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# Patents versus ex post rewards: A new look

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**Abstract**

Economic studies that aim at comparing the patent system social efficiency versus an ex post reward system rest on an outdated view of patents. They assume that firms use the patent system only in order to be granted a short-term commercial monopoly rent. This assumption is convenient because it allows straightforward comparisons between patents and rewards but it is not confirmed by empirical studies, which stress that in many industries most firms use patents as strategic devices to trade technologies and to ease R&D collaborations. This change leads to rethinking the framework of the patent–reward debate.


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## 1. Introduction

"The reward mechanism raises considerable questions and received only little attention from economists and scholars in other disciplines. Given the (justified) renewal of interest for this mechanism, it would be desirable to develop new studies on this topic" (Tirole, 2003, p. 41)

Patents are often regarded as a reasonable consensus providing increased incentives to invest in knowledge production and at the same time, ensuring a wide diffusion of the knowledge underlying the patented innovation. But, problems inherent to this system, mainly the deadweight monopoly loss it generates, has led researchers to explore alternative solutions to patents.[1]

Among these alternative solutions, the present paper focuses on ex post rewards and public patents buy-out[2] (Polanyi, 1944; Wright, 1983; Kremer, 1998; Llobet

[1] Quotation originally in French. The translation is mine.

[2] Systems of patents buy-out and ex post rewards are not exactly similar, as we will see in Section 3. Nevertheless, in this work we use these two expressions alternatively without making any difference between them because the point we want to make (that the patent system cannot be reduced to a simple amount of money and, as such, that it cannot be properly replaced by a system that gives only money to innovators) applies similarly to both of them.

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et al., 2001; Shavell and van Ypersele, 2001). Under a system of ex post reward, innovators are paid directly by governments for their contributions to social welfare and their innovations pass immediately into the public domain. Similarly, under a patent buy-out system governments buy patents from the innovators and put them into the public domain in order to ensure free access of the patented innovation to everybody. Such systems are appealing since, under certain conditions, they have: "The potential to eliminate monopoly price distortions and incentives for wasteful reverse engineering, while encouraging for original research" (Kremer, 1998, p. 1138). In other words, they could preserve the benefits of the patent system while mitigating its main disadvantages.

However, studies that attempted so far to appraise the social efficiency of a system of ex post reward and to compare it with patents are somehow all based on a similar approach. They rest on a classical perspective of patents in the sense that they make the central assumption that firms apply for patents for the sole purpose to exploit a commercial monopoly position, the other benefits provided by patents entering only marginally into the decision to patent or not. This hypothesis reduces, by far, the role of patents but is convenient because within such a framework it is straightforward to compare patent and reward systems.

Indeed, if firms use patents only in order to secure short-term monopoly rents, governments can compute the expected monopoly profit of each innovation and pay this amount to innovators. Instead of granting a patent, the government can thus directly reward innovators, so that incentives to invest in R&D are held constant but the deadweight monopoly loss provoked by the patent is removed. Following this traditional approach of the patent system, the social desirability of patents versus ex post rewards rests mainly on the quantity and quality of information available to policy makers. If a central planner can gather enough information to appraise, even approximately, the expected monopoly profit of each innovation then it is worth replacing patents by ex post rewards.

This paper aims at widening this discussion about the social desirability of patents or rewards. With the exception of a few industries (mainly chemicals, pharmaceuticals, petroleum), firms are far from considering patents as efficient devices to appropriate their innovations and, therefore, to secure monopoly rents (Mansfield et al., 1981; Mansfield, 1986; Levin et al., 1987; Goto and Nagata, 1996; Arundel and van de Paal, 1995; Cohen et al., 2000; Arundel, 2001; Hall and Ziedonis, 2001; Reitzig, 2003). Nowadays, the consensus that emerges from empirical studies is that in a knowledge-based economy patents assist the collective process of innovation by easing technology trading and inter-firm collaborations. In other words, the patent system may be a central element of the knowledge production process not because it provides incentives to invest in knowledge production, but because it facilitates coordination among actors of innovation (Pénin, 2003b).

It follows that in most industries, the central hypothesis that allows a straightforward comparison between patent and reward systems collapses. Usually, a patent cannot be reduced merely to a single amount of money. This new vision of the patent system leads to re-thinking the debate between patents and ex post rewards and to orienting it towards a ground that would take into account the coordination properties of patents. The central issue when comparing patents and ex post rewards may not be whether or not policy makers have enough information to compute the optimal reward but may rather rest on the effect of ex post reward on the collective process of innovation. Before deciding to replace patents by ex post rewards, we must assess how this replacement affects technology trading and inter-firm collaborations.

The paper is structured as follows: we start by recalling the classical foundations of patent policy. Then we introduce the ex post reward system and we analyse the traditional line of comparison between this system and the patent one. In Section 3, we review the empirical criticisms that have affected the classical view of patents and we discuss the role of patents as devices to ensure coordination. We conclude by an investigation of how this new vision of patents affects the patent–reward debate and by focusing on the special case of the pharmaceutical industry.

## 2. The theoretical background of patent policy

Current innovation policies, including patents, are based on a vision of knowledge that goes back to the pioneer work of Nelson (1959) and Arrow (1962). Knowledge is considered as a non-rival and non-appropriable good and as such, its production

generates spillovers. New knowledge flows from its creative source to other agents who, although they do not share the production costs, share the benefits of this new knowledge.

The presence of knowledge spillovers implies that there is a gap between the amount of investment in research activities achieved by the market and the ideal amount of investment for society. Market mechanisms lead to under-investments in knowledge production as compared with an ideal. However, on the one side the default of appropriation leads to under optimal level of knowledge production, but on the other side if it was possible to dismiss knowledge spillovers by allowing inventors to appropriate perfectly their new knowledge, the situation may not be improved from a social point of view because the distribution of knowledge among individuals would not be optimal. Indeed, knowledge is not only a non-appropriable good, but also a non-rival and a cumulative good. And these properties of non-rivalry and cumulativeness, since they require that the price of any given piece of knowledge must be as low as possible in order to enable everybody to access the knowledge, are hardly compatible with the property of appropriation that gives market power to owners and hence that leads to high prices.

