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REGULAR ARTICLE

Technological knowledge as an essential facility

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Abstract The economics of regulation has articulated the notions of essential facility and mandated interconnection. Their application to the governance of technological knowledge can be fruitful especially when implemented by the adoption of a compensatory liability rule and the parallel reduction in the exclusivity of patents. Because knowledge is at the same time an output and an input in the production of new knowledge, exclusivity, traditionally associated to patents, is the cause of actual knowledge rationing with major drawbacks in terms of both static and dynamic efficiency. This institutional innovation can improve the governance of technological knowledge and increase both its rates of dissemination and generation.

Keywords Knowledge governance · Intellectual property right regimes · Essential facility · Compensatory liability regime

JEL Classification 031

1 Introduction

The basic notion of essential facility, and its implications in terms of mandated interconnection, introduced in regulation economics, has a wide scope of application, well beyond network industries. The economics of knowledge stresses the role of indivisibility and cumulability. Knowledge is not only an output, but also an input in the generation of further knowledge. Hence knowledge can be considered an essential facility itself. The analysis of the direction of localized technological change suggests that there are strong incentives to innovate and make an intensive use of idiosyncratic production factors that are locally abundant and specific to innovators. Hence innovators enjoy a far stronger appropriability of the stream of

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rents generated by the applications of knowledge than currently assumed. From a normative viewpoint, this analysis has major implications for a re-assessment of the intellectual property right regime, a new understanding of knowledge as an essential facility and the introduction of the liability rule in the governance of patents.

The rest of the paper is structured as follows. Paragraph 2 introduces the notion of essential facility, as it has been first elaborated in telecommunication economics and shows how it can be applied to the economics of knowledge. Paragraph 3 elaborates the analysis of the informational role of patents and presents the opportunity for a drastic reduction of exclusivity of patents. Paragraph 4 elaborates the application of the liability rule to fix ex-post the proper rewards for innovations that have been used. Paragraph 5 elaborates the implication for knowledge governance. The conclusions summarize the main findings.

2 Essential facility: economies of density and mandated interconnection. From the economics of telecommunications to the economics of knowledge

The notion of essential facility has been elaborated in the economics of telecommunications to regulate the problems raised by complementarity and cumulability. A production factor is an essential facility when its use in the production process is characterized by substantial indivisibility. Relevant economics of density take place when the repeated use of the same input is possible. Increasing returns take place because output increases with the increase of variable factors only. When long-term duration, excess capacity and little wearing characterize fixed inputs, marginal costs remain below average costs. Moreover incremental costs, i.e. the costs of additional production units, display low average costs, lower than total average costs. The social use of essential facilities requires strong regulation as the rights of exclusive use have significant asymmetric effects on competition in the market place, which favor the exclusive users. When a piece of property acquires the characteristics of an essential facility, the rights to use, access and interconnection cannot be exclusive. A separation between the rights of ownership and the rights of use is necessary in order for actual and workable competition to be implemented and eventually made possible (Baumol and Sydak 1994).

As it is well known, privatization of networks and competition in the telecommunication industry has been made possible by mandated interconnection. Mandated interconnection has been a major factor of change and evolution in the definition of property rights. The ownership rights on the one hand and the rights of exclusive use on the other, traditionally associated in one single right, have been separated and rights of use of the network have been separated from the ownership rights. Firms do and can own telecommunication networks and can claim their property on all the segments of the network, but cannot claim any longer the right to the exclusive usage. Other firms have the right to access the network and make a selective use of it. Dedicated authorities have been established since the late 1980s in most advanced countries in order to implement the right to interconnection, to regulate it and to fix the prices of interconnection (Fransman 2002).

Communication Authorities have been established to monitor the effective separation between the right of ownership and the rights of usage of telecommu-

nication networks. Their activity here is most necessary because of the ever changing conditions of the technology and hence the ever changing conditions of the separation between ownership and usage. Second and most important, Communications Authorities have been established in order to fix ex-ante the levels of interconnection tariffs. Interconnection tariffs must reflect properly the costs of the network and must make possible both appropriate returns on the investments for the owners and viable conditions of entry to new competitors. In order to avoid suboptimal provision of communication infrastructure, investors need to receive appropriate rewards and hence incentives for future investments. At the same time however, newcomers must be put in conditions of actual cost symmetry in downstream markets with respect to incumbents and other competitors in the telecommunications industry (Madden 2003). The evolution of property rights in the telecommunications industries has been the result of the understanding of the role of sunk costs and complementarities and their effects in terms economies of density and incremental costs on the actual costs of both incumbents and new competitors in the industry. Mandated interconnection is indeed a significant departure from a full fledged and traditional definition of property rights.

A process of widespread generalization of the application of the notion of essential facility has been taking place since the last decade of the twentieth century. The separation between ownership and rights of exclusive use and the introduction of mandated interconnection is now regarded as a necessary regulation within economic and physical systems where and when complementarities and indivisibilities matter, in order to restore and enforce the conditions for the viability of competitive markets. Such evolution of the property rights regime has been spreading from the original application in the telecommunications industry to all the network industries from electricity to gas and railway.

There are today strong reasons to believe that the notion of essential facility and mandated interconnection is directly relevant for the governance of technological knowledge.

According to the results of much economics of knowledge, knowledge shares all the relevant characteristics of an essential facility. Knowledge is characterized by intrinsic indivisibility and yet it is dispersed and fragmented in a variety of uses and possessed by a variety of owners. Each bit of knowledge is complementary to each other along chains of weak and strong indivisibilities, which act both synchronically and diachronically. The exclusive access to each bit of knowledge can prevent others from cumulative undertakings (Antonelli 2001, 2003).

Since the path breaking contribution of Arrow (1962), the economics of knowledge builds upon the analysis of knowledge as a good per se and explores all the limitations to its production and dissemination in the market place that are engendered by its limited appropriability, non divisibility and non-rival use. Intellectual property rights regimes have been built mainly to increase the appropriability of the benefits generated by the introduction of new technological knowledge. The basic claim has been that the natural appropriability of knowledge is too low to induce investors to fund appropriate levels or research activities.

Following the resource-based theory of the firm, however, technological knowledge cannot be separated from the firm. Technological knowledge can be considered both the primary input of the firm and its basic output. The firm exists

because it is the institution that, by means of the valorization and direction of learning processes, makes it possible the accumulation of technological knowledge. At the same time the firm can be considered the basic tool of exploitation of new knowledge that cannot be sold as a good itself. The choice whether to sell technological knowledge or to use it and make with it, is especially relevant for the analysis of the firm.

