced to "information" categories). Second, and related, there exist a wide range of devices for appropriating knowledge, themselves high technology and sector specific, among which intellectual property protection is only one of the many and according to many empirical studies (cf. the next section) not even a prominent one in many industries and technologies.

On the first point, 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 (Winter 1982). It primarily concerns problem-solving activities involving - to varying degrees - also tacit forms of knowledge embodied in individuals and in organizational procedures. The notion of technological paradigm (Dosi 1982), in this respect, is precisely an attempt to account for the nature of innovative activities. Paradigms entail specific heuristic 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. Paradigms often also define basic templates of artifacts and systems, which over time are progressively modified and improved. These basic artifacts 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 implication 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.

All in all, any analysis of the conditions for appropriation and diffusion of knowledge cannot abstain from considering the specific features of the knowledge itself. Knowledge complexity, cumulativeness, tacitness, replicability, and degree and location of technological opportunities are fundamental dimensions for understanding the dynamics of productive knowledge (Winter 1987).

On the second point, diversity of knowledge characteristics is reflected into diversity of appropriability regimes. For instance, Teece (1986) rightly claims that an innovation is never an isolated well defined entity, but it is dependent upon a series of complementary assets whose control is often more fundamental for reaping the economic returns to innovation than the regime of legal protection of the rights of the "innovator".

In conclusion, one can observe many fact 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 both to the innovator and to society. 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 90's 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).

3 A concise view of empirical evidence

Needless to say, such a lack of any robust theory-backed relation between IPRs and rates of innovation, puts the burden of proof upon the actual empirical record.

Indeed, the past two decades have witnessed the broadening of the patent 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 (for discussion, 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, Nelson, Sampat, and Ziedonis (2001)). Finally also corporate strategies vis-à-vis the legal claim of IPRs 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 existence (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 favor 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.

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 appropriality 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 appear to be ambiguous. Hortsmann, Mac Donald, and Slivinski (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 gain 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, Schwartz, and Wagner (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, Schwartz, and Wagner (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, Klevorick, Nelson, and Winter (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.

Cohen, Nelson, and Walsh (2000) present a follow-up to Levin, Klevorick, Nelson, and Winter (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. 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 simple 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 (2004)).

It is interesting also to compare Cohen, Nelson, and Walsh's (2000) with the old Levin, Klevorick, Nelson, and Winter (1987) which came before the changes in the IPR regime and before the massive increase in patenting rates. Still, also in Cohen, Nelson, and Walsh (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 19^{th} 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 80's) particularly striking. As Hall and Zidonis report, in the semiconductor industry patenting per R&D dollar doubled over the period 1982-92. (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'[3] work reasonably well to facilitate exchanges of technology. 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 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 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 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 strengthen 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 semi-conductors while having been among the most innovative industries in the last forty 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 80's. Bessen and Maskin suggest that "far from unleashing a flurry of new innovative activity, these stronger rights ushered in a period in which R&D spending leveled 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 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 comple-

---

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

mentarity (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 IPR's, the existence of markets for technologies and the rates of innovation and diffusion (see Arora, Fosfuri, and Gambardella (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, Fosfuri, and Gambardella 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 IPT protection is only one of the mechanism 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, Nelson, and Walsh (2000) and Levin, Klevorick, Nelson, and Winter (1987)), the cross-sectoral evidence on technological opportunities (cf. Klevorick, Levin, Nelson, and Winter (1995)) and the evidence from multiple sources on the modes, rates and directions of innovation (for two surveys, cf. Dosi (1988) and Dosi, Orsenigo, and Sylos Labini (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.

4 The model

4.1 technology space

We model products as systems made of n components $\{x_1, x_3, \ldots, x_n\}$. Each component can take one out of a countable set of values $x_j = \{0, 1, \ldots\}$, which are labels for different and progressively "better" – in a mere technological sense – types of components (e.g. different CPU types, different wing shapes, different brake cooling systems, etc.). We call X the set of all the possible products, i.e. of the vectors $x^i = [x^i_1, x^i_2, \ldots, x^i_n]$ with $x^i_j = \{0, 1, \ldots\}$.

This product space has a natural structure which describes the diversity of products. In particular, we will use two notions of distance between products: horizontal diversity and vertical distance, which are useful to measure, respectively, the horizontal and vertical scope of patents. The horizontal diversity of between two products x^i and x^j is given by the share of components in which x^i and x^j are not identical:

$$H(x^i, x^j) = \sum_{\nu=1}^{n} h(x^i_\nu, x^j_\nu)/n$$

where $h(x^i_\nu, x^j_\nu) = 0$ if $x^i_\nu = x^j_\nu$ and $h(x^i_\nu, x^j_\nu) = 1$ if $x^i_\nu \neq x^j_\nu$.

The vertical distance is instead the average of the distances between single components:

$$V(x^i, x^j) = \frac{\sum_{k=1}^{n} |x^i_k - x^j_k|}{n}$$

Products have some exogenously given performance measure, where performance is a function of the specific combination of components. We suppose that quality is measured by a non negative scalar: $f : X \mapsto R^+$.

How does the performance of a product change when components are modified? It depends upon the "complexity" of the product space, that is the presence, extent and direction of interdependencies among the components forming a product-system. In particular, with respect to the presence and direction of interdependencies we will consider the following cases:

- *without interdependencies*: if $\frac{\partial^2 f}{\partial x_i \partial x_j} = 0 \ \forall i \neq j$
- *with monotonic interdependencies* (or complementarities): if f is super-modular, i.e. $\frac{\partial^2 f}{\partial x_i \partial x_j} \geq 0 \ \forall i \neq j$
- *with non-monotonic interdependencies*: if $\frac{\partial^2 f}{\partial x_i \partial x_j} \gtreqless 0 \ \forall i \neq j$

With respect to the extent of interdependencies, we distinguish among the following case:

- *decomposable*: if the system can be decomposed into subsystems such that components within a subsystem are interdependent with each other but independent from components belonging to a different subsystem. The size of such subsystems is an an indicator of the extent of interdependencies. If each component forms such a subsystem we are in the case without interdependencies.
- *nearly-decomposable* (or "modular") if the system can be decomposed into subsystems such that most interdependencies are within individual subsystem whereas different subsystems are not fully independent (as in the previous case) but weakly interdependent.
- *non decomposable*: if all components interact with each other and independent or nearly independent subsystems cannot be found.

The reader is referred to Marengo, Pasquali, and Valente (2005) and Marengo and Dosi (2005) for a more detailed and formal treatment of these cases and their properties.