There is, therefore, an opposition between the optimal allocation of knowledge within an economy and the optimal level of knowledge production (Arrow, 1962). On the one hand, non-appropriability is not desirable, since it decreases firms' incentives to invest in knowledge production but on the other hand, non-rivalry and cumulativeness imply that the produced knowledge must remain as much as possible non-appropriable. It results from this dilemma that non-market mechanisms must be implemented both in order to increase incentives to invest in knowledge production and to increase the distribution of the new knowledge within the economy.

This statement is at the origin of the implementation of the patent system. In theory, a patent ensures its owner with a monopoly position, limited in time and in space, over the applications of the patented innovation. This issue of a monopoly position aims at increasing firms' expected returns from innovation, which in turn, should increase their incentives to innovate. Moreover, in theory a patent ensures a wide diffusion of the knowledge (codified) underlying the patented innovation. When an inventor applies for a patent, he must provide a description of his invention that allows a person knowing the state-of-the-art to reproduce it. Once the patent is granted, or in some countries even if the patent is not granted, this description is published and everybody has free access to it. At the very least, even if patents do not disclose important technical results, they still remain an indicator of which field may be worth exploring and which one may not. Such information about the map of the technological field is also quite valuable.

To summarize, patents are traditionally considered as major instruments of innovation policy because they can reconcile two apparently opposite but equally necessary goals. They restore the incentives to invest in knowledge production, since they allow to some extent the appropriation of the innovation, and they ensure the necessary dissemination of the research results, since the knowledge enabling the reproduction of the patented innovation is published.

However, there is a counterpart to this idyllic picture: the patent system, by granting innovators a monopoly position, also triggers a static monopoly deadweight loss as compared with a situation of perfect competition.[3] During the time the patent holds, social welfare is not maximized because the monopoly pricing penalizes consumers more than it favours producers. A monopoly situation penalizes consumers because some of them, who value the good above its marginal cost (and hence, who could afford to buy it in a situation of perfect competition), do not consume it at the monopoly price. For this reason, it is often argued that the patent system leads to sacrificing the static efficiency of the economy in order to ensure the dynamic efficiency. Today's welfare diminution due to the monopoly price distortion created by patents leads to an increase of tomorrow's welfare, because higher incentives to invent mean further innovation in the future.

## 3. The patent–reward debate in the literature

### *3.1. Presentation of ex post rewards and patent buy-outs*

Before presenting the traditional line of comparison between patents and rewards, let us first introduce and

[3] We do not mention here the other "embarrassments of an exclusive patent" (Jefferson, 1813, p. 335). For an overview of the shortcomings of the patent system one can consult Andersen (2003).

illustrate by historical examples the systems of ex post reward and patent buy-out. These two systems can be considered as identical in the sense that they both replace the patent monopoly rent by an amount of money determined by the central authority and they both make it possible to release the innovation into the public domain.

Conversely to the patent system, in which innovators must earn their remunerations through the exploitation of a monopoly position, under an ex post reward system the government distributes prizes to successful innovators in order to reward them for their contribution to the social welfare. An important difference between those two systems is, therefore, that under the patent system the market determines the amount of the reward whereas under an ex post reward system, this amount is appraised by the central planner. The idea to substitute an ex post reward system for the patent system is not new. Already in 1944, Polanyi (1944, p. 65) claimed that: "In order that inventions may be used freely by all, we must relieve inventors of the necessity of earning their rewards commercially and must grant them instead the right to be rewarded from the public purse".

Nowadays, such a system of rewards is widely used in several domains: for instance, the Nobel prize for academic work and arts, the Pulitzer prize for journalistic excellence, the Hollywood Oscar for actors, etc. These prizes are not merely honorary, they are often accompanied by immediate monetary benefits and they often trigger long-run benefits due to the reputation the prize ensures to the laureate. In the industrial world, there also exist prizes and rewards for successful creators but such rewards are distributed on a small and not systematic scale, as the following examples will show.

In 1714, the British government announced its decision to grant a £10,000 prize to the first inventor of a reliable method for measuring longitude. This incentive led to the invention of the chronometer by Harrison (Horrobin, 1986).[4] Similarly, the French Academy of Science announced, in 1775, that it would pay a 12,000 franc reward to the first to invent an artificial alkali form. Later, the Napoleon Society decided, in 1795, to offer a prize of 12,000 franc to the first to invent a method of food preservation that could be used by soldiers. It was awarded in 1810 to Nicolas Appert, the inventor of food canning (Wright, 1983).

These examples illustrate prizes for which the amount of the reward is computed ex ante of the invention and that aim at attracting resources for invention toward a precise technological domain. As such, they are closer to research tournaments or races (Taylor, 1995) than to ex post rewards. However, our own interest lies in systematic prizes for which the reward is computed ex post, once the invention has been discovered, and therefore, that aim at widely encouraging innovation in all economic sectors, in the same way the patent system does.

Instead of implementing such a general and systematic ex post reward system, governments may decide to buy patents granted to innovators systematically, in order to put them into the public domain, that is, in order to let them be used freely by all. This idea of patent buy-outs comes from the purchase by the French government in 1839, of the daguerreotype photography technique, named after its inventor Daguerre. Kremer (1998) explained that initially: "Daguerre offered to sell detailed technical instructions to a single buyer for 200,000 francs or to 100–400 subscribers at 1000 franc each" (Kremer, 1998, p. 1144). However, Daguerre was not able to find any buyer and finally, the French government purchased the patent in exchange for pensions of 6000 franc per year to Daguerre, 4000 franc to his partner, and half that amount to their widows upon their death. Then, the French government released the rights into the public domain (except in England), resulting in a wide adoption of this technology all around the world. Instructions were translated into several languages and many technological improvements emerged quickly. Another example of patent buy-out is the cotton gin patent that was sold to the state of South Carolina by its inventor Eli Whitney, who was unable to make money with it.

A major drawback of both systems of ex post rewards and patent buy-outs is that they can work only provided that the central planner (the policy maker) has

[4] Wright (1983, p. 704) explained that: "Awards of £10,000, £15,000 and £20,000 were offered by the British board of longitude in 1713 for a chronometer which measured longitude to within 60, 40 and 30 min, respectively. John Harrison claimed the £20,000 reward in 1762, and full payment was completed by 1773 (Encyclopedia Britannica, 1929, vol. 11, p. 220)".

access to almost perfect information.[5] Indeed, in order to implement such systems, the central planner must be able to compute the optimal (from a societal point of view) amount of the reward or the optimal price of the patent buy-out. And this ideal amount must encompass all the benefits the innovation generates for society, including all the spillovers either positive or negative. In other words, without taking any equity concept into account, the ideal reward is equal to the social value of the innovation. Only then can policy makers be sure that all the profitable innovations, from a social point of view, and only those innovations are implemented. Indeed, when the remuneration is more than the social surplus, there is a risk that some innovations with a social cost higher than the benefit they generate for society are implemented. Conversely, when the reward is less than the social surplus, some innovations profitable for society (with a social cost lower than the social benefit) may not be implemented. Thus, it is only when the reward for an innovation equals the social surplus of this innovation that the social and private goals are perfectly balanced.[6]

### *3.2. Patents or rewards: what is more desirable for society?*

The presentation of both patent and reward systems clearly shows that in a world where information is complete ex post rewards perform at least as well as patents because they preserve the advantages of the patent system (they increase the incentives to invent and they help to diffuse the research results widely), whereas they do not induce monopoly distortions.

Once the reward has been granted or the patent has been bought-out, the innovation is put into the public domain, meaning that it is accessible to everybody without having to pay a licence to the innovator. Thus, ex post rewards increase the competition for the production and distribution of a given innovation and they lead to price decrease as compared with the patent system. Moreover, rewards provide higher incentives than patents as soon as the amount of the prize surpasses the expected monopoly rent, which is what innovators get under the patent system. Specifically, patent buy-outs are very attractive for small firms because they ensure them with a certain reward and thus, they eliminate the risk associated with the need to earn the reward commercially.

To put it plainly, when information is complete a sufficient condition for patent buy-outs or ex post rewards to perform better than patents is to warrant to innovators a reward at least equal to what they can expect by exploiting a monopoly while allowing a full disclosure and use of the new knowledge. Polanyi already stressed this point in 1944: “If the government were to fix the total sum allocated for public rewards at a level which will just suffice to induce inventors and financiers to be as eager to obtain patents as they are today (which would presumably require a sum about equal to the profits derived from their patents today), the general public would be left with a handsome balance” (Polanyi, 1944, p. 68).

Yet, in a world where information is scarce and costly, and therefore, where the central planner does not know exactly the value of the innovations, the conclusion that rewards are socially more desirable than patents does not hold any more. As it is mentioned above, implementing a reward system that dominates the patent one requires the government to fix the amount of the rewards at a level at least equal to the expected monopoly profit. Clearly, in most cases a central planner will be unable to gather the needed information to compute this amount because the relevant information is mainly private.[7]

[5] Following Tirole (2003), a system of ex post rewards would face four main problems:

- *Information*. Governments cannot gather the information enabling them to compute the ideal reward.
- *Coordination*. Governments will have problems to agree on the functioning of a worldwide institution that will finance the system.
- *Corruption*. There is a risk of collusion between innovators and governments.
- *Commitment*. Innovators must be certain that, after the innovation is implemented, the government will not expropriate them and pay them less than what they deserve.

[6] It can be argued that policy makers are not obliged to give the entire social surplus generated by an innovation to the innovator. They could, for instance, give only an amount equal to the cost of the innovation plus a bonus. However, in such a case, our argument still holds since policy makers must, nevertheless, know the social value of the innovation in order not to give more than this value to innovators, which would induce the production of socially undesirable innovations.

[7] The method proposed by Kremer (1998), although interesting and original, illustrates perfectly the difficulties faced by a central

These informational problems encountered by centralized solutions provide patents with a fundamental advantage over ex post rewards. Indeed, the patent system is decentralized and as such: "Patent leaves nothing to anyone discretion; because the reward conferred by it depends upon the invention being found useful and the greater the usefulness, the greater the reward" (J.S. Mill, 1872, cited in Shavell and van Ypersele, 2001, p. 527). The special advantage of patents arises from the Hayekian argument that private researchers have far more information about their own inventions than any central authority and the patent system exploits this private information by letting the market determine the value of innovations.

To summarize, following the economic studies that have documented the topic, conclusions on a global and systematic superiority of patents over rewards, or vice versa, are reasonably straightforward: when information is complete, it may be advisable to implement a centralized solution, such as an ex post reward system, since this will not result in any of the distortions that may come with a monopoly. But when the public authority responsible for rewarding innovators does not have complete information about the benefits of an invention, then it may be optimal to rely on a decentralized system, such as the patent one. In other words: "Information and its distribution are major elements in the rationale for the patent instrument" (Wright, 1983, p. 695). Yet, this conclusion rests on a strong and controversial hypothesis.

### *3.3. The hypothesis underlying the patent–reward debate*

The patent–reward debate, as it was treated so far not only in this paper, but also in most of the works devoted to it, is anchored in a classical perspective of patents. It is based on the hypothesis that firms rely on the patent system only in order to secure short-term monopoly rents and hence, that the economic role of patents is only to provide incentives to invest in R&D. The role of patents as a coordination device is widely neglected in this debate.

Under this assumption it is possible, with the help of formal models, to compute the expected monopoly profit that firms can earn from their patents, i.e., it is possible to associate to each patent an amount of money that would ensure the same level of incentives to invest in R&D. This assumption implies, therefore, that patents can be reduced to a single amount of money, thus making it possible for a central planner to replace them by a monetary counterpart. Within this framework, the only criterion to choose between patents or rewards is whether or not a central planner has access to the relevant information in order to compute the optimal amount of the reward. Yet, under the opposite assumption that patents cannot be reduced to a simple amount of money, it is likely that the comparison between patents and rewards would not be so straightforward.

To sum up, the hypothesis that underlies the patent–reward debate and that allows the kind of reasoning presented here is that patents are used only in order to secure firms with commercial monopoly positions. The point we advocate in the following is that empirical works on the economic role of the patent system usually contradict this core assumption.

## 4. Evolution of the role of patent: from an appropriation to a coordination device

### *4.1. Patents are not central to appropriating the returns to R&D in most industries*

Empirical works mostly stress that the classical explanation of patents presents serious dysfunctions (Mazzoleni and Nelson, 1998; Jaffe, 2000). In most industries, firms do not rely on patents to protect, and hence, to appropriate their innovation. This conclusion appears quite robust in the sense that it is based on several empirical studies, concerning different periods, countries and industries that all converge to similar results.

planner to compute only an approximate value of the optimal reward. Kremer suggested to implement an auction mechanism in order to compute the private value of innovations. Briefly, and not going into the details, the intuition of Kremer's method is the following: first, an inventor informs the government that he wants to sell his patent. Then, public authorities diffuse this information widely and firms who want to buy this patent must reveal the price they are willing to pay in order to be granted the monopoly right. The outcome of this auction process should theoretically lead to the private value of the invention. The government can then use this information in order to approximate the social value of the invention (Kremer suggests to double at least the auction outcome). Finally, the government can buy the patent at this price and put the innovation into the public domain.

The pioneer empirical evaluations of the way in which firms use the patent system are due to Scherer et al. (1959) in the U.S. and to Taylor and Silberston (1973) in the U.K. Both studies conclude similarly that with the notable exception of the pharmaceutical industry, firms do not consider patents to be efficient to ensure a monopoly position on a given market or even to be a necessary condition to make an innovation profitable. This was considered as quite surprising then but it has been confirmed by all further studies.

In the 1980s, Levin et al., 1987[8] reported that firms value many methods of protection from imitation (such as secrecy, lead time or superior services) more highly than the patent system. Only firms located in industries that involve chemical-based knowledge (pharmaceuticals, organic and inorganic chemicals, petroleum, plastic materials) seem to rely strongly on the patent system in order to protect their innovations from imitation. These conclusions hold for both process and product innovations, except for secrecy that is rated below the patent system for product innovation (which is not surprising since in this case secrecy can easily be broken through reverse engineering). Mansfield et al., 1981 found similar results by studying 48 major innovations in four industries (chemicals, drugs, electronics and machinery). When firms are asked whether or not their inventions would have been achieved in the absence of the patenting institution, the authors explain that more than half of the firms answer positively, suggesting that patents do not really play the incentive role that is traditionally attributed to them. When firms in the drug industry are excluded, it is less than one quarter of the innovations that would not have been implemented without the patent system.[9]

In the 1990s, studies carried out in the USA (Cohen et al., 2000), Japan (Goto and Nagata, 1996) and Europe (Arundel and van de Paal, 1995; Arundel, 2001) reached similar conclusions. For instance, Cohen et al. (2000) report that, on average, for both product and process innovations firms rate patents far below the other methods of protection of an innovation from imitation.[10] For Europe, Arundel (2001)[11] showed that firms of all sizes find secrecy to be relatively more important than patents but small firms find secrecy to be of greater importance than larger firms.[12] Furthermore, these conclusions appear to strengthen through time, as firms tend to value secrecy more highly than patents nowadays as compared to some years ago.

Not only questionnaire-based studies, but also econometric studies come to the conclusion that patents are not central to appropriate the benefits of innovations. For instance, Sakakibara and Branstetter (2001) examined the macro effects of the patent laws reinforcement and the patent scope broadening that occurred in 1988 in Japan. Following the traditional patent theory, this event should have increased the number of patent applications as well as the rate of innovation in the country. However, the authors' findings do not confirm this view: "Our evidence suggests that the responsiveness to changes in patent scope is limited [. . .]. These results challenge the notion that broader patents will induce additional innovation" (Sakakibara and Branstetter, 2001, pp. 78 and 98).

Rarely did such a number of empirical reports, over a 40-year period, reach such similar conclusions. It seems, therefore, that one can take for granted that

[8] The results of Levin et al. (1987) are based on a survey administered to 650 U.S. manufacturing firms (The *Yale survey*; see also Levin, 1986,1988).

[9] Mansfield (1986) also attempted to assess the extent to which the rate of development and commercialisation of inventions would decline in the absence of patent protection. He uses data about 100 firms in 12 industries over the period 1981–1983. His conclusions are similar to those reached by Mansfield et al. (1981). Pharmaceuticals apart, patents are not essential to the development and introduction of more than 70% of the innovations.

[10] The results of Cohen et al. (2000) are based on a questionnaire administered to 1478 R&D labs in the U.S. manufacturing sector in 1994 (The *Carnegie–Mellon University survey*). On average, firms rated patents and other legal devices far below secrecy, lead time, complementary sales and services and complementary manufacturing.

[11] Arundel (2001) used the data of the 1993 European Community Innovation Survey (CIS) that includes information about 2849 European firms from 1990 to 1992.

[12] The explanation of this finding is likely to deal with the overall cost of a patent (application, defense, etc.). Of course, patent offices do not price discriminate in favour of big firms. On the contrary, legislations sometimes even attempt to facilitate patenting for small firms, for instance by decreasing the application fees as does the Canadian Intellectual Property Office (CIPO). The major problem is that a patent does not ensure a monopoly de facto but only offers a right to exclude competitors, which the owner will still have to defend in court. A patent is no more than a license to sue (Silberston, 1967). Yet, small firms often do not have the capacities, financial or others, to defend their monopoly right in court, which means that a patent is absolutely useless for them. As Polanyi (1944) argued, under the patent law justice is available only to millionaires.

patents are not effective to secure monopoly rents in almost all industries. And this conclusion holds for many industries regarded as high-tech, such as computers and semi-conductors (chemicals and pharmaceuticals are exceptions).[13]

### 4.2. Patents as coordination devices

Results displayed in the previous section lead to an apparent paradox: firms report to rely weakly on patents in order to protect their innovations but the number of firms that apply for patents has sharply increased since the mid-80s. The USPTO received 60,000 patent applications in 1983 and more than 120,000 in 1999.[14] Yet, if firms do not rely heavily on patents then why are they patenting so much? Several explanations of this paradox have been proposed.

Kortum and Lerner (1999) identified and tested four assumptions that may help to explain the recent patent application surge: (i) the first one is called the "friendly court hypothesis" and attributes this surge to new legislations that favour patent holders and make it more profitable to patent innovations; (ii) the second is called "fertile technology hypothesis" and attributes the patent application surge to the emergence of new knowledge-intensive technologies, such as biotechnologies and software that widened the technological opportunities set; (iii) the third assumption to be tested is called "regulatory capture hypothesis" and ascribes the surge to incumbents' over-patenting strategies aiming at increasing the barriers to potential entrants; (iv) finally, the last hypothesis attributes this surge to a change in the way firms manage their patent portfolios.[15]

After a thorough check, Kortum and Lerner rejected the first three hypotheses and concluded that the recent patent application surge is due to a change in firms' management of their patent portfolios. It is also the conclusion we adopt here: in a knowledge-based economy, in which coordination problems may be more important than appropriation ones, firms use patents not in order to appropriate their innovations and to exclude other firms but rather in order to facilitate coordination with the other actors of innovation. There are many ways through which patents can help the coordination among the actors of the innovation process.

(i) *Patents signal that a firm is competent*. As argued by Mazzoleni and Nelson (1998) the focus here is on the advertising value of patents. When an innovation is patented it means in theory that this innovation is new, non-obvious and has an industrial application. In this sense, a patent allows signalling to industrial and scientific communities that the owner holds given competences (Pénin, 2003a).[16] This signalling dimension of patents enable patentees to find partners with whom to collaborate, to collect funds, to hire bright students, etc.[17] This point was stressed by Cohen et al. (2000), for instance, who found that the willingness to enhance firms' own reputation is often quoted as a reason that induces firms to apply for a patent (it is quoted by almost half of the respondents (47.9%) to their questionnaire). As the authors notice, although a fraction of this figure may reflect a vanity component, overall it indicates that patents are efficient devices for approaching capital markets, venture capitalists or other potential partners (see also Hall and Ziedonis, 2001).

[13] Let us add to this categorical denial of the classical role of patents another one, less robust but nevertheless meaningful, concerning the role of patents as knowledge carriers. Empirical studies tend to confirm that patents do indeed convey some technical information but they, nevertheless, mitigate the optimistic view that patents disclose the knowledge underlying an innovation perfectly (Jaffe et al., 1998, 2000).

[14] See www.uspto.gov.

[15] It is to be noted that other motives not explored by Kortum and Lerner can be added to these four reasons, such as a shift to more applied research (which could be more easily patented), a higher R&D efficiency, a higher propensity to patent public research (following the Bayh–Dole Act) or the effect of globalisation.

[16] At first glance, one may see a contradiction between this view of patents as devices to signal competences and what was argued earlier about the shortcomings of patents as knowledge carriers (see footnote 13). However, these two points can be reconciled easily by noticing that even if patents do not disclose valuable knowledge they, nevertheless, disclose some information that may be sufficient to signal to other firms where competences are located. In other words, patents may not disclose technical knowledge but only information about who holds specific competences.

[17] Patents also encourage firms to publish their results in the scientific literature and in this sense too they help to break secrecy and to signal competences. Indeed, firms are usually reluctant to let their researchers publish before they have been granted a patent. Hence, patents, by protecting the disclosed knowledge, encourage the publication of research results, which in turn, also improves the coordination among agents.

(ii) *Patents help technology trading*. The existence of the patent system also plays a key role in facilitating the purchase and sale of technologies, i.e., patents contribute to the creation of a market for technology. Firms specialized in research can produce knowledge, patent their results and then sell them as licensing contracts that specify the price and the terms of the transaction. Such a market for technology could hardly emerge without the existence of the patent system since only the combination of the two properties of a patent permits it. On the one hand, the property of knowledge disclosure of patents allows firms to advertise their products and on the other hand, the exclusive right of exploitation ensured to patentees supports this disclosure by dismissing problems of free rider. Empirically, Arora and Fosfuri (2000) found evidence of such markets for technology based on the patent system. They stress that in the case of the chemical industry, only one-fifth of the technologies used by firms is produced internally and that in the 1980s, the average annual value of the transaction of technologies was between 10 and 20 billion US$ (this figure must be put in perspective with the total R&D spending of the 30 largest U.S. chemical firms in 1986, which was about 8 billion US$). Markets for technology in other industries, such as semiconductors, biotechnologies, electronics, were studied by Arora et al. (2000).

(iii) *Patents as "legal bargaining chips"*. In many sectors firms gather strong patent portfolios mainly in order to be able to trade those patents with other patent holders (Levin et al., 1987; Grindley and Teece, 1997; Cohen et al., 2000; Rivette and Kline, 2000). In this way patents are defensive devices that aim at protecting their holders from uncertain and risky lawsuits. In sectors in which technologies are overlapping and in which innovations are most of the time incremental firms are likely to be blocked during their research by other firms' patents. Expecting such situations, firms are, therefore, induced to gather important patent portfolios that will serve as "legal bargaining chips" and will be traded when firms need to use technologies that are protected by patents held by other firms. To amass patent portfolios enables, therefore, firms who are notified that they are infringing other patents to propose cross-licensing agreements rather than engaging in costly and uncertain patent litigations.[18]

In situation of patent litigations, agreements are facilitated by the fact that to defend a patent in front of a court involves important costs and uncertainties, i.e., agents eager to dismiss risks will always prefer to negotiate. Agreements are also encouraged by the fact that, in some countries, legal battles may involve preliminary injunctions that allow a patent holder to close down his competitors' operations for some time. When two firms pretend that the other infringes one of her patents, the danger represented by a mutual injunction is a powerful incentive for both firms to find an agreement (Lanjouw and Lerner, 2001). Finally, practices of cross-licensing are motivated by the cumulative and collective nature of the innovation process. In a context of complex innovation in which technologies are all inter-dependent, if patent holders do not find an agreement then the technological progress may be seriously slowed down. Indeed, a patent does not grant a right to use a given technology but only a right to exclude others from using it. A situation in which many patents protect each a fraction of a single technology and in which all firms use their exclusive rights to exclude others, is hence, likely to lead to a point in which no firm can use the technology. Therefore, most of the time, firms have a strong interest to set up cross-licensing agreements and to use their exclusive rights only with parsimony in order to prevent such dead-ends from occurring.[19]

[18] Von Hippel (1988) described the following situation: "Firm A's corporate patent department will wait to be notified by attorneys from firm B that it is suspected that A's activities are infringing B's patents. Because possibly germane patents and their associated claims are so numerous, it is in practice usually impossible for firm A – or firm B – to evaluate firm B's claims on their merits. Firm A, therefore, responds – and this is the true defensive value of patents in industry – by sending B copies of "a pound or two" of its possible germane patents with the suggestion that although it is quite sure it is not infringing B, its examination shows that B is in fact probably infringing A. The usual result is cross-licensing, with a modest fee possibly being paid by one side or the other. Who pays, it is important to note, is determined at least as much by the contenders' relative willingness to pay to avoid the expense and bother of a court fight as it is by the merits of the particular case" (Von Hippel, 1988, p. 53).

[19] Historically, we have examples of situations in which the multiplicity of patents and the unwillingness of their owners to collaborate and to grant licenses damaged the technological pace of the industry

Empirical studies support this view of patents as defensive devices. Lanjouw and Schankerman (2001) found that having a larger portfolio of patents reduces the probability of being involved in a suit on any individual patent. Similarly, Somaya (2003) studied 449 patent litigations in the computer industry and showed that in almost every case involving a suit and a counter suit, the counter suit was filed only 1 day after the suit, thus suggesting that in computer patents serve mainly as strategic devices in negotiations with other firms (see also Hall and Ziedonis, 2001; Harhoff and Reitzig, 2004, for cases of litigations at the European Patent Office). Furthermore, empirical studies indicate that strategic use of patents in negotiations is especially important in areas where innovation is complex (i.e., where innovation relies on multiple components). Lanjouw and Schankerman (2001) found that being part of a large patent portfolio is much less important for drug patents than for any other patents. Somaya also found a difference between firms' patenting strategies in computer and in research medicine (pharmaceuticals and biotechnologies). Hence, in industries with simple technologies, such as pharmaceuticals, the primary role of patents remains to exclude rival firms.[20]

(iv) *Patents ease collaboration among firms*. Yet, more than a defensive use that aims at protecting firms' against lawsuits and at exchanging technologies through licensing agreements, patents can be used in an explicit cooperative way, in order to ease collaborations among firms. For isolated actors who need to develop collaborations with other firms, patents can be precious devices to signal competences and to bargain favourable agreements. In this respect, patents clearly play a role at an early stage of the innovation process. They are used in a perspective of knowledge creation and not only in a perspective of resources allocation. In the process of inter-firm or inter-organisation collaborations, patents are susceptible to play a role at several stages.

First, as it was raised earlier, before collaboration patents signal the competences of their holders to other firms, and hence, help to identify potential partners. Furthermore, before the beginning of the collaboration patents are also useful because they induce firms to participate. Indeed, R&D cooperation is a risky process in the sense that participants must often share parts of their most important intellectual assets. Since patents protect the knowledge held by a firm from plundering by her partners, they decrease the risk of opportunistic behaviours and of hold up of competences. It follows that firms protected by patents may be more willing to be involved in R&D cooperation. In other words, patent protection decreases risks inherent to R&D cooperation, and hence, stimulates this cooperation (Ordover, 1991).

At a later stage, patents are important devices during the negotiations aiming at setting up the terms of the collaboration. Indeed, patents are a way to assess the competences of each partner, i.e., they provide a benchmark that allows firms to compare their relative competences. Without patents, firms would have difficulties to evaluate their relative competences, and therefore, could hardly agree on the terms of the entente. Moreover, not only patents allow evaluating the competences of the different partners but since they represent a credible threat to block the entente, they also allow firms to enforce their claim. In this sense patents are central devices to determine the bargaining power of each part and, as such, they can entail a distortion of the terms of the entente in favour of the firm who holds the most important patents.After the collaboration, patents may also be used as instruments to share the outcome of the collaboration, through a joint application for instance. Hagedoorn (2003) explained that: "co-owned patents are largely the result of small scale inter-firm R&D col-

seriously. It occurred, for instance, in the semi-conductor industry in the early days of radio at the beginning of the century. Radio is a multi-technology product and the problem was that a number of firms had important patent positions and could block each other's access to key components. These firms refused to cross-license each other and the result was a deadlock that lasted until 1919, when pioneers of the electronic industry (American Marconi, General Electric, American Telephone and Telegraph (AT&T) and Westinghouse) formed the RCA (Radio Corporation of America) and agreed to sell their patents to the RCA. This cross-licensing agreement, which led to the creation of the RCA, became a model for the future and nowadays firms in the semi-conductor industry still nurture a tradition of cross-licensing (Grindley and Teece, 1997).

[20] Kingston (2001, p. 408) explained that: "In complex technologies the motivation for firms' extensive use of patents is, therefore, quite different from that of firms in simple technologies. In the latter, the emphasis may be said to be primarily offensive (to prevent other from using the innovation); in complex technologies it is primarily defensive (to avoid being denied the use of an innovation)".

laborations where companies are unable to divide the invention among the partners" (Hagedoorn, 2003, p. 1045). According to Hagedoorn, joint patenting is thus more likely to arise following informal R&D partnerships and small joint research projects when the outcome of the collaboration is indivisible. Patents, in such cases may, therefore, encourage the collective process of innovation by facilitating the sharing of the dividends of collaborations.

Finally, patents, all along the collaboration, help the coordination between sometimes very heterogeneous actors because they represent a common language that can be understood by all of them (public labs, big multinationals, consulting agencies, financing organisations, etc.). Patents are an element of culture shared by all the actors and in this sense too they may ease collaboration.

To summarize, as Hall and Ziedonis (2001, p. 104) put it, in most industries: "Instead of being driven by a desire to win strong legal rights to a stand alone price, firms are driven by broader motives". Be it in order to trade technologies, to facilitate cooperation with other firms or to signal a firm's specific competences, the main reason for patenting is often triggered by other considerations than by a mere appropriation and exclusion motive. This feature must be taken into account when trying to assess the social desirability of patents versus ex post rewards.

## 5. Implications for the patent–reward debate

### *5.1. A new ground of comparison between patents and ex-post rewards*

When patents are regarded as instruments that provide incentives to invest in R&D the main question to compare patents and ex post rewards is "Would a central planner be able to gather enough information to compute the optimal amount of the reward?" But when the role of patents as coordination devices is included in the debate the central question becomes rather: "Would ex post rewards also manage to perform the role of coordination that patents seem to fulfil?" In other words, we need to know the impact of replacing patents by ex post rewards on knowledge disclosure, technology trading and inter-firms collaborations. It is beyond the objective of the present paper to give a complete answer to those questions but we can, nevertheless, speculate on some propositions and propose a background for future discussions.

For instance, it is straightforward to observe that ex post rewards can contribute to the disclosure of relevant knowledge and help to break secrecy. Indeed, the central authority in charge of the reward can require innovators to disclose a description of their innovation prior to being granted a reward. This also means that ex post rewards can signal where competences are located as well as patents do. Relevant information, such as the description of the rewarded innovation, the general features about the rewarded firm, etc., can be gathered in reward databases (in the same way this information is gathered in patent databases), thus enabling other firms to consult this information and to build their personal list of experts that can be contacted when they need to solve specific problems. In short, ex post rewards can without any doubt perform the signalling function of patents. Yet, regarding the question of knowledge disclosure there is one point on which the patent system may be more efficient than the reward system, namely the disclosure of knowledge not disclosed in the patent but, nevertheless, protected by it. Under a patent system firms are often induced to let their researchers disclose this type of knowledge, since it does not harm her. But under a reward system, it is likely that this knowledge would not be released.

Furthermore, one of the most important ways in which firms use patents is for defensive purposes, in order to have something to cross-license, and thus, to prevent being excluded from using certain technologies. Yet, it is clear that patents are used defensively because patents held by other firms force them to do so. Firms need to be protected against patents because patents exist, i.e., the existence of the patent system shapes firms' strategies. But in the absence of patents, such defensive strategies would not be necessary. Hence, under a reward system firms would not need to amass patents in order to be protected against lawsuits and the argument that rewards cannot replace patents because they do not protect the firm in the same way patents do does not hold.

Another central question deals with the effect of ex post rewards on technology trading. We have seen that patents help technology trading because they both signal where competences are located and protect those competences, thus preventing free riding from occurring. We have, therefore, argued that, paradoxically,

property rights may often favour knowledge transfer. However, under a reward system such a market for technology would be useless since rewarded technologies would become public, i.e., available to everybody for free. Firms would not have to buy rewarded technologies as they have to buy patented technologies. The only point of importance for the central authority under a system of ex post reward is, therefore, to implement rewards high enough to induce innovators to disclose their innovation. Indeed, the argument that under a system of reward innovations are public is valid only provided that the reward is high enough to deter innovators from keeping their innovation secret.

The problem of technology trading also involves a trickier question, concerning the exchange of the tacit component of technologies. This tacit part is not disclosed in the reward, and therefore, does not become available to other firms. Sometimes, the patent system allows the trading of this tacit component by including in licensing contracts clauses of assistance, of exchange of employees, etc. For instance, Foray (2004, p. 136) wrote: "Patents create transferable rights and can therefore help to structure a complex transaction that also concerns unpatented knowledge". Yet, this transfer of tacit knowledge would be hard to realise in the case of ex post rewards.

Before choosing to replace patents by rewards a central authority must also envisage the effects of this replacement on R&D collaborations. Patents assist R&D collaborations (i) by signalling potential partners; (ii) by providing a benchmark to compare firms' competences during negotiations; (iii) by allowing the sharing of the dividends of the collaboration. We already mentioned that ex post rewards could fulfil the signalling function as well as patents, i.e., they can help partners to meet as well as patents. Furthermore, regarding the sharing of the dividends of the collaborations, it is likely that ex post rewards work even better than patents, since an amount of money (which is what participants get under the reward system if the collaboration is successful) can easily be shared among the different participants. Hence, there remains only one central question, namely the effect of rewards on the process of inter-firms negotiations that aim at fixing the terms of the entente.

During such negotiations, it is not obvious whether ex post rewards could play a role similar to the one performed by patents. For instance, under the patent system, firms can evaluate their patents portfolio, compare it with the portfolio of their partners, and hence, fix the relative importance of each partner within the entente or within the joint venture. In case firms do not agree on the terms of the entente a patent holder can threaten to quit the collaboration and eventually use his patent to enforce his threat (by blocking the collaboration, for instance). There is, therefore, a manner to test whether or not a patent is central and would deserve more consideration: going to court. Could this be achieved under the reward system? Could the firms who won the highest rewards claim more favourable terms than other less rewarded firms? Of course, rewards can be a way to evaluate the relative knowledge stock of each partner but they do not allow firms to enforce their claim in case other firms disagree. In this sense, rewards may not favour collaboration as well as patents. Furthermore, patents induce collaborations because they prevent firms from remaining isolated. Under the patent system firms have to take care not to infringe patents held by others. Firms are thus obliged to consider the research undertaken by other organizations, which may often trigger inter-firm R&D collaborations. Conversely, under a reward system in which there is no risk of being sued for infringement, firms may not feel the same need to be aware of the research undertaken by other institutions. In this sense, compared to patents rewards may induce firms to do research alone, without any consideration of what others are doing. Here again, we may have raised a case where ex post rewards would not assist the collective process of innovation as well as patents.

Finally, a central point that must be discussed when considering the collective process of innovation is the problem of the "tragedy of the anticommons" rose by Heller and Eisenberg (1998). A tragedy of the anticommons may occur when multiple owners have each a right to exclude the others from the exploitation of a given resource but none of them has an effective privilege to use it. In such a case, firms willing to use the technology have to gather exploitation licenses from all the other owners, which may involve huge transaction costs, and hence, may prevent the use of the technology. It is straightforward to observe that the patent system multiplies the risk of emergence of a "tragedy of the anticommons"[21] whereas under an ex post reward

[21] Yet, the formation of patent pools can help to solve this problem of anticommons, since in this case firms willing to use a given

system, such a tragedy cannot occur. In sectors where innovation is complex (i.e., relies on multiple components that must be assembled together), the problem of anticommons is likely to give an important advantage to ex post rewards over patents.

To summarize, the decision to replace the patent system by an ex post reward system must take into account the impact of this replacement on R&D collaborations and knowledge exchanges. After a rapid first glance it comes out that when including the impact on the collective process of innovation, rewards may not always substitute successfully for patents. In some cases, patents may favour collaborations and knowledge circulation better than ex post rewards would do.

### 5.2. The case of the pharmaceutical industry

This discussion must be completed by introducing the special case of the pharmaceutical industry that, as empirical studies all stressed, stands in sharp contrast to other industries when dealing with patents. In pharmaceuticals, it seems that the traditional view of patents is valid: patents are essential to spur innovation and to induce firms to invest in R&D.[22] The reason is two-fold: first, innovation in pharmaceuticals is a long and costly process while imitation (i.e., the exact reproduction of a new drug) is relatively easy. It follows that without non-market assistance, firms would have very few incentives to invest in R&D. Second, patents protect a new medicine efficiently in the sense that they really prevent other firms from merely reproducing it. Conversely to what happens in most industries where patents are often easy to circumvent, imitating around a patented drug is almost impossible.[23] Those two features explain why the propensity to patent is higher in pharmaceuticals than in any other industry (Arundel and Kabla, 1998).

Yet, if overall it is hard to deny the central role of patents to provide incentives to create new drugs, it is also difficult to ignore the negative effects of pharmaceutical patents on social welfare. First, patents do not provide incentives to invest in treatments for rare (orphan) diseases or for diseases that affect only people in developing countries, where the purchasing power is low (Lanjouw, 2003). As Kremer (2000, p. 35) stated: "Malaria, tuberculosis and the strain of HIV common in Africa kill approximately five million people each year. Yet research on treatments for these diseases remains minimal". Furthermore, not only patents may provide few incentives to invest in the discovery of some treatments, but patents also contribute to increasing the price of existing treatments, thus preventing the most impoverished people from accessing vital medicines. Of course, the patent system is neither the only nor the most important reason that explains the difficult access to medicines in developing country.[24] But, for some specific diseases it may have disastrous consequences.[25]

The question of patents in the pharmaceutical industry leads, therefore, to a paradox: on the one hand, it is in this industry that patents are viewed as the most necessary to spur research but on the other hand, it is also in this industry that patents can have the worst consequences on social welfare.

It follows that in pharmaceuticals it may be profitable for society to implement a system of ex post reward or patent buy-out instead of a system of patent. A system of ex post reward would both eliminate the

technology have to be granted a license from one single firm (the administrator of the patent pool) and not from many fragmented owners.

[22] For instance, the Federal Trade Commission (2003) interviewed several panellists on this topic. Some argued that without patents, the innovation rate would decline by approximately 60% in pharmaceuticals while others assessed that innovation would merely disappear.

[23] This specificity of the pharmaceutical industry can easily be explained by its technological characteristics. The production of me too drugs (drugs based on different molecules, i.e., protected by different patents, but that have similar therapeutic effects) is difficult because the effects through which a molecule is efficient to cure a symptom remain largely unknown. After many trials, firms know that a molecule has a positive effect but do not know why because the search for new molecules is made randomly, by screening, rather than rationally. This explains that, as Von Hippel (1988, p. 53) puts it: "Potential imitators cannot gain much helpful insights from examining a competitor's patented product".

[24] According to Tirole (2003, p. 38), 95% of essential medicines listed by the WHO are not covered by a patent.

[25] It is usually estimated that for some diseases patents can increase the price of a treatment by more than ten (Solagral report, 1999). Regarding aids, for instance, of the 6 million people in developing countries who were affected by this disease in 2002, only 230,000 benefited from Tri-therapy, which is a treatment that has reduced the mortality rate due to aids by more than 60% in developed countries. Yet, the WHO considers that the price of this treatment, which is highly sensitive to patents, is the main obstacle to its generalised use in developing countries (WHO report, vol. 80, no. 9, 2002, pp 689–766).

monopoly distortion triggered by patents (i.e., it would decrease the price of existing medicines) and provide more incentives than patents to discover new treatments for some specific diseases. This view is shared by Kremer (2000a, p. 65), who examined the economic rationales for committing in advance to purchase medical treatments (commitment to purchase is in some sense equivalent to rewarding innovators ex post). Tirole (2003) also explained that, given the costs triggered by the patent system in developing countries, it is worth investigating alternative solutions (such as ex post rewards). Yet, those authors warned us about the problems that may be encountered in implementing a system of ex post rewards: first, governments must be able to assess the social value of medical treatments. Second, governments must agree on how to share the financing of the public organization endowed with the distribution of the reward. Third, governments must succeed to convince innovators that they will not change (decrease) the amount of the prize once the treatment is discovered, i.e., they must make sure that innovators will be fairly rewarded for their research.

This discussion was of course too short to embrace fully all the problems at work when dealing with pharmaceutical patents. Many investigations (about, among others, the optimal design of a system of ex post reward, see Kremer, 2000b) are still needed before being in position to claim that alternative solutions are preferable to pharmaceutical patents but those investigations are beyond the scope of this paper. Our objective was only to stress that in the pharmaceutical industry, it may be possible to compare patents and ex post rewards on the basis of the traditional reasoning explained at the beginning of this paper. Indeed, in this sector it makes sense to consider replacing patents by a system that would give innovators an amount of money because the role of pharmaceutical patents is essentially to increase incentives by ensuring firms with a monopoly position.

## 6. Conclusion

This work aimed at reorienting the patent–reward debate. The usual line of comparison between patents and ex post rewards rests on the hypothesis that firms use patents for the sole purpose of being granted an immediate short-term monopoly rent. Under this assumption the social desirability between patents and rewards depends exclusively on the quantity and quality of information accessible to a central planner. But this central hypothesis is not validated by empirical studies, which stress that patents perform different functions than the one traditionally attributed to them. In most industries they have a role of coordination and not only a role of incentive. They signal where competences are located, they ease technology trading and they help inter-firm collaborations.

This finding may have tremendous consequences on the patent–reward debate. Without being able to assess the impact of rewards on R&D collaborations and knowledge exchange, one cannot conclude on the desirability of rewards over patents. Indeed, a patent cannot be reduced merely to an amount of money earned from the exploitation of a monopoly position. A patent is something far more complex, and therefore, policy makers must take into account this complexity when considering replacing patents by rewards. For instance, even when a central planner holds perfect information it may not be desirable for society to replace the patent system by a system that would give only money to innovators, if it can be shown that this system is less efficient in terms of coordination of the innovation process. In other words, the fundamental advantage of patents over other policy instruments may not arise from informational concerns, but rather from the fact that they sometimes help reduce the coordination failure that hinders the innovation process.

After having restated the patent–reward debate and put more emphasis on the role of patents as a coordination device, it is therefore, not so clear why patents should be replaced by a centralised system. Maybe policy makers should renounce the embarrassment provoked by a centrally planned solution and focus their attention on how to modify the patent system in order to take in consideration the specificity of innovation as a collective process. Patents are ambivalent instruments since they are both sources of conflicts within the innovation process (source of tragedy of the anticommons) and instruments of coordination. Public policies must include those two features of patents and combine them so that the risk of conflict is reduced and the potentiality of coordination maximal. In short, policies aiming at improving the role of patents and mostly at adapting it to a model in which innovation is the outcome of a collective process may be essentially required

rather that policies aiming at replacing it by another system.

The present work did not aspire to draw absolute conclusions about the social desirability of patents over rewards. We limited ourselves to emphasising the shortcomings of the traditional line of comparison between patents and ex post rewards and to re-orienting the debate on a ground that seemed more appropriate. By doing so, we provided a background for future studies and raised interesting research questions. For instance, the role of the patent system in the process of R&D collaboration, which is central to this discussion and, more generally, to every discussion regarding the social desirability of patents, is still not well comprehended and would clearly deserve to be the topic of further studies.

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