**Compulsory Licensing: The Foundations of an Institutional Innovation**



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*THE WIPO JOURNAL: ANALYSIS OF INTELLECTUAL PROPERTY ISSUES, volume 4 e fascicolo 2, anno 2013, pagg. 157-174*

# COMPULSORY LICENSING: THE FOUNDATIONS OF AN INSTITUTIONAL INNOVATION[1]

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ABSTRACT. Compulsory licensing is an important institutional innovation that improves the knowledge governance and can help fostering the pace of generation of technological knowledge and the rate of introduction of technological innovations. So far the analysis of the effects of compulsory licensing has been focusing the effects in the markets for the products that embody new knowledge. Recent advances in the economics of knowledge solicit a shift in perspective calling attention of the characteristics of the knowledge generation process. Intellectual property right regimes based upon exclusivity increase the incentives to generate new technological knowledge but reduce the efficiency and the actual viability of the knowledge generation process. The costs of the reduction in the access to existing knowledge are larger, the larger is the scope of application of new technology. Compulsory licensing for technological knowledge can increase the rate of generation of new technological knowledge, only if the appropriate level of royalties is identified. The paper contributes the debate with a simple model that enables to identify the correct levels of royalties for compulsory licensing analyzing the generation of knowledge rather than the markets for the products that embody it.

KEY WORDS: KNOWLEDGE AS AN INPUT; RECOMBINANT GENERATION OF TECHNOLOGICAL KNOWLEDGE; KNOWLEDGE FUNGIBILITY; MANDATORY LICENSING; OPTIMAL ROYALTIES

JEL CODES: O30

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[1] I acknowledge the funding of the European Union D.G. Research with the Grant number 266959 to the research project 'Policy Incentives for the Creation of Knowledge: Methods and Evidence' (PICK-ME), within the context of the Cooperation Program / Theme 8 / Socio-economic Sciences and Humanities (SSH), and the support of the Collegio Carlo Alberto with the project IPER. A preliminary version of this paper has been presented at the International Workshop ESDES-MIPI1-Université Catholique de Lyon – GATE/Université Lumière Lyon 2 "Nouveaux comportements d'innovation et nouvelles fonctions du brevet" at Lyon, December 2011. I acknowledge the useful comments of many participants, of the anonymous referees and of Elisabetta Ottoz and Franco Cugno.

## 1. INTRODUCTION

Compulsory licensing has been practiced for quite a long time in the copyright regime. Recently its use has been advocated also in the patent law and especially in the debates on the trade related intellectual property rights. The shift of compulsory licensing from the copyright to the patent law can be considered an important institutional innovation that can help fostering the pace of generation of technological knowledge and the rate of introduction of technological innovations.

The analysis of compulsory licensing has been implemented so far assuming the markets for the products that embody new knowledge as the exclusive perspective. Much progress can be done with the tools of the economics of knowledge, implementing the analysis the role of compulsory licensing directly in the generation of new knowledge.

Compulsory licensing cum royalties has not yet been analyzed with sufficient depth with the tools of the economics of knowledge. This paper aims at use this framework of analysis to expanding the analytical foundations of this important institutional innovation so as to facilitate its fast diffusion and widespread adoption. From an analytical viewpoint compulsory licensing seems an intriguing device that, when it is coupled with mandatory royalties, may help addressing in an innovative way the well-known Schumpeterian trade-off between static and dynamic efficiency (Schumpeter, 1942).

Recent advances in the economics of knowledge have confirmed the medieval wisdom according to which to make knowledge it is necessary to stand on giants' shoulders[2]. The generation of new technological knowledge is possible only if the stock of existing knowledge can be used as an input. All barriers and delays in the access to existing knowledge risk to reducing the capability to generate new technological knowledge. Intellectual property right regimes based upon exclusivity may increase the incentives to generate new technological knowledge but reduce the efficiency and the actual viability of the knowledge generation process. This risk is all the more relevant when the levels of knowledge fungibility are high. The costs of all barriers to the access to existing knowledge are larger the larger the scope of application of new technology. Compulsory licensing for technological knowledge especially if it exhibits high levels of fungibility can increase substantially the rate of generation of new technological knowledge.