This approach can contribute the debate on the governance of knowledge. A new appreciation of the role of intellectual property rights can now be found in the assessment of their positive effects from an informational viewpoint in terms of higher levels of specialization and division of labor, rather than in terms of the assignment of exclusive property rights. From this viewpoint the so called knowledge trade-off, that is the balanced assessment of both the positive effects of the monopolistic control of patents in terms of increased incentive to the supply of knowledge and the negative effects in terms of the reduced distribution of knowledge, needs to be reconsidered (Boldrin and Levine 2002; David 1993; Machlup and Penrose 1950).

3 The informational role of patents: signaling and licensing

The economic analysis has much debated the positive and negative consequences of intellectual property rights. Two well distinct knowledge trade offs have been identified.

The first knowledge trade-off has emerged from the cost-benefit analysis in terms of the balance between the positive effects in terms of dynamic efficiency and the negative effects in term of static efficiency. Increased dynamic efficiency stems from the assignment of intellectual property rights as they increase the incentives to invest resources in the creation of new technological knowledge because of the positive effects in terms of appropriability and hence tradability of technological knowledge. The negative effects on competition stemming from exclusive property rights however diminish static efficiency. Monopolistic market power, engendered by intellectual property rights, makes it possible the extraction of consumer surplus by patents holders and induces them to technical inefficiency.

The second knowledge trade-off has been identified by the dynamic cost-benefit analysis in terms of the balance between the positive and negative effects on the dynamic efficiency of an economic system. As soon as the joint character of knowledge as an input and an output is acknowledged, in fact, the positive effects in terms of the increased incentives to invest resources in the generation of new technological knowledge stemming from intellectual property rights are now confronted with their negative effects in terms of reduced dissemination and access for third parties. Reduced dissemination in turn limits the use the knowledge for the production of new knowledge with clear negative effects in terms of decreasing efficiency in the production of further knowledge.

Combining the two knowledge trade-offs it seems that intellectual property rights risk to reduce both static and dynamic efficiency at the system level. These results are reflected in the recent renewed interest in alternative solution to existing intellectual property rights, especially patenting regime, like the awarding of prizes. The risks of a

major state-failure as opposed to market-failure seem to limit the applicability of the prize mechanism beyond the scope of well-identified problems especially in the case of diseases and epidemics (Davis 2004; Shavell and Van Ypersele 2001).

An attempt to highlight the positive elements of intellectual property rights so as to select the features that are more conducive to foster the rates of generation and dissemination of new knowledge, and, possibly to limit the effects of the most negative ones, seems more promising than venturing in the design of new institutional devices.

It is clear, in fact, that the debates about the twin knowledge trade-off has been concentrated upon the positive and negative effects of the creation of intellectual property rights in terms of exclusivity. Little attention had been paid to the informational role of intellectual property rights (Stiglitz 2000, 2002). From the viewpoint of welfare analysis, at the system level, intellectual property rights have an important role from an informational viewpoint and as such exert relevant consequences. According to the localized technological change approach, technological change is the emergent property of an economic system, if, when and where the latent complementarities among the fragmented bits of indivisible knowledge possessed by a myriad of agents dispersed and isolated, are valorized and exploited. From this viewpoint the role of patents as signaling mechanisms, that provide information about new inventions and relevant technological applications, seems far more relevant than their traditional role of appropriability mechanisms based upon the enforcement of excludability.

Secrecy is the alternative to intellectual property rights, to secure exclusive ownership and reduce non-appropriability. Secrecy, however, can have dramatic effects upon the amount of knowledge externalities and knowledge complementarities, which can be effectively activated (Arundel 2001). The systematic use of secrecy would limit drastically the information and access to external knowledge for each firm with dramatic consequences in terms of the general efficiency in the production of new knowledge. The exploration of external knowledge, the searching and screening of relevant bits of complementary knowledge would become much more expensive with an increase in the costs of new knowledge. As a matter of fact, and beyond the intentions of each patent holder, patents play a major role as signaling devices: patents help the social identification of the advances of knowledge and hence help locating the available bits of complementary knowledge and their owners so as to reduce search and exploration costs.

Intellectual property rights are a remedy to tight vertical integration between the generation of new technological knowledge and its application to the production of new goods or to new production processes, rather than to its undersupply. This analysis contrasts the traditional argument according to which the market supply of technological knowledge is deemed to undersupply because of its public good nature. The public good nature of technological knowledge, as a matter of fact, does not necessarily lead to undersupply but rather pushes the knowledge-creating firm to use it as an intermediary input for the sequential production of economic goods. The markets for the products that are manufactured and delivered by means of the technological knowledge they embody can generate the incentives to generation of appropriate quantities of knowledge (Mokyr 2002).

Effective property right systems favor the creation of markets for disembodied technological knowledge where the firms can specialize in the production of

knowledge as a good per se. With a weak intellectual property right regime and low appropriability, in fact, the holders of each bit of knowledge have much a stronger incentive to integrate vertically into the production of new goods and processes based upon the novel ideas and to rely upon industrial secrets as a way to reduce the informational leakage with the radical reduction of the circulation of the relevant bits of disembodied knowledge. The embodiment effect can be especially negative when the scope of application is wide and reverse engineering is complex, at least for unrelated perspective users. An effective intellectual property right regime, able to secure appropriate returns to inventors, reduce the incentive to internalize the valorization of technological knowledge by means of downward vertical integration, and favor the creation of markets for technological knowledge, as a good per se, and hence favor the division of labor with the well-know positive effects in terms of specialization and dissemination of fungible technological knowledge to a wider range of economic activities. The assignment of intellectual property rights seems by now a necessary condition not only to increase appropriability, but also as an institutional device which can improve the viability of the markets for knowledge and facilitate the interactions among holders of bits of complementary knowledge. Patents in fact can help transactions in the markets for knowledge because they make it easier for demand and supply to meet (Arora et al. 2001).

The systematic use of patents, because it helps the identification of bits of relevant knowledge for perspective users, is essential to reducing the waste of duplication due to lack of information and to make it easier the working of social cumulability in the production of new knowledge, provided the use of knowledge by third parties is not restricted. Patents make knowledge interactions easier, provided the exclusivity of ownership is properly tuned. The basic problems of the knowledge trade-off emerge can be tackled in a different way, if the excludability of patents is reconsidered (Jaffe and Lerner 2004; Kingston 2001).

4 The liability rule as a mechanism for the governance of technological knowledge

The separation between ownership and usage conditions and the extension of the notion of essential facility to technological knowledge experienced in the case of the telecommunications industry can apply with success to intellectual property rights.

The application of the notion of essential facility and mandated interconnection to the governance of technological knowledge can be implemented by the adoption of the liability rule and the parallel reduction in the exclusivity of patents. Because knowledge is at the same time an output and an input in the production of new knowledge, exclusivity, traditionally associated to patents, is the cause of actual knowledge rationing with major drawbacks in terms of both static and dynamic efficiency. This institutional innovation can improve the governance of technological knowledge and increase both its rates of dissemination and generation.

The present intellectual property right regime, based upon exclusive rights suffers from at least four main problems: (a) exclusive intellectual rights delivered to inventors reduce the allocative and technical efficiency in the product markets and favor their strategic use in a oligopolistic rivalry (McDonald 2004); (b) exclusive

intellectual rights delivered to inventors reduce dissemination of proprietary knowledge and hence limit the dynamic efficiency of the system. Such effects are especially negative when knowledge complementarities apply and bits of knowledge can have important effects for the production of other knowledge in other fields of applications, often remote from those of original invention and introduction (Nelson 2004); (c) litigation costs and generally transaction costs, typically associated to the delivery and defense of exclusive intellectual property rights, have been growing with a dangerous pace, actually faster than investment in R&D (Barton 2000); (d) duplication of efforts and major coordination problems limit the general efficiency of the system in the production and use of knowledge.

In this context, the present intellectual property right regime can be improved substantially with the reduction of the levels of exclusivity. Here the guidance provided by the evolution of property rights with the application of the notion of essential facility to technological knowledge and the related institutional innovations introduced in telecommunications provides basic guidance. The separation between the ownership of intellectual property and the right of exclusive use, already experienced with success in the telecommunications industry with the notion of mandated interconnection, can apply in this central and strategic area as well.

Such a reduction of the exclusivity of intellectual property rights can be realized by means of the application of a compensatory liability regime. The extension of the liability rule in this field seems to be able to provide important positive effects. The application of a compensatory liability regime in intellectual property rights can be considered a useful device to implement 'mandated interconnection' in intellectual property rights. The application of a compensatory liability regime consists in the elimination of the exclusive rights of use of an intellectual property of the owner—the assignee of a patent—compensated by the right to claim for appropriate payments for the usage of her rights. In this context, the right of exclusive use is no longer associated to the rights of ownership of any intellectual property. Inventors have a clear incentive to hold such a patent: it entitles them to command a claim upon the rents stemming from the use of the proprietary knowledge by third parties.

4.1 The proposed regime and its antecedents

Reichman (2000) deserves the credit of the first explicit and articulated analysis of the application of the compensatory liability regime to knowledge governance. The notion of a compensatory liability regime deserves, however, a generalized and extensive application to large-scale innovations in the broad markets for knowledge, well beyond the limitations of its original suggestion applied only to small-grain-sized-innovations within the boundaries of monopolistic competition. For this purpose it seems useful to trace the antecedents to the new proposed regime for intellectual property rights.

A first important antecedent to the application of a compensatory liability regime, as already noted, is provided by the evolution of property rights in network industries. Mandated and compensated interconnection, introduced in telecommunications networks, and eventually in many other network industries, can be considered as a new form of non-exclusive ownership of a capital good that combines the compensation to the owners of the infrastructure for all users with the

right of third parties to access it. The separation of ownership rights from exclusivity rights means that the right of ownership to oblige users to comply with some obligations including the payment for the use of a proprietary asset is recognized as well as the right of other parties to take advantage of it.

Compulsory licensing of course provides a useful reference. Compulsory licensing has been often advocated and debated. The generalized application of compulsory licensing however seems problematic because of the low protection recognized to the assignees of intellectual property rights. Too low levels of compensations have a twin negative effect: (a) reduce the incentive to generate new knowledge, and, even more threatening, reduce the incentive to patent new knowledge and, hence, risk to favor the recourse to secrecy. Ultimately compulsory and non-compensatory licensing is likely to exert negative effects in terms of both the amount of new knowledge being generated and disseminated.

An important antecedent to the articulated application of a compensatory liability rule to managing intellectual property rights can be traced into the notion of General Public License elaborated by Richard Stallman and Eben Moglen to implement the governance of open source software platforms. According to the General Public License, in fact, all agents can access prior and proprietary software provided that owners of the original software are notified, new users make a clear and explicit reference to the original knowledge used and they make available to third parties the results of their elaboration. In this context, the right of exclusive use is no longer associated to the rights of ownership of any intellectual property: users have free access but are obliged to meet some basic requirements. The public registration of the use and the quotes to prior, proprietary software has a strong economic value as a main factor in building and increasing the reputation of their owners—the 'inventors —with positive effects in terms of the levels of professional fees they can claim in the markets for professional services (Lessig 1999; Raymond 1999; Stallman 1998).[1]

The generalized application of the compensatory liability rule to managing intellectual property rights can take advantage of the experience gathered with the elaboration of the General Public License in the Open Source Software community. Three elements can be retained: (a) users notify the assignee that the proprietary knowledge is being accessed and used, either for the production of additional knowledge or for direct use in the production of goods; (b) users acknowledge the role of the original knowledge in the production of new knowledge, if this is the case; (c) users agree that their use engenders a specific obligation in favor of the assignee of patent being used. In this case the obligation takes the form of a payment of eventual fees to the assignee of the patent. In so doing the 'inventor' has still a clear incentive to patent the new knowledge. The patent becomes the legitimate foundation to a claim upon the total surplus stemming from the direct or indirect economic application of the new knowledge. The drawbacks of secrecy are avoided. The advantages of patents as a powerful mechanism to enhancing the dissemination of information about new advances in scientific and technological knowledge

[1] From a strict legal viewpoint the General Public License remains in the domain of the property rule. From an economic viewpoint, however, once the 'inventor' has selected the GPL, as an appropriate form of intellectual property right for his own purposes, the consequences are similar to those exerted by the liability regime. See Samuelson et al. (1994).

become even stronger. The definition of a compensation mechanism, able to engender the best mix of both static and dynamic efficiency, becomes the corner point for an effective application of the new regime.

4.2 Cost-based versus revenue-based compensation schemes

The definition of the 'correct' compensation mechanism is not simple. A major problem is whether the compensation for the free access to the patented knowledge should be based upon the costs of the new knowledge or the revenue stemming from its application.

Here the analogy between the new institutional arrangements put in place in network industries and intellectual property rights fails to apply. Communication Authorities have been successfully put in place and performed quite well their task to fix the fair value of interconnection. The creation of an independent authority charged with the task of assessing the ex-ante value of a new piece of technological knowledge seems far less credible for the amount of ingenuity and Olympian, far-sighted rationality required.

In the case of intellectual property rights, the definition of the cost of a successful patent and hence of the contributions due to the 'inventor,' the equivalent of interconnection tariffs, seems difficult and problematic on many counts: the basic requirements of dynamic efficiency, i.e. the need to increase the allocation of resource to the generation of new knowledge, need to be properly assessed. First of all research activities are characterized by high levels of risk and intrinsic uncertainty, in terms of the chances of generating an output so that the allocation to each novelty of the effective costs is most difficult. Second, because of the role of cumulability in the production of knowledge, the identification of the actual levels of incremental costs, that is the identification of the specific costs for the last bit of knowledge as distinct from the sunk costs is problematic. Thirdly, technological knowledge is very much the result of the valorization of bottom-up processes built upon learning processes and accumulated competence: it is difficult if not impossible to disentangle the specific cost items that can be charged: major issue of indivisibility applies. Fourthly and consequently, it seems that sheer cost-pricing cannot apply when technological knowledge is concerned.[2] The role of creativity and ingenuity here is a key factor and its costs impossible to assess. Moreover creative talent is a scarce and rare

[2] The analysis of the reasons for the rebuttal of the ex-ante measurement of the value of innovation for licensing purposes is clearly stressed by Richard Nelson (2004:458): "Virtually all empirically oriented scholarly accounts of how technology progresses have highlighted that the process is evolutionary in the following senses (...). First, at any time there generally are a wide variety of efforts going on to improve prevailing technology, or to supersede it with something radically better. These efforts generally are in competition with each other, and with prevailing practice. And the winners and the losers in this competition to a considerable extent are determined through an ex-post selection process. Second, today's efforts to advance a technology to a considerable extent are informed by and take off from the success and failures of earlier efforts." This quote makes clear also how unfair it would be any attempt to remunerate the use of a successful technology on the basis of its specific research costs. It seems clear that, because only a small fraction of many tentative technologies is sorted out, ex post, in the competition process, the success of one technology should be able to provide the 'inventor' a payback for many aborted efforts.

resource, which needs to be valorized and used in the social applications, which are more valuable.[3]

From the viewpoint of dynamic efficiency the correct reward for technological knowledge should be influenced by its value in terms of the total surplus stemming from its application and hence is necessarily influenced both by supply and demand forces. A divide between the fair price for knowledge and its cost emerges. Relevant technologies are characterized not only by a larger derived demand curve, but also by lower levels of price elasticity with higher levels of total surplus stemming from their industrial application.

In the effort to define the compensation for the inventor stemming from the application of the liability rule to the governance of knowledge it seems clear that the correct compensation for the inventor who no longer commands exclusive rights on the successful technological knowledge generated, should be generated from a mimic of the working of Schumpeterian markets where the incentives for risky research activities are provided to successful innovators by the appropriation of the surplus generated by its application: the value of the technological knowledge is influenced by the demand, rather than by the sheer costs of the single research program that is at the origin of the rare success. The issue then is the identification of the criteria for the distribution of the total surplus between the inventor and the user(s) that do attract new risky research activities and scarce creative talents without preventing the 'free to use,' but 'not free of charge' access to the new relevant technological knowledge.[4]

The substitution of the property rule with the liability rule and its application of revenue-based compensation schemes based upon actual and measured—hence necessarily ex-post—total surplus stemming from the application of the new technology can overcome the traditional problems associated with compulsory licensing. With the liability rule in fact the definition of the payments for the owner of the intellectual property right used by third parties can be defined ex-post, that is after its use has been experienced. The ex-post identification of the economic value stemming from the application of a given specific piece of new knowledge is much less difficult than the ex-ante assessment. Only an ex-post approach, to defining the levels of the rents due to inventors, which builds upon the notion of knowledge as an essential facility and hence on the notion of non-exclusive intellectual property rights implemented by the liability rule, can grasp the specific levels of markups which are likely to actually implement the overall levels of research activities in a system. The ex-post definition of a value for the unrestricted use of proprietary technological knowledge by third parties, based upon the actual evidence about its economic

[3] See, for a parallel analysis on the value of artistic talent, Swann (2006).

[4] Hence the compensation should not take the form of "a set of off-the-rack liability rules allocating contributions to the costs of R&D for unauthorized uses of sub patentable innovations within a specified period of time" (Reichman 2000:1791), but rather they should be based on a royalty scheme. Reichman agrees that when direct competition between inventors and imitators is considered, a shift from cost-based to revenue-based compensation schemes is appropriate:" ...thus can be achieved by imposing a higher percentage royalty than would ever apply in the case of follow-on innovations, by extending the period of compensatory liability beyond that applicable to follow-on innovation, or by some combination of the two." (Reichman 2000:1791).

effects, and hence the basic reference to the derived demand for the knowledge considered, seem the proper solution.

By means of negotiations the parties involved can try and find an agreement about the share of the value stemming from the use of the technological knowledge that the owner should receive from the user. As soon as a patent holder realizes that her proprietary, albeit no longer exclusive, knowledge has been put in place by a third party, a litigation procedure can be activated. The patent holder will claim a share of the actual economic value generated by the applications of the proprietary knowledge. The evidence about the effects of the use of the new knowledge can be gathered and an economic assessment elaborated. A formal litigation will be the extreme context into which the parties involved will solve the problem (Reichman 2000). The judiciary system will enforce the procedure and define the correct share of the revenue stemming from the use of the new knowledge, which should be paid by the user to the original owner.

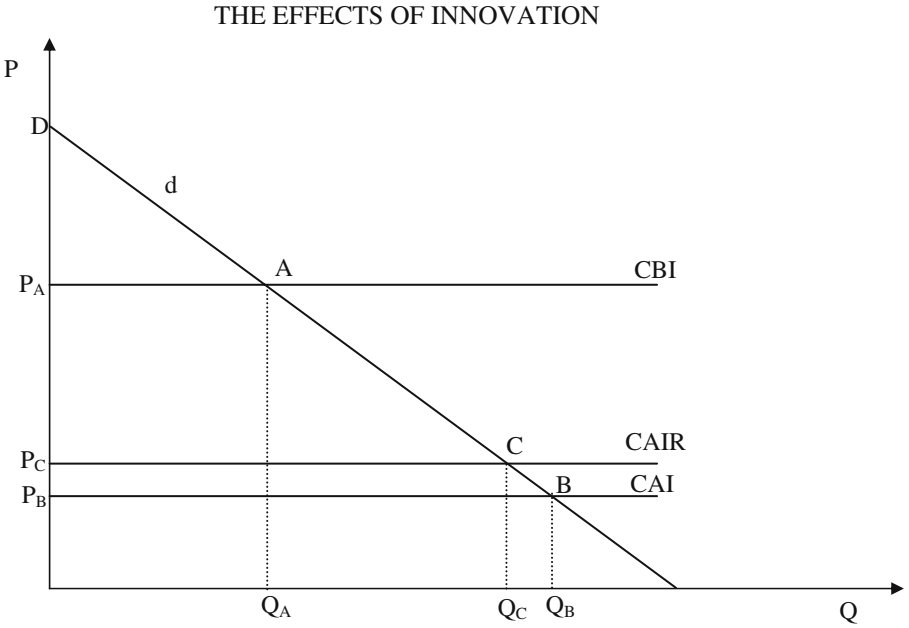
4.3 Welfare effects

A simple application of welfare analysis can help to identify the correct level of the share of the revenue stemming from the use of proprietary knowledge. From a system viewpoint the allocation of the shares between the owner and the user(s) is most important.

The traditional arrovian setting (Arrow 1962) can be used to assess the definition of the correct level of the royalties and generally the criteria for the allocation of the revenue stemming from the use of the new knowledge. With the present intellectual property right regime, the monopolistic owner has the right to take all the benefits stemming from the use of the new knowledge. In the context elaborated here the owners of technological knowledge should receive only a portion of the total benefits stemming from the application of their proprietary knowledge: as we have seen knowledge dissemination has a key role in securing appropriate levels of generation of new knowledge. On the other hand, fair incentives to the generation of new knowledge are necessary to avoid the well-known risks of undersupply of such a key input for economic activity. The size of the royalty paid to the knowledge by the knowledge user is influenced by the size of the total surplus generated by the use of the knowledge.

The size of the total surplus engendered by the introduction of an innovation of course is very much influenced by the kind of market forms, before and after the introduction of the innovation. Let us consider first the extreme case that competitive pricing applies before and after. Following Arrow (1962) diagram 1 shows how that the introduction of an innovation measured by a reduction in production costs from the levels of the costs before innovation (CBI) to the level of the costs after innovation (CAI) yields positive effects in terms of total surplus (TS) measured by the size of the difference between the area of the triangle DPB and the triangle DPA. This case can be confronted with the possibility that monopolistic pricing applies before and after the introduction of the innovation: in this latter case the amount of total surplus shrinks. Finally and consistently with the results of the analysis on the dynamics of localized technological change we shall also assume that the downstream markets for the products that use knowledge as a production factor,

are characterized by monopolistic competition with relevant barriers to entry and mobility. For this reason relevant extra profits are likely to persist in the long-term[5]



Specifically the relative markup, that is the difference between the amount of the costs incurred in the generation of the new knowledge (CK) and the royalties (R) paid to the inventor, weighted by the knowledge costs, can be set to be a function of the total surplus stemming from the introduction of the new knowledge in the markets for the products that use it:

$$(8)(R - CK/CK = f(TS)) \tag{1}$$

A maximum level or the relative markup needs to be identified. The rationale behind such a ceiling is clear: excess profitability for inventors would easily become an incentive to duplication efforts and inventing around activities with clear costs in terms of social welfare. Such a maximum level can be empirically defined with specific reference to the industrial context of application.

The royalties paid to the knowledge owner will enter the costs of the firm and increase the market cost for the product and hence the price: see in diagram 2 the new costs after the introduction of the innovation now including the royalties (CAIR). In a competitive market firms should account for the royalties to be paid. In

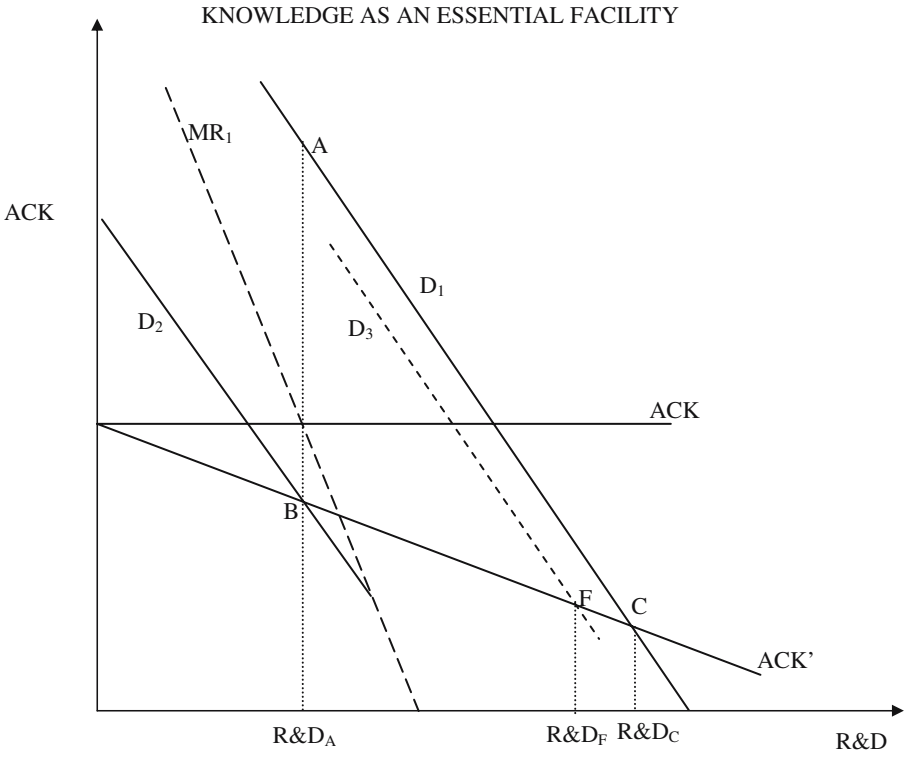
[5] Following our argument it can be claimed that the introduction of the notion of knowledge as an essential facility and the related substitution of the liability rule to the property rule is likely to change the market structure and hence to increase the actual levels of the total surplus stemming from the introduction of an innovation. With exclusive intellectual property rights in fact the exclusive owner of the knowledge can take advantage of monopoly power in the markets of the product that use and benefit from the application of the proprietary knowledge. With monopolistic pricing the welfare effects of the introduction of the new knowledge are clearly lower that the effects of the use of the new knowledge with competitive pricing. Competitive pricing is clearly made possible by the application of non-exclusive intellectual property rights.

a market characterized by monopolistic competition with barriers to entry and to mobility, royalties can be charged on the profits of the firm.

Let us now try and show how the proposed extension of the liability rule affects the generation of knowledge in an economic system. A simple geometric exercise helps defining how non-exclusive intellectual property rights increase the amount of knowledge an economic system is able to generate.

Unlike Arrow (1962) however we frame the analysis in a derived demand context, where the firms decide, on the base of the marginal productivity of knowledge how much knowledge to use to introduce innovated products in downstream markets and to generate new knowledge. The demand for knowledge can be considered a derived demand expressed by two kinds of users: innovators and inventors. Innovators are firms that are engaged in the introduction of innovations in downstream product markets. Inventors are firms or agents that use existing knowledge as an input in the generation of new knowledge. The horizontal summation of these two well distinct derived demand curves generates the aggregate derived demand for knowledge in the economic system.

We shall assume that all the firms decide, on the base of the marginal productivity of knowledge how much knowledge to use. Firms, in fact, can generate the same knowledge with the traditional dynamics of multiple inventions. If firms can access external existing knowledge at costs that are below internal generation ones, they shall use it rather than duplicating it. Let us consider first the case where both the demand and the supply of knowledge are elastic to knowledge rents.



As diagram 2 presents, D_1 identifies the derived demand for knowledge and the average costs of knowledge (ACK). The latter decline significantly if and when all potential users can take advantage of it: the working of economics of density in fact makes it possible to share the same fixed costs, necessary to generate a given piece of knowledge, among all eventual users. If, instead, exclusive intellectual property rights apply, all eventual users need to reinvent the piece of knowledge and average costs remain at a constant level. From the viewpoint of sheer costs, non-exclusivity of intellectual property rights seems to yield a clear social benefit. When the reduction of the incentives to generate new knowledge stemming from such a reduction in exclusivity is considered however, the picture is worsened. Now agents are reluctant to fund research activities when the knowledge generated cannot be appropriated. A reduction in exclusivity engenders a reduction in appropriability. A reduction of knowledge appropriability reduces the profitability of its downstream applications —i.e. of the transient monopolistic rents stemming from the ensuing introduction of innovations. The lower is the appropriability of knowledge and the lower is the duration of monopolistic rents, the lower are the incentives to innovate and to engage in the generation of new technological knowledge. The schedule of the derived demand for knowledge is likely to shift on the left, because of the exit of a number of perspective investors and the general reduction in the levels of knowledge generating activities.

With exclusive intellectual property rights the traditional monopolistic equilibrium is found in A. In A the profitability for inventors is very high and hence the incentives to fund R&D activities. When the equilibrium is in A, however, the costs of R&D activities are much higher, as well. If non-exclusivity applies and the ACK' is relevant, the new equilibrium, on the same demand curve, would be found in C. Clearly if the derived demand for knowledge were not affected by the reduction in exclusivity the system would benefit from the increased level of research activity $R\&D_{\mathbf{C}}$.

The reduction in exclusivity however, as already noted, has a negative effect on the demand side. As the knowledge trade-off teaches, the reduction in exclusivity is likely to reduce the profitability of the knowledge generated: hence the derived demand for knowledge is expected to bunch back. If and when such a leftward movement from D_1 towards D_2 goes beyond the point B, it is clear that the amount of knowledge generated in the system shrinks, yet its costs also decrease. At the same time however, the reduction in the costs for knowledge should engender a positive shift in the overall demand for research activities fueled by both output and substitution effects. The goods manufactured with cheaper knowledge cost less in the final markets and their demand is larger. Moreover firms are now induced to substitute more knowledge to other production factors. In sum the new position of the derived demand for knowledge is likely to be affected by both a negative shift due to a reduction in monopolistic rents and a positive one, stemming from output and substitution dynamics. The actual position of the demand curve after taking into account both negative and positive effects should be D_3, hence the equilibrium level of R&D expenditures should be found in R_F.

At the system level it is clear that the area between the ACK' (with a negative slope because of the effects of economies of scope), the ACK parallel to the horizontal axis (when exclusive property rights apply), and the actual demand curve,

defines the social benefit of the non-exclusive access to proprietary knowledge from the supply side.[6]

The notion of knowledge as an essential facility and the introduction of the right of usage of proprietary knowledge by third parties, provided that the compensatory liability regime applies and hence that the users of proprietary knowledge generated by third parties can be forced to pay a fee to original inventors is likely to increase the amount of knowledge a system can generate.

Diagram 2 exhibits the working of the twin effects of the knowledge trade-off and shows with clarity that all reductions in exclusive intellectual property rights affect both the supply and the demand side with contradictory effects. Only the fine-tuning of both effects can yield positive aggregate effects in terms of increased levels of knowledge generated at the system level. Diagram 2 shows how the definition of the 'appropriate' levels of the mark-up for inventors must take into account both the effects on the supply of knowledge and the effects on its derived demand. The crucial issue is the elasticity of the position of the derived demand, together with the price elasticity of each of the schedules of the derived demand. When the price of proprietary knowledge is larger than its costs, and hence rents are granted to inventors and the totals surplus is shared between producers and users, the derived demand shifts towards the right. When instead the markup is low and the price for proprietary knowledge is close to its costs, the derived demand shifts towards the left.

In sum, it is clear that the 'optimum rent' for technological knowledge is influenced by: (A) the extent to which the supply curve reflects the effects of the economies of density; (B) the elasticity of the position of the supply curve, as shaped by the elasticity of entry; (C) the extent to which the derived demand is elastic to the levels of the markup in defining the equilibrium levels of the research activities, both in terms of slope and position.

4.4 Implementation

The identification of the optimum level cannot be done by means of simple mathematical calculus, but rather by means of societal processes of trial and error. Ex-post controls upon the effective social relevance of the knowledge used and generated are necessary. On an ex-ante basis, different types of knowledge can be identified and different classes of knowledge rents can be created according to rules of thumb. It is clear in fact that both knowledge users and knowledge producers need to know ex-ante what kind of knowledge rents are applied to the kind of knowledge they want to generate. A more articulated legal framework should be implemented to make effective the social usage of the economic framework proposed.

The definition of an ex-ante temporary price is in any case necessary to allow the choice of the perspective user, whether and to what extent to rely upon internal or external knowledge as inputs for the generation of new knowledge. Hence a temporary price for the access to proprietary knowledge can be defined ex-ante on

[6] Actually the positive effects of the application of the notion of knowledge as an essential facility and of the liability rule should include the reduction of monopoly power in the downstream markets for the products that use the proprietary knowledge. Now in fact many firms can use it and patents are no longer a cause of downstream monopoly.

the basis of the precautionary estimations of the expected demand. If the actual demand is larger, the actual price for the proprietary knowledge used by third parties can decrease. The ex-ante price can be only larger than the actual ex-post price. An ex-post assessment about the actual position of the demand curve for knowledge is in any case necessary. When a new knowledge module has a radical and unexpected effect on a wide range of downstream activities, the position of the demand curve would be clearly far more on the right than anticipated, and hence the fair price for it, far smaller.

With such a framework, the tuning of the intellectual property rights regime and of the royalties that knowledge-users should pay to knowledge-producers so as to make it possible at the same time the minimization of the rents paid to inventors, the maximization of the net social surplus stemming from the introduction of new technological knowledge and the maximum level of efficiency in the production of technological knowledge become possible.[7]

5 Implications for knowledge governance

Building upon the arrovian tradition of analysis, knowledge as a private good suffers from many and relevant limitations stemming from its well-known characteristics of non-appropriability, indivisibility and non-rivalry in use. Intellectual property rights are a necessary and yet amendable economic institution. It seems useful to try and assess the application of the notion of knowledge as an essential facility and of a compensatory liability regime based upon a participation of inventors to a share of the total surplus generated by the application of their proprietary but no longer exclusive intellectual property rights with the classic categories of the arrovian analysis.

It seems clear that the stronger are the effects of the indivisibility of technological knowledge in terms of cumulability, fungibility and compositeness, and the stronger are the incentive to remove the exclusivity of property rights (Antonelli 2006). This is true for many reasons. First from a general 'technical' efficiency viewpoint: when technological knowledge is characterized by high levels of cumulativity, fungibility and complementarity the long term cost curve exhibits a negative slope (see ACK' in diagram) and the cost elasticity is steeper the larger are the levels of divisibility. Hence the larger are the effects of knowledge economies of density and the larger the social waste stemming from exclusive intellectual property rights. Second, from an allocative viewpoint: exclusive intellectual property rights provide to initial inventors the control on the sequence of additional bits of knowledge that build up the previous with clear asymmetric effects. With high levels of knowledge cumulability and knowledge fungibility, strong inventors are likely to be primarily sequential inventors. Thirdly,

[7] This result is consistent with the new views of Reichman, who originated the proposal for a liability regime. In a recent contribution Reichman has come around to the view that litigation costs could be fatal to it. He now refers instead to "compensatory royalties falling within a specific statutory range for a specified period of rime." So that the 3–9% royalty rate which he thought in his original article might be appropriate, would now have the sanction of law and argues that "about a couple of percentage points in royalties, ideally before an arbitrator or mediator, is socially preferable to litigating costly actions for infringement"(Reichman and Maskus 2005:360). I owe these comments to the suggestions of one of the anonymous referees.

relevant effects on the demand side can take place when knowledge compositeness matters. Knowledge compositeness is defined by the variety of specific knowledge units that are necessary to generate new knowledge in any specific field (Antonelli 2005). With high levels of knowledge compositeness, increased levels of access to a given bit of knowledge can exert strong widespread effects across the board with typical network externalities. The larger is the number of users of a given piece of technological knowledge and the wider the incentive to increase its usage. In such a case the position of the derived demand for knowledge would not be changed towards the left by the introduction of non-exclusive intellectual property rights, but actually towards the right with significant incremental benefits in terms of the levels of research and development activities undertaken in a given economic system.

The implementation of the liability rule seems most promising in presence of patent pools, i.e. when there are many patents per one innovation (Cohen et al. 2000; Reitzig 2004). The literature refers in such cases to two quite distinct notions of patent-thickets and patent-fences. Groups of patents are 'fences' when they protect substitute technologies. Patent fences are used to exclude potential competitors from adjacent markets. Typically, in the case of patent-fences, there are a large number of patents and one assignee. Group of patents are thickets when actual knowledge complementarities are at work and many different original technologies, implemented by many 'inventors,' are complementary in the generation of a new composite technology. In the case of patent-thickets, there are, often, a large number of assignees. The liability rule should have a clear impact on 'fences' that would be no longer useful, because of the end of exclusive property rights, with strong positive welfare effects. The implementation of a compensatory liability rule should also have positive effects on the complex definition of both procedural and content contracts among the parties involved when patents as thickets are concerned. The holders of complementary units of knowledge retain the same incentive to participate into the collective undertaking based upon the royalties that stems from the successful introduction of a new technology. The actual value of the collective undertaking and hence the distribution of the benefits can now be made on a ex-post basis, after the actual economic effects of the introduction of the new knowledge have been quantified in the market place. The objective definition of the outcome should reduce the coordination costs in building and managing the technological club.

For the same token the suggested implementation of the intellectual property right regime with the application of a compensatory liability regime seems especially effective when non-rivalry-in-use, another key feature of knowledge, is considered.[8]

[8] See Nelson (2004:462): "For our purposes here, the most salient aspect of the economist' public good concept is that a public good is 'non-rivalrous in use.' By that it is meant that, unlike a standard economic good, like a peanut butter sandwich, which either you or I can eat but not both (although we can split it), as a public good can be used by all of us at the same time without eroding the quality for any of us. Knowledge is a canonical case of something that is non-rivalrous in use in this sense, and this is not a proposition conjured by economists. The notion that I can tell you what I know, and then you will know it, and I will too, almost surely has been widely understood by sophisticated persons for a long time. There is no 'tragedy of commons' for a public good like knowledge. And to deny access, or to ration it, can result in those denied doing far less well than they could if they had access. In this case in point, if access to certain bodies of scientific knowledge or technique can be withheld from certain researchers, they may be effectively barred from doing productive R&D in a field."

The distinction between user-value and exchange-value rooted in the classical legacy comes useful in this context. Knowledge is clearly a non-rivalrous-in-use, hence a public good, from the user-value viewpoint. But knowledge is quite a rivalrous, hence a private good, from the exchange-value viewpoint. In fact, the larger is the number of users of a new knowledge and the lower are the rents that can be extracted from its application. When everybody has unlimited access to the same unit of knowledge and everybody can apply it, no rents can be extracted from it. The contradiction between these two notions is key to understanding the need for an effective incentive system that guides the allocation of resources to the generation of new knowledge. The definition of royalty based liability rule to compensate the loss of exclusive intellectual property rights seems an effective solution, able to save a portion of the rivalrous character of knowledge as a private good from the exchange-value viewpoint, and yet to valorize the public good nature of knowledge from the viewpoint of user-value.

It is clear that the implementation of revenue-based compensatory liability regime to knowledge governance can engender significant litigation costs that might diminish the positive impact of the suggested regime in terms of social welfare. The levels of possible litigation costs stemming from the suggested procedure need, however, to be confronted with the huge levels of actual litigation costs. According to Hall et al. (2003) in fact, average, per patent, legal costs for litigation vary in the range of the astonishing level of 400,000–2,500,000 US$ in the US and 50,000–500,000 US$ in the European Union.[9]

6 Conclusions

Technological knowledge is a collective, highly imperfect and heterogeneous activity. Moreover it is not only an output, but also an input, an essential intermediary production factor that is relevant both in the generation of new technological knowledge and in the generation of other goods. The dynamic efficiency of each firm and of the system at large depends upon the factors affecting the dissemination and the conditions of access to existing knowledge, as a basic essential facility.

This analysis has clear consequences in terms of allocation of knowledge total surplus. In the allocation of the total surplus stemming from knowledge indivisibility, a larger portion, in terms of consumer surplus, should be granted mainly to users, rather than to producers. Lower levels of exclusivity and lower rents for such technological knowledge seem useful also from a competitive advantage. The larger are the effects of the economies of density in knowledge generating activities and the stronger are the asymmetric advantages for incumbents that are for old inventors. Old inventors in fact can retain for themselves and for a long stretch of time larger portions of the competitive advantages stemming from the repeated use and the non-exhaustibility of the knowledge generated at time $t-1$ and appropriate all the stream of additional bits of knowledge which build upon the previous ones.

[9] As McDonald (2004) notes: "Patents are even now being taken out so that their owners can make money out of vexatious and aggressive litigation rather than from actual innovation."

Such a new governance of intellectual property rights, based upon the notion of knowledge as an essential facility and hence the extension of the notion of mandated interconnection with the application of compensatory liability regime can balance the defense of intellectual property rights and the rewards stemming from the introduction of an original piece of knowledge with the need to increase the dissemination of relevant knowledge so as to favor its cumulative and competitive applications.

The evolution of the intellectual property rights regime towards the separation between ownership and the exclusive right of access to knowledge can provide important opportunities for the systematic valorization of both the markets for technology and the interactions among holders of complementary bits of knowledge. The mandated right of interconnection to bits of knowledge owned by third parties can take place with the implementation of the compensatory liability regime and the ex-post payment of royalties without the preliminary consensus of the patents holders.

The reduction of the rights of exclusive use of intellectual property, the introduction of the mandated right to access intellectual property for third parties, combined with the eventual enforcement of the compensatory liability regime such that the judiciary system can help securing ex-post the payment of fair levels of royalties to the effective owners, can become an effective institutional innovation. Intellectual property and hence patents can play a strong role in increasing the quality of the knowledge interactions. Full visibility of intellectual ownership can help locating bits of complementary knowledge and hence reducing the costs of technological communication and networking activities at large. Especially when the parties can agree eventually upon the payments of appropriate royalties. By means of non-exclusive property rights, implemented by liability rules, knowledge interactions come closer to market transactions and hence increase the scope for the valorization of knowledge complementarities.

The informational role of patents as carriers of relevant information about the actual levels of technological competence of agents and the availability of new bits of knowledge in this context is crucial. Technological signaling becomes relevant as a device to reduce knowledge transaction and networking costs.

The appreciation of the informational role of patents has significant implications for their characteristics. With respect to the automatic granting of intellectual property rights, as in the case of copyrights, the selective and discretionary assignment of patents seems even more appropriate. The scrutiny of an Authority is in fact most useful as a screening device, which makes it possible to sort out the bits of new knowledge that are actually relevant and useful. For this very same reason patents assigned following the first-to-invent procedure seem more useful than patents assigned with the first-to-file approach: the latter procedure better qualifies the content of the patent in terms of novelty and ingenuity. Second, it seems also clear that a narrow definition of the scope of a patent is more useful, from an informational viewpoint, than a wide one. The identification and location of the relevant bits in the great map of knowledge becomes easier for each perspective user. In such a context of governance of intellectual property rights, it seems clear that the granting of patents should be made easier and the fees charged for renewal should be lowered also so as to increase the role of patents as signals: patentees are now

charged with far higher knowledge transactions costs in the form of litigation and judiciary activities. The costs of the identification of the imitations and the activation of the liability rule in fact are now fully shifted to the undertaking of original inventors.

Patents are essential tools to signal the levels and the characteristics of the knowledge embodied in each organization. A new chapter in the economics of intellectual property rights emerges here. Patents are no longer regarded only as tools to increase appropriability, but also as devices to increase transparency in the knowledge markets and hence facilitate markets transactions. The new assessment of the informational role of intellectual property rights in terms of increased incentives to the production and trade of knowledge and hence a remedy to undersupply needs however to be reconsidered, because of the perverse effects of exclusion on the efficiency of the generation of new knowledge, especially when radical innovations are under question. The notion of knowledge as an essential facility becomes relevant. The extension and generalization of the notion of essential facility, elaborated in the telecommunications industry in the last decades of the twentieth century, is fruitful in the economics of knowledge and hence in the governance of knowledge commons.

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