To summarize, at one extreme we have the most restrictive and least realistic case of full separability: the performance contribution of each component is independent of the value taken by other components. Each component can be improved in isolation of the others and the resulting performance surface is smooth.

In the more general case we have instead diffused non-monotonic interdependencies, i.e. an improvement in one component may increase or decrease the overall performance of the system depending upon whether some (possibly all) other components are co-adapted or not. The degree and extent of these interdependencies may vary and render the performance surface more or less rugged.[4] On the one hand interdependencies may be more or less broad: single components may interact with just a few others, or viceversa all n components may interact together. A special but important case is when interactions have a modular or quasi-decomposable structure (Simon 1969, Baldwin and Clark 2000), i.e. when the set of components is divided into subsets characterized by strong interactions within each subset and weak interactions among subsets.

Moreover a further, and related, indication of the intensity of interdependencies is given by the correlation structure of the performance surface. Take product x^i and its performance level $f(x^i)$, then suppose "small" local innovations are made, i.e. only single components are mutated, leaving unchanged the other $n-1$, i.e. find all the neighbors of x^i and their performance. Are such performances very close to $f(x^i)$ or on the contrary small changes in the product components determine large changes in performance? In the former case the performance surface is highly correlated and smooth, in the latter instead correlation is weak and the search for better performing products will be much more complex as the consequences of small local changes will be more abrupt and unpredictable.

---

[4] The reader may notice the similarities, but also some important differences, with Stuart Kauffman's rugged fitness landscapes and his NK-model (Kauffman 1993).

All in all, the features of the performance surface describe the *difficulty*[5] of the innovation process. At one extreme we have the case without interdependencies and with high correlation among the performances of similar products, in which autonomous local (i.e. on single components) improvements can generate a stream of steady innovation. Innovation can be effectively decentralized and innovators can specialize on single components or small modules, whereas coordination is effectively ensured by market selection forces. At the other extreme we have non-monotonic widespread interactions which generate uncorrelated performance surfaces. In this case autonomous local changes are ineffective and innovation requires coordinated search on many, possibly all, components together and a deliberate re-designing of the system. Decentralization is highly ineffective in the latter case (see Marengo and Dosi (2005) for a more detailed and formal development of these arguments).

In addition to difficulty (or complexity from interdependencies), it is relatively easy to construct indicators for two other important dimensions of technological knowledge: opportunities and cumulativeness. The former can be modelled as the degree to which performance can be fast improved by innovation in some components of the system. Technological opportunities are high whenever $\frac{\partial f}{\partial x_i} \gg 0$ for some i. Cumulativeness instead indicate that there are increasing returns to research in some components: $\frac{\partial^2 f}{\partial x_i} \gg 0$ for some i.

Finally, we suppose that each product type x_i has an associated variable cost of production c_i which is an increasing function of quality with some random error:

$$c_i = a + bf_i + \epsilon_i$$

where ϵ_i is an idiosyncratic normally distributed error. For the sake of simplicity we set production fixed costs to zero.

4.2 demand

Demand depends upon price, quality and positioning of products in the space of product characteristics. We follow the literature on discrete choice model for products defined in the space of characteristics, and in particular Anderson, De Palma, and Thisse (1989). We assume there exist a finite set C of consumers. Each consumer purchases at most one unit (possibly none) of a differentiated good. Each consumer has an ideal product profile, i.e. his or her type $t^i = [t^i_1, t^i_2, \dots, t^i_n]$ with $\sum_{i=1}^{n} = 1$. A profile is therefore an ideal combination of characteristics the consumer would prefer to purchase.

A consumer's utility depends upon four factors: product performance, the distance between the product profile and the consumer's ideal one, price and, finally, a normally

---

[5] This is only one of the many possible sources of difficulty or complexity of technological innovation, the one which stems from the interdependencies between the parts of the technological system and of the underlying knowledge. Other possible sources are not modelled here.

distributed error. We assume that the elasticities of utility with respect to the first three factors are consumer specific.

All in all, the utility of consumer i buying product x^j is given by:

$$U_i(x^j) = A f_j^{w_i^f} (1/p_j)^{w_i^p} d_j^{w_i^d} \epsilon$$

where f_j and p_j are performance and price of product x^j, d_j is the distance between the product's profile and consumer's i type t_i, $\epsilon \sim \mathcal{N}(0, \sigma)$ is a normally distributed error. Finally, w_i^f, w_i^p and w_i^d are consumer specific elasticities with respect to performance, price and distance and A is a constant.

We call the market space of product x^j the set of consumers:

$$M_{x^j} = \{i \in C; U_i(x^j) \geq U_i(x^h)\} \; \forall h \neq j$$

Demand for product x^j is thus given by the cardinality of the set M_{x^j}.

We assume that consumers are potentially utility maximizers, but also that there is some inertia in their decision, i.e. we suppose that each iteration only a few consumers (in the simulations below we normally set this parameter equal to 1/4 of the population of consumers) may choose to but the product which maximizes their utility, while all the other consumers simply buy again the same product as they did in the previous iteration.

4.3 firms

Firms produce only one type of product exactly in the amount demanded by the market and take decisions on prices and R&D investment. Concerning R&D investment decisions, we follow the philosophy of evolutionary models of technical change and industrial dynamics (Nelson and Winter 1982, Winter 1984, Winter 1993) and assume that firms take routine decisions by applying rules-of-thumb, and in particular that they invest in R&D a given share of their profits. As to price decisions instead we assume that firms are more rational than usually assumed by evolutionary models [6], in particular we make the hypothesis that they are myopically rational. We also assume that prices are sticky and can be modified only after some random intervals.

4.3.1 price decisions

At every iteration one firm is randomly chosen and can modify its price. Also firms launching a new product in the market can fix a new price following to the same procedure. All other firm keep instead their prices unchanged.

---

[6] This departure from the philosophy of evolutionary models was chosen because of the main purpose of this model: we want to analyze the advantages and disadvantages of patents, and among the former are the possibility for firms holding important patents to exploit their monopoly power, make large profits and invest them in further R&D and innovation. Setting high prices when possible (and especially when launching an innovative product) is therefore a crucial ingredient of the pro-patent argument.

We assume that the price setting procedure is rational, i.e. is based upon deliberate profit maximizing calculations, but myopic, in the sense that is based upon the assumption that the other firms will not modify their prices and that all and only the consumers for whom the product maximizes their utility will buy it.[7] In brief, we assume that the price setting procedure is the following: the price setting firm computes the highest price at which each individual consumer would buy from the firm itself and then computes the profit maximizing price.

4.3.2 R&D and innovation

Firms invest a share of their gross profits (for simplicity we assume that no external financing is available) in R&D. There can be two types of R&D investment: imitative R&D and innovative R&D. Let us call r_i^M the share on profits of the former and r_i^I the one of the latter, total R&D expenses of firm i will be $(r_i^M + r_i^I)\pi_i$.

We model imitative search (which can take place when not precluded by patent protection norms) in a straightforward way: the imitator can observe the characteristics of the product of the most profitable firm with which it competes and imitate part of it. The number of components which can be imitated is a function of the money invested in imitative R&D, i.e. $r_i^M\pi_i$.

As to innovative R&D, firms may have more or less specialized R&D activities, meaning that they can concentrate their research effort only on one or a few components or viceversa make extensive search on the entire vector of components. We call the scope of R&D of firm i, $1 \leq \theta_i \leq n$ the number of components on which money for innovative R&D is spent. Given the amount invested in R&D and the scope of research, firms engaged in innovative R&D make random draws in the space of components in the neighborhood of their current value, where the size of the neighborhood is directly proportional to the money invested and inversely proportional to the scope θ_i.

Finally, routine decisions on how much to spend into the two types of R&D are subject to adaptive learning, according to a procedure that we basically borrowed from Winter (1984) and is based upon a simple "satisficing" heuristic. Very simply, if a firm has higher then average cumulated profit will keep coefficients r_i^M and r_i^I unchanged. Otherwise it will adaptively adjust them in the direction of the industry's average but with random disturbances:

$$r_i^M(t+1) = (1-\beta)r_i^M(t) + \beta\overline{r}^M(t) + \epsilon_i^M(t)$$

$$r_i^I(t+1) = (1-\beta)r_i^I(t) + \beta\overline{r}^I(t) + \epsilon_i^I(t)$$

---

[7] In other words we assume that firms do not act strategically and that they base their pricing decision upon the long term potential profit (though, as we mentioned before, consumers do not immediately all switch to their utility maximizing product) under the assumption that competitors will not modify their decisions.

where $\overline{r}^M(t)$ and $\overline{r}^I(t)$ are the industry average at time t and $\epsilon_i^M(t)$ and $\epsilon_i^I(t)$ are normal i.i.d. random errors.

4.4 patents

In the framework outlined so far it is quite easy to introduce the role of patents. We will first compare a world without patents with one in which patents are legally enforced and than test different strengths of the patent system.

When a firm introduces a new product x^i it can immediately (and costlessly) obtain a patent on it if and only if it meets the patentability standards, i.e. if it differs sufficiently from all products already protected by a patent both horizontally and vertically. In particular, two conditions have to be met for product x^i to be granted a patent:

1. $H(x^i, x^P) \geq H_P$ far all products x^P holding a patent
2. and $V(x^i, x^P) \geq V_P$ far all products x^P holding a patent

The parameters H_P and V_P are called, respectively, the horizontal and vertical patentability standards.

If a product x^P is patented we assume that no other firms can produce any product which is similar enough to it. Thus any new product x^j has two satisfy the following two conditions in order to be marketed:

1. $H(x^j, x^P) \geq H_A$ far all products x^P holding a patent, except those of firm j
2. and $V(x^j, x^P) \geq V_A$ far all products x^P holding a patent, except those of firm j

The parameters H_A and V_A are called, respectively, the horizontal and vertical amplitude of patents and are the outcome of legislation and judicial practice.[8]. Such amplitude parameters are important indicators of the strength of the patent system: the ampler a patent the stronger the protection from imitation and the stronger the legal monopoly power granted to the patent holder. Notice that, in general, $H_P \neq H_A$ and $V_P \neq V_A$, that is the requirements for obtaining a patent and those for legally selling a product both without infringing an existing patent may be different, if anything because usually different subjects are called to decide on the two questions (see again O'Donoghue (1998) for an analysis of the possible consequences of such differences).

Finally, all patents have a finite life as they expire after a number L_P of iterations.

4.4.1 "coarse" vs. "fine" patents

Our model of products as complex systems of interdependent components allows us to tackle the issue of the coarseness of patents. Patents are "coarsest" if they are granted only

---

[8] See for instance O'Donoghue (1998) for a detailed analysis of the relationships between standard and amplitude of patents and their consequences for sequential innovation.

on the whole product, if instead they are granted not only on the product but also on each single component they are “finest”. In the latter case suppose that firm i introduces a new value for components x_h^i and patents it. As a consequence, no other firm will be allowed to market a product whose $h-th$ component x_h^j is within a distance $|x_h^j - x_h^i| \leq V_A$ from it, nor to patent a product containing a component x_h^j within a distance $|x_h^j - x_h^i| \leq V_P$ from it.

Finer patents place more restrictions on imitation. In fact whereas a patent on a single component x_h^i prevents all other firms from selling products containing that or a similar component, if patents are instead granted only on whole products, that same component could be sold by other firm without breaching the patent, provided it is part of product sufficiently diverse from the patented one. Thus the granting of finer patents is also a sign of an institutional framework more inclined to providing stronger IPR protection.

As already mentioned above, in a Coasian perspective and abstracting from transaction costs, finer property rights should inevitably lead to higher efficiency as they increase the internalization of knowledge externalities.

5 Simulation results

The model outlined in the previous section is relatively rich and complex, with many elements which interact to produce the dynamics of the industry. For the time being we present a few simulations[9] which capture some fundamental properties of the model. For the sake of clarity we begin with a synthesis of the main results obtained so far, then we provide some details for each of them in the following subsections.

The main results can be summarized as follows:

- **product complexity** is an important cause of inefficiency for a strong patent system. In our model innovating firms are capable of exploiting their competitive advantage, reap high profits and re-invest them in further R&D activities. If product complexity is low, this virtuous mechanism determines indeed a loss of efficiency due to prices which persistently remain above the competitive level and determines higher concentration, but in the long run these effects are more than outweighed by higher rates of innovation, higher product quality and higher overall consumers' welfare. If on the contrary product complexity is high, a strong patent system, in addition to leading to higher prices and concentration, is also a cause of lower overall rates of innovation and product quality growth.

- **patent coarseness** is also an important complexity related issue. Are patents

---

[9] All simulations are run in the L.S.D. (Laboratory for Simulation Development) platform developed by Marco Valente. The platform may be downloaded along with manuals and tutorials at: http://www.business.aau.dk/ mv/Lsd/lsd.html. Programs for the simulations described in this paper may be obtained from the authors upon request.

granted only on whole products or also on single components? We show that in the latter case patents are much more likely to generate long run inefficiencies even in environments characterized by low complexity.

5.1 The effect of product complexity

The first question we address is whether product complexity is a factor affecting the efficiency of different patent regimes. We mentioned above that concerns have been raised on the possibility that in complex technologies a strong patent system may stifle technological progress because of such phenomena as tragedies of the commons, patent thickets and the like. Our model allows to test this concern in a more fundamental sense and within a dynamic model of industry evolution.

We ran a bunch of simulations in which we tested the properties of different patent regimes in industries characterized by either low or high product complexity. The following figures report the time series of some key variables in an industry without interdependencies among product components respectively with or without the possibility of patent protection (holding equal all other parameters).

In the absence of product interdependencies patents do indeed, in our model, increase overall efficiency and welfare. Although our firms do not choose the level of R&D investment with forward looking rationality but by routinely investing a share of their profits, the higher profits that can by reaped by innovators lead to higher R&D and further innovation.[10] Overall product quality rapidly increases and so does social welfare, in spite of higher prices and concentration. Notice also that in the absence of interdependencies product innovation is relatively "simple", in the sense that each component can be improved independently of the others: putting more money into R&D therefore increases the probability of finding some better components, and better components inevitably result into better products because of the separability of the product system.

---

[10] Notice however that in our model firms are rational enough to exploit the competitive advantage given by product differentiation through innovation and maximize long-term profits. If we dropped this hypothesis and let also pricing decisions be routinized, conclusions on the efficiency of patents might be be different as in Winter (1993).

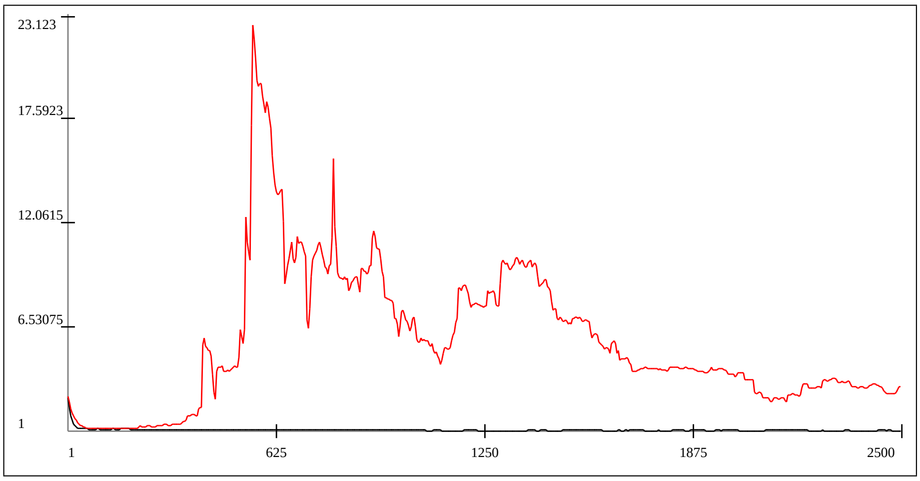

Figure 1: **Average price**, with patents (red) and without patents (black). (N=10, no interdependencies)

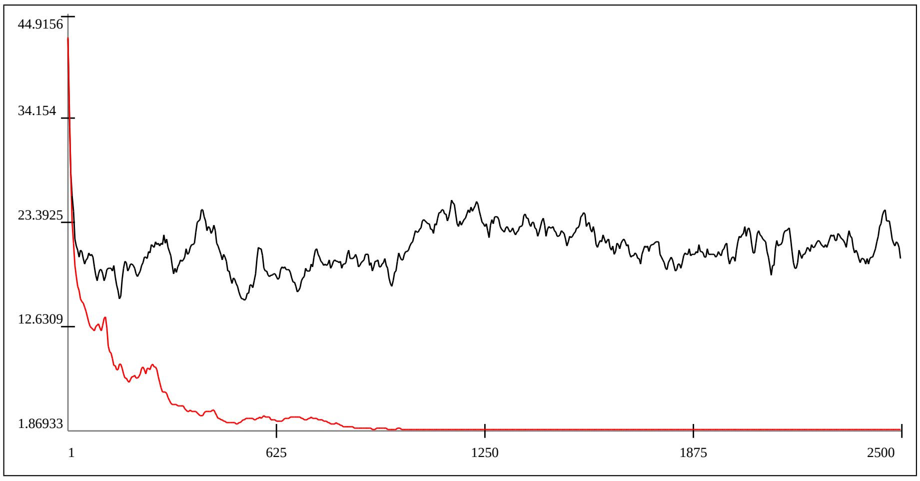

Figure 2: **Industry concentration** (inverse Herfindal index), with patents (red) and without patents (black). (N=10, no interdependencies)

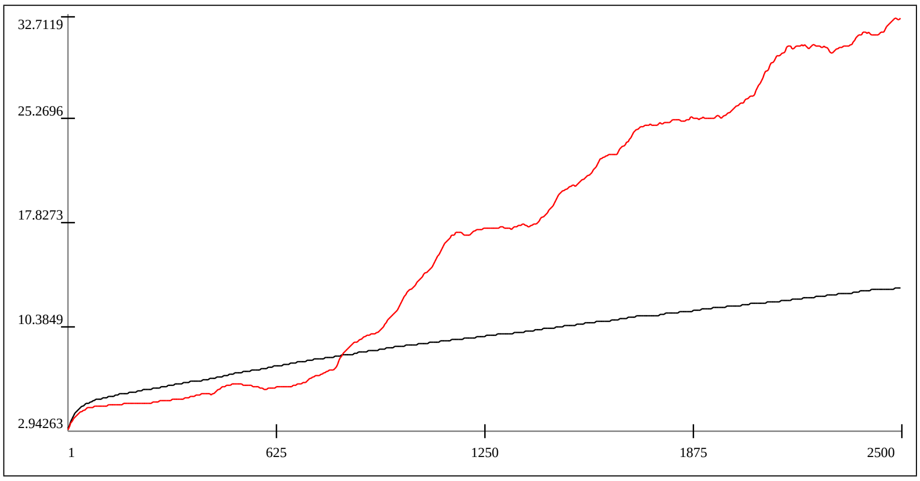

Figure 3: **Consumers' welfare**, with patents (red) and without patents (black). (N=10, no interdependencies)

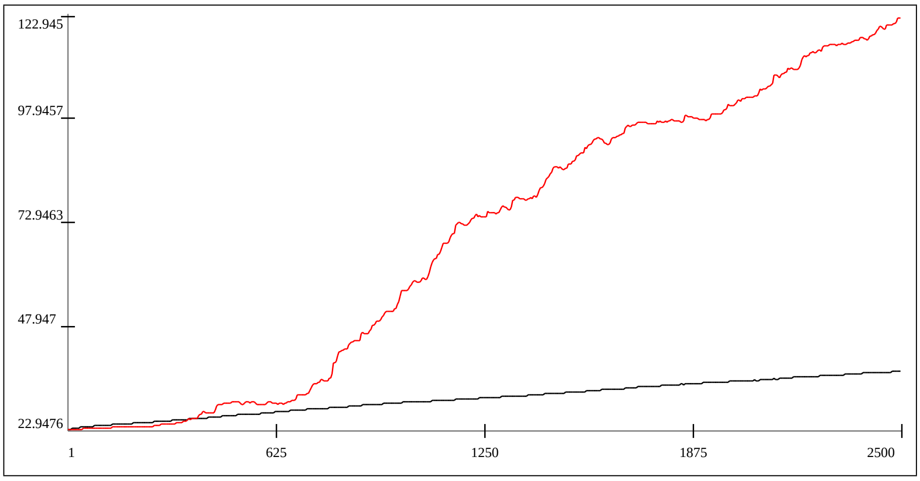

Figure 4: Average product quality, with patents (red) and without patents (black). (N=10, no interdependencies)

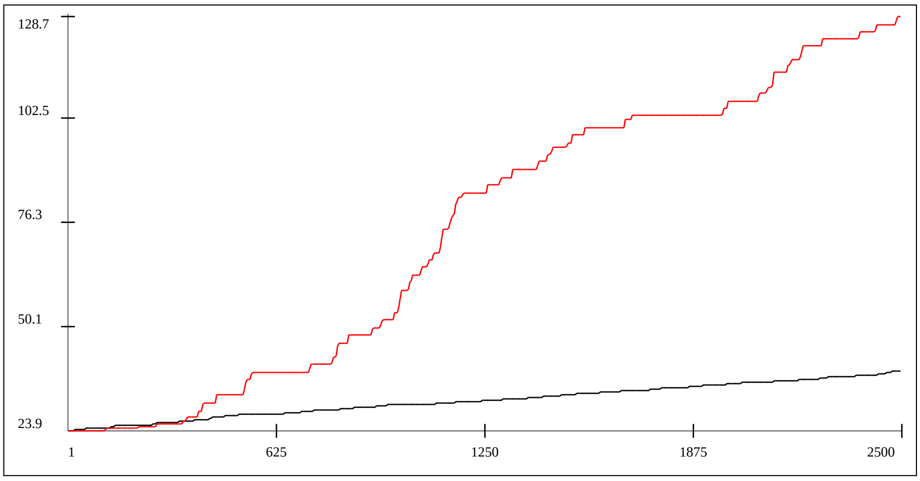

Figure 5: Maximum product quality, with patents (red) and without patents (black). (N=10, no interdependencies)

The following figures present the same variables for an industry characterized instead by high technological interdependencies. It can be noticed that in this case in the absence of patent protection not only are prices and industry concentration lower, but also innovation and product quality show a consistently higher level and therefore consumers' welfare is obviously higher without patent protection.

In the presence of high interdependencies, innovation is far more complex a process: finding better components does not necessarily increase overall product quality, because components have to fit together in some specific way. Holding a patent on a product configuration may therefore *de facto* block many more innovative paths than what established *de jure*. If for instance product $x^* = x_1^* x_2^* \dots x_n^*$ is a patented innovation and H_A^* and V_A^* are respectively the patent's horizontal and vertical amplitudes prescribed by the legal and judicial system, when products are made of independent component only products which are outside the boundaries around x^* determined by the amplitudes. If instead the product system is characterized by interdependencies, many local innovations may decrease the performance of the product if the rest of the product is not co-adapted, this implies that feasible innovative paths are much fewer than in the case without interdependencies and when such paths pass through a configuration protected by the patent, the entire path may be blocked.

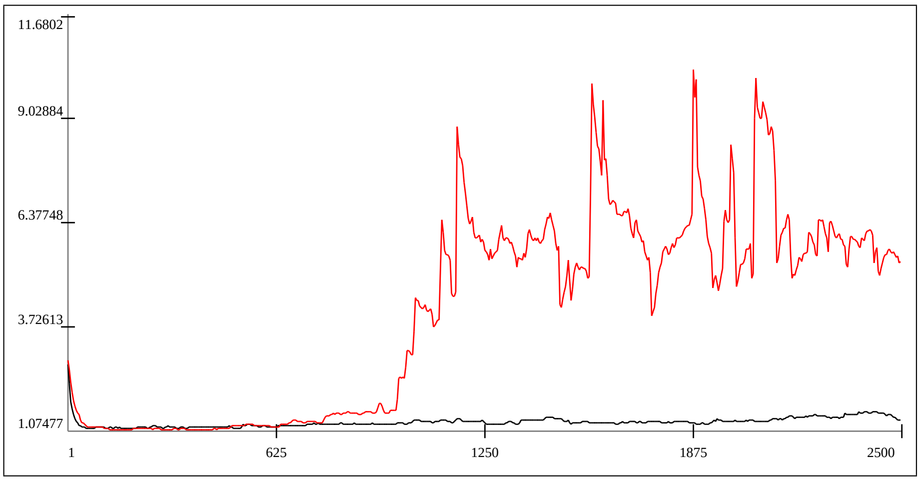

Figure 6: Average price, with patents (red) and without patents (black). (N=10, high interdependencies)

5.2 Coarse vs. fine patents

What is the granularity of patents? That is, can firms patent the whole product, modules thereof or each single component? Coarse patents, granted only on whole products or large modules prevent the marketing of products which are too close (horizontally or vertically) in the whole product (or modules) space, while if each single component is a patent *per se*, a product containing only one components which is similar enough to a

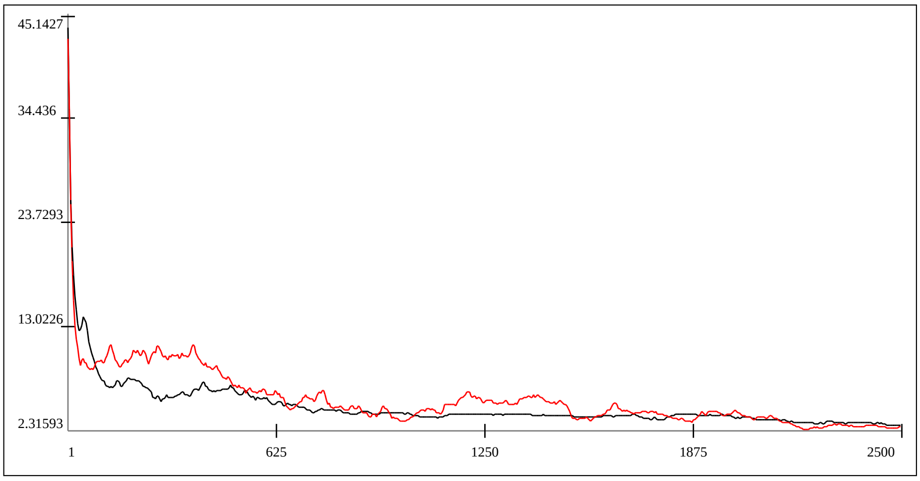

Figure 7: Industry concentration (inverse Herfindal index), with patents (red) and without patents (black). (N=10, high interdependencies)

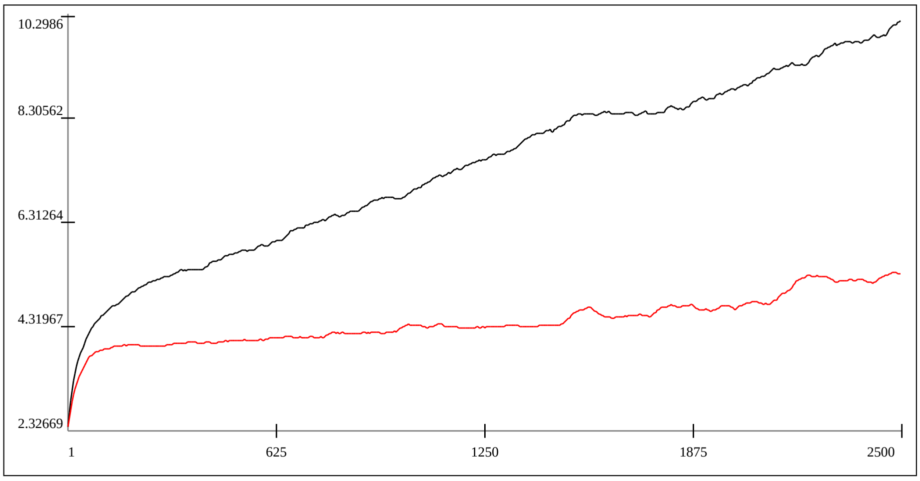

Figure 8: Consumers' welfare, with patents (red) and without patents (black). (N=10, high interdependencies)

patented one can be prohibited.

This phenomenon, which is similar to the tragedy of the anticommons and to the patent thicket problem described by the empirical literature, usually connected to the complexity of products, can indeed emerge also in "simple" highly separable products, as indicated by the following two graphs which report consumers' welfare and average product quality in an industry characterized by full separability with two different patents regimes: one in which only whole products can be patented, and one in which each single components can be granted a separate patent. We can see that in the latter regime both consumers' welfare and average product quality are inferior in spite of the separability of product components.

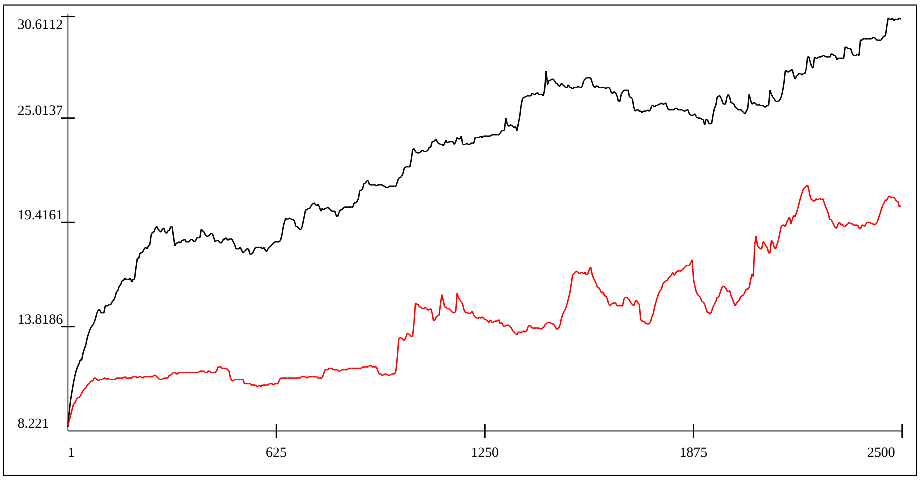

Figure 9: Average product quality, with patents (red) and without patents (black). (N=10, high interdependencies)

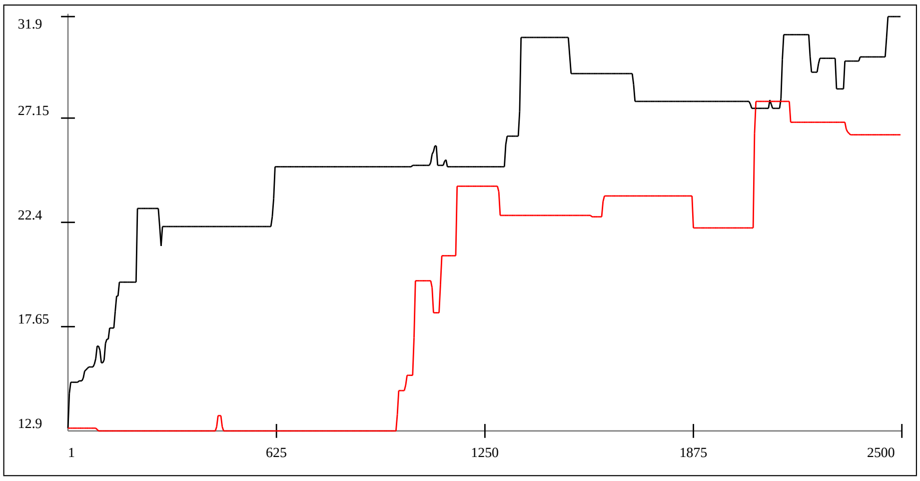

Figure 10: Maximum product quality, with patents (red) and without patents (black). (N=10, high interdependencies)

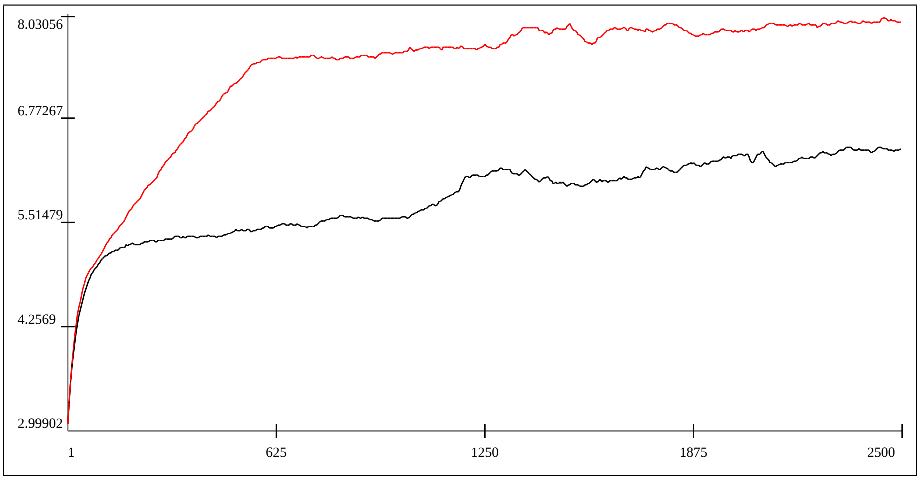

Figure 11: Consumers' welfare, with coarse patents (red) and fine patents (black). (N=10, low interdependencies)

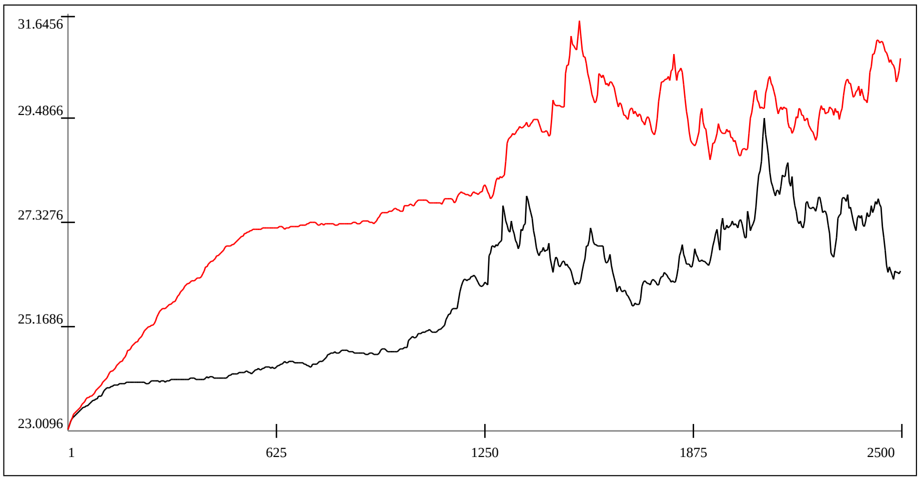

Figure 12: Average product quality, with coarse patents (red) and fine patents (black). (N=10, low interdependencies)

6 Conclusions

Evolutionary models of industry dynamics have greatly contributed to the understanding of the sources and consequences of technical change, but have mostly concentrated on process innovation. Product innovation has attracted a considerable amount of empirical work, but remains relatively understudied in formal models: this is indeed a heavy limitation of evolutionary theory, as product innovation is certainly playing a key role in the current historical phase.

Product innovation poses a few important challenges: the role of demand, the role of product diversification and the creation of submarkets through which firms escape the curse of competition. An important dimension concerns product complexity: many important products are actually complex systems of components and characteristics. How does such complexity influence the dynamics of industry evolution?

Finally, when considering product innovation the role of patent appears more paramount than with respect to process innovation: patents directly confer a monopoly power within a submarket and prevent imitators from serving it directly. Moreover, if the product space is complex, favoring or blocking innovation in single components through patents has effects which propagate throughout the entire product system in ways which are difficult to predict.

In this paper we have approached the study of the effects of patents on the dynamics of an industry and on consumer welfare by means of an evolutionary model of product innovation where firms adaptively search in a complex space of product characteristics and where consumers are characterized by ideal types and look for low prices, high quality and low distance from their ideal type. We show how patents influence the dynamics of industry evolution in this more realistic setting. Our main conclusion is that product / technological complexity is a key factor determining the long run efficiency or inefficiency of the patent system. Within complex product industry patents show in general a wealth reducing effect.

References

ANDERSON, S. P., A. DE PALMA, AND J.-F. THISSE (1989): “Demand for differentiated products, discrete choice models and the characteristics approach,” *Review of Economic Studies*, 56, 21–35.

ARORA, A., A. FOSFURI, AND A. GAMBARDELLA (2001): *Markets for Technology: Economics of Innovation and Corporate Strategy.* MIT Press, Cambridge, Ma.

BALDWIN, C. Y., AND K. B. CLARK (2000): *Design Rules. The Power of Modularity.* MIT Press, Cambridge Mass.

Barton, J. (2000): "Reforming the Patent System," *Science*, 287, 1933–1934.

Bessen, J., and E. Maskin (2000): "Sequential Innovation, Patents and Imitation," Working Paper 00-01, MIT Department of Economics, Cambridge, MA.

Boldrin, M., and D. Levine (2002): "The Case Against Intellectual Property," *American Economic Review Papers and Proceedings*, 92, 209–212.

Coase, R. (1960): "The problem of social cost," *Journal of Law and Economics*, 3, 1–44.

Cohen, W., R. Nelson, and J. Walsh (2000): "Protecting their Intellectual Assets: Appropriability Conditions and why US Manufacturing Firms Patent or not," Discussion Paper 7552, NBER.

David, P. (1992): "Knowledge, property, and the system dynamics of technological change," in *Proceedings of the World Bank Annual Conference on Development Economics*. World Bank.

Dosi, G. (1982): "Technological Paradigms and Technological Trajectories. A Suggested Interpretation of the Determinant and Direction of Technological Change," *Research Policy*, 11, 147–162.

——— (1988): "Source, Procedures and Microeconomic Effects of Innovation," *Journal of Economic Literature*, 26, 1120–1171.

Dosi, G., L. Orsenigo, and M. Sylos Labini (2005): "Technology and the economy," in *The Handbook of Economic Sociology*, ed. by N. Smelser, and R. Swedberg. Princeton University Press, Russell Sage Foundation.

Gallini, N. (2002): "The Economics of Patents: Lessons from Recent U.S. Patent Reform," *Journal of Economic Perspective*, 16, 131–154.

Grandstrand, O. (2005): "Innovation and Intellectual Property Rights," in *The Oxford Handbook of Innovation*, ed. by I. Fagerberg, D. Mowery, and R. Nelson, pp. 266–290. Oxford University Press, Oxford.

Hall, B. (2005): "Exploring the Patent Explosion," *Journal of Technology Transfer*, 30, 35–48.

Hall, B., and R. Ziedonis (2001): "The Patent Paradox Revisited: Firm Strategy and Patenting in the US Semiconductor Industry," *Rand Journal of Economics*, 32, 101–128.

Heller, M. (1998): "The Tragedy of the Anticommons: Property in Transition from Marx to Markets," *Harvard Law Review*, 111, 698–701.

Heller, M., and R. Eisenberg (1998): “Can Patents Deter Innovation? The Anticommons in Biomedical Research,” *Science*, 280, 698–701.

Hortsmann, I., J. Mac Donald, and A. Slivinski (1985): “Patents as Information Transfer Mechanisms: To Patent or (maybe) not to Patent,” *Journal of Political Economy*, 93, 837–858.

Jaffe, A. (2000): “The US Patent System in Transition: Policy Innovation and the Innovation Process,” *Research Policy*, 29, 531–557.

Jaffe, A., and J. Lerner (2004): *Innovation and its Discontents.* Princeton University Press, Princeton, NJ.

Kauffman, S. A. (1993): *The origins of order.* Oxford University Press, Oxford.

Klepper, S., and P. Thompson (2007): “Submarkets and the evolution of market structure,” *RAND Journal of Economics*, forthcoming.

Klette, T. J., and S. Kortum (1984): “Innovating firms and aggregate innovation,” *Journal of Political Economy*, 5, 986–1018.

Klevorick, A., R. Levin, R. Nelson, and S. Winter (1995): “On the Sources and Interindustry differences in Technological Opportunities,” *Research Policy*, 24, 185–205.

Kortum, S., and J. Lerner (1998): “Stronger Protection or Technological Revolution: What is Behind the Recent Surge in Patenting?,” *Rochester Conference Series on Public Policy*, 48, 247–307.

Lerner, J. (2002): “150 Years of Patent Protection,” *American Economic Review Papers and Proceedings*, 92, 221–225.

Levin, R., A. Klevorick, R. Nelson, and S. Winter (1987): “Appropriating the Returns from Industrial R & D,” *Brookings Papers on Economic Activity*, pp. 783–820.

Mansfield, E. (1986): “Patents and Innovation: An Empirical Study,” *Management Science*, 32, 173–181.

Mansfield, E., M. Schwartz, and S. Wagner (1981): “Imitation Costs and Patents: an Empirical Study,” *Economic Journal*, 91, 907–918.

Marengo, L., and G. Dosi (2005): “Division of Labor, Organizational Coordination and Market Mechanisms in Collective Problem-Solving,” *Journal of Economic Behavior and Organization*, 58, 303–326.

Marengo, L., C. Pasquali, and M. Valente (2005): “Decomposability and modularity of economic interactions,” in *Modularity: Understanding the Development and Evolution of Complex Natural Systems*, ed. by W. Callebaut, and D. Rasskin-Gutman, pp. 835–897. MIT Press, The Vienna Series in Theoretical Biology, Cambridge MA.

Merges, R. (1996): “Contracting into Liability Rules: intellectual property rights and collective rights organizations,” *California Law Revies*, 84, 1293–1386.

Merges, R., and R. Nelson (1994): “On Limiting or Encouraging Rivalry in Technical Progress: the Effectsof Patent Scope Decisions,” *Journal of Economic Behavior and Organization*, 25, 1–24.

Moser, P. (2003): “How do Patent Laws Influence Innovation? Evidence from Nineteenth-Cenury World Fairs,” Discussion paper, NBER.

Mowery, D., R. Nelson, B. Sampat, and A. Ziedonis (2001): “The Growth of Patenting and Licensing by US Universities: An Assessment of the Effects of the Bayh-Dole Act of 1980,” *Research Policy*, 30.

Nelson, R. R., and S. G. Winter (1982): *An evolutionary theory of economic change.* The Belknap Press, Cambridge, MA.

O’Donoghue, T. (1998): “A patentability requirement for sequential innovation,” *RAND Journal of Economics*, 29, 654–679.

Scotchmer, S. (1991): “Standing on the Shoulders of Giants: Cumulative Research and the Patent Law,” *Journal of Economic Perspectives*, 5, 29–41.

Shapiro, C. (2000): “Navigating the Patent Thicket: Cross Licenses, Patent Pools and Standard Setting,” in *Innovation Policy and the Economy*, ed. by A. Jaffe, J. Lerner, and S. Stern, vol. 1. NBER and MIT Press, Cambridge, Ma.

Simon, H. A. (1969): *The Sciences of the Artificial.* MIT Press, Cambridge, MA.

Stiglitz, J. (1994): *Wither Socialism.* Mit Press, Cambridge, Mass.

Sutton, J. (1998): *Technology and market structure.* MIT Press, Cambridge, MA.

Teece, D. (1986): “Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy,” *Research Policy*, 15, 285–305.

Tirole, J. (2002): “Protection de la propriété intellectuelle: une introduction et quelques pistes de réflexion,” Discussion paper, Conseil d’Analyse Economique, Paris.

Winter, S. (1982): “An Essay on the Theory of Production,” in *Economics and the World around It*, ed. by H. Hymans, pp. 55–93. University of Michigan Press, Ann Arbor.

——— (1984): “Scumpeterian competition in alternative technological regimes,” *Journal of Economic Behavior and Organization*, 5, 287–320.

——— (1987): “Knowledge and Competences as Strategic Assets,” in *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, ed. by D. Teece. Harper and Row Ballinger Div., New York.

——— (1993): “Patents and Welfare in an Evolutionary Model,” *Industrial and Corporate Change*, 2, 211–231.

——— (2002): “A View of the Patent Paradox,” Presentation at London Business School, May 20 2002.

Ziedonis, R. (2004): “Don’t Fence Me In: Fragmented Markets for Technology and the Patent Acquisition Strategies of Firms,” *Management Science*, 50, 804–820.