[2] The quote is often attributes to Isaac Newton. John Salisbury in his *Metalogicon*, however, a few centuries before had attributed quite the same sentence to Bernard of Chartres: "*Dicebat Bernardus Carnotensis nos esse quasi nanos, gigantium humeris insidentes, ut possimus plura eis et remotiora videre, non utique proprii visus acumine, aut eminentia corporis, sed quia in altum subvenimur et extollimur magnitudine gigantea*." (Salisbury, 1159:167). It seems clear that Sir Isaac was actually standing on the shoulders of a giant.

The paper contributes the debate on the role of compulsory licensing within intellectual property rights regimes in three ways. First it articulates the advantages of mandatory licensing as an institutional innovation that can provide a fertile solution to the new and old trade-offs of intellectual property right regimes. To do this, it applies the tools of the economics of knowledge to show why compulsory licensing can be considered an actual improvement in the allocation of property rights and hence a reduction of social costs. Second, the paper stresses the limits of the attempts implemented so far to base the search of the optimum levels of royalties on the analysis of the markets for products that embody the new technological knowledge. Finally it provides a simple approach based upon the economics of knowledge that enables to identify the optimum level of royalties.

The rest of the paper is structured as it follows. Section 2 elaborates the implications of the new understanding of knowledge as both and input and output to grasp the importance of compulsory licensing with an optimum level of royalties. Section 3 presents compulsory licensing as an institutional innovation. Section 4 synthesizes the results of the literature on the effects of compulsory licensing and stresses the limits of the analysis implemented so far exclusively on the markets for the products that embody new technological knowledge. Section 5 presents a simple model that makes it possible to identify the correct levels of the royalties building upon the recent achievements of the economics of knowledge. The conclusions summarize the results of the analysis.

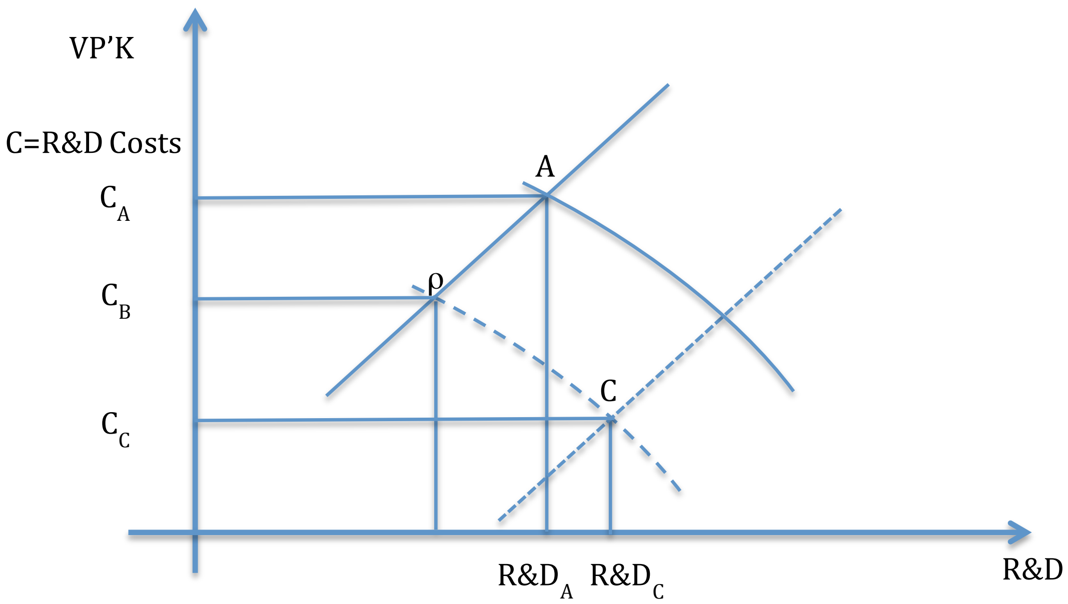
## 2. INTELLECTUAL PROPERTY RIGHTS WHEN KNOWLEDGE IS BOTH AN OUTPUT AND AN INPUT

For quite a long time the economic of knowledge has focused attention on the negative consequences of the limited appropriability, non-excludability and intrinsic information asymmetries of technological knowledge as an economic good. Limited appropriability and non-excludability limit: a) the benefits stemming from the generation and exchange in the market place, b) the incentives to the allocation of resources to generate it, c) the opportunities for division of labor and hence specialization. These limits make the case for market failure. Because knowledge is 'worst-than-standard-economic-goods', markets are unable to allocate the correct amount of resources into the generation of technological knowledge. Public intervention is deemed necessary to help sustaining the generation of adequate quantities of knowledge in the economic system (Nelson, 1959; Arrow, 1962 and 1969).

Figure 1 illustrates the point. The dotted line of the actual schedule of the marginal product of knowledge in value (VP'K) lies below the levels of the straight line that it would exhibit were it a normal economic good. Because of limited appropriability and non-excludability, the value of the knowledge that has been generated is lower than it would be with standard goods. For a given costs schedule of research development and learning activities (R&D), the equilibrium level is found in B rather than in A and the system is led to engage in levels of R&D activities that are lower than equilibrium levels with standard goods.

INSERT FIGURE 1 ABOUT HERE

RO[-1]Figure 1: From knowledge non appropriability to knowledge as a non exhaustible input



The size of the segment $R\&D_A$- $R\&D_B$ measures the undersupply of research, development and learning activities in the economic system engendered by the 'worst-than-standard-economic-goods' characteristics of knowledge.

Intellectual property rights are an important institutional remedy as they enable 'inventors' to (better) appropriate the results of the generation of technological knowledge and its application to the production of other goods. As a consequence intellectual property rights and specifically patents can increase the incentives to generate new technological knowledge and contrast the risks of market failure and undersupply. Repeated attempts to build up a consensus to dismantle intellectual property rights highlighting their negative consequences on the product markets have failed (Machlup and Penrose, 1950; Boldrin and Levine, 2002).

Much attention has been paid to the analysis of the consequences of the characteristics of patents in terms of breadth, length and assignment procedure in the attempt to identify their best mix from the viewpoint of the trade-off between the negative effects of patents in term of static efficiency in product markets and their positive effects, in terms of dynamic efficiency, on the actual levels of appropriability and hence on the incentives to introduce further innovations (Gilbert, Shapiro, 1990; Ayres, Klemperer, 1999).

The growing empirical evidence provided by the economics of knowledge has progressively made clear that the generation of new technological knowledge consists in the recombination of existing modules of knowledge. Technological knowledge is at the same time an output and an input of the recombinant generation of new technological knowledge and external knowledge is an essential –indispensable- input. Eventually knowledge enters the production function of all goods: as such it is twice an input: an input into the generation of new technological knowledge and an input into the generation of all the other goods (Weitzman, 1996 and 1998).

According to the last advances in the economics of knowledge, new technological knowledge is generated by means of the recombination of the existing technological knowledge. As Brian Arthur puts it: "I realized that new technologies were not 'inventions' that came from nowhere. All the examples I was looking at were created-constructed, put together, assembled-from previously existing technologies. Technologies in other words consisted of other technologies, they arose s combinations of other technologies" (Arthur, 2009:2).

The theoretical analysis of technological knowledge has unveiled and stressed new characteristics that had received lesser attention, namely indivisibility and hence complementarity and cumulativity, and, most importantly, non-exhaustibility. Because of non-divisibility new technological knowledge impinges necessarily upon the stock of knowledge. Hence it can be generated only if and when existing technological knowledge can be used as an intermediary input. Its non-exhaustibility makes these repeated uses not only possible, but more and more effective along with the increase of the stock of knowledge (David, 2003).

Figure 1 illustrates the point. Now the dotted cost schedule of research and learning activities lies well below the straight line that would be appropriate if knowledge were a standard good. The dotted line accounts for the positive effects of knowledge-non-exhaustibility and non-divisibility. The costs of conducting research and learning activities are lower than those of any other standard good because of the positive effects of knowledge externalities stemming from its non-exhaustibility and cumulability. Because of non-exhaustibility and cumulability, technological knowledge, once generated adds on to the stock of existing knowledge that can be used as an intermediary input into the generation of new technological knowledge again and again. When the positive effects of knowledge-non-exhaustibility are accounted and the role of knowledge non-divisibility is properly considered, the equilibrium is found in point C. The amount of R&D activities in the system is now $R\&D_C$ well above the levels of a standard good. In fact on the vertical axis the size of the segment $C_B$- $C_C$ measures the reduction in the costs of research and learning activities made possible by knowledge externalities. Now, because of non-exhaustibility and cumulability, the equilibrium costs of knowledge are lower than those of standard economic goods and the equilibrium quantities are far larger. Knowledge exhibits idiosyncratic characteristics that make of it a good far 'better-than-standard-economic-goods' (Antonelli, 2005).

Technological knowledge appears to be 'better-than-standard-economic-goods' to the point that the increase of total factor productivity growth can be accounted by the amount of knowledge that, like a pure externality, spills from inventors to third parties (Griliches, 1979 and 1992). Building upon this intuition, the first wave of models of the new growth theory elaborated an interpretative framework according to which a system, where existing knowledge generated for a specific purpose by an agent spills freely in the atmosphere and is used as an intermediary input in the production of other goods by third parties, can experience fast rates of growth of both output and productivity (Romer, 1994).

The empirical evidence about the relevant absorption costs that are necessary to actually benefit of knowledge spillovers have brought to appreciate the role of both the systemic conditions and the intentional strategies of actors in qualifying the access to existing knowledge and stressed the role of pecuniary knowledge externalities – as opposed to pure externalities- in shaping the actual costs of the use of the stock of knowledge. As pecuniary knowledge externalities can measure the actual costs of external knowledge, they can actually account for the differentiated rates of productivity growth across regions, countries and firms (Mokyr, 1990 and 2002; Antonelli, 2012).

The discovery of the dual role of technological knowledge as both an input and output throws new light upon intellectual property right regimes. It becomes clear, in fact, that all barriers and delays to the use of existing knowledge as an input into the generation of new technological knowledge may increase the appropriability and hence the incentives to generate new technological knowledge but damage or even hinder the possibility to generate new technological knowledge as they impede the necessary use of the indispensable stock of knowledge as an intermediary input (David, 1993; Antonelli, 1999).

Intellectual property right regimes based upon full excludability force inventors to invent around and invent again bearing duplication costs that reduce the overall efficiency of the generation process. In the extreme case, an actual case for knowledge rationing takes place when existing knowledge cannot be used at all and no inventing around can overcome the non-availability of the existing knowledge. Inventors may be forced to wait until the expiry of the patent to use it as an input into the generation of new technological knowledge with major social loss in terms of reduced pace of technological advance (Jaffe and Lerner, 2004; Buzzacchi, Scellato, 2008).

The discovery of the dual role of knowledge as an output and an input unveils a second additional, inter-temporal, bundle of trade-off(s). The exclusive intellectual property rights traditionally associated with patents provide patent holders at time t with the exclusive use of knowledge as an input in the production of knowledge at time t+1. Hence patent holders can generate new technological knowledge at incremental costs while all the other knowledge producers should bear the full costs of rediscovering the knowledge that is possessed by the inventor. In order to generate new technological knowledge that uses the incumbent technological knowledge as an input, patent holders bear only the costs of the additional costs while the costs of the existing knowledge is already sunk. Patent holders enjoy the benefits of substantial economies of density from which non-patent holders are excluded[3]. If perspective inventors cannot replicate the existing technological knowledge by means of inventing-around strategies, the monopolistic rights are likely to stay forever and actually increase over time as the working of knowledge cumulability displays its exclusive effects over historic time. In both cases it is clear that monopoly rights at time t are likely to become persistent and convey asymmetric cost advantages that are most likely to reduce not only static efficiency in product markets, but also dynamic efficiency in the long-term generation of knowledge (Antonelli, Crespi, Scellato, 2012).

[3] The economies of density engendered by exclusive intellectual property rights have the consequence that the slope of the long terms cost curve for the generation of technological knowledge is negative for patent holders and positive for non-patent holders obliged to invent around (See Antonelli, 2007)

From the social viewpoint it is clear that a new bundle of dynamic knowledge trade-offs is at work. Patents have negative effects not only because they imply monopoly rights in the markets for products that apply technological knowledge, but also because they may delay and in any event create twisting asymmetries in the sequential generation of new technological knowledge.

As Heller and Eisenberg (1998) note the strengthening of the intellectual property right regime that has characterized the last decades may actually deter innovation and make the case of an anticommons. The current intellectual property right regime together high transaction costs in the markets for knowledge and excess expectations of patentees on the value of their knowledge assets produce a fragmented knowledge landscape where owners of small complementary bits of knowledge are unable to participate in the collective effort that is necessary to generate new knowledge as an output while using existing knowledge an input (David, 2010).

At the same time, however, it remains clear that intellectual property rights play a key role not only to secure the necessary appropriability, and hence the incentives to the generation of technological knowledge, but also to contrast the active search of secrecy, as the extreme remedy implemented by 'inventors', to reduce non-appropriability. Without effective intellectual property rights 'inventors' may try and disguise the knowledge that they have been able to generate relying upon secrecy with great harm for the generation of new technological knowledge. Patents, even with exclusive property rights, do disseminate effective information about the existence of new technological knowledge (Cohen, Nelson, Walsh, 2000; Arundel, 2001; Besse, 2005; Cugno, Ottoz, 2006 and 2011)

The understanding of the new trade-off has stirred the search for a new functionality of patents trying to combine their indispensable role to enforce the necessary property rights on technological knowledge with the need to increase the dissemination and access to existing knowledge (Corbel, Le Bas, 2011).

In the new approach intellectual property rights are necessary both to prevent the active use of secrecy and to increase appropriability. At the same time intellectual property rights may become an obstacle not only to static efficiency and the working of competitive product markets but also to the actual use of technological knowledge as an input into the sequential generation of new technological knowledge. The critical levels of the exclusivity of intellectual property rights emerge as the key issue that may solve the intrinsic contradiction (Antonelli, 2007).

The positive experience of free software has attracted much attention in this context and suggested that this specific evidence might be generalized. Software provides strong evidence about the central role of knowledge complementarity and cumulability in the recombinant generation of new technological knowledge. New software produced by each developer impinges upon the source that has been generated in the past and in the myriad of applications that have been and are being, at each point in time, generated by other developers. In the software industry it seems quite clear that a bottom up spontaneous mechanism of knowledge governance centered upon the practice of a general public license to the advances in software source made available by each developer to any other has become the common practice (Stallman, 1998).

The spreading of the FLOSS (Free Libre Open Source Software) practice in a fast growing industry characterized by high levels of knowledge complementarity and cumulability coupled with the clear evidence of the fast advances of the software technology have suggested the viability of an intellectual property regime based upon the citation mechanism and led to articulate the hypothesis that gains of the free access to new technological knowledge embodied in the advances in the software source were sufficient to counterweight the lack of incentives associated with intellectual property rights (Dalle, David, den Besten, Steinmueller, 2008).

At a closer analysis, however, it seems that the specificities of the software industry matter more than it is recognized. In the case of free software the social recognition of the contribution made available by each 'inventor' and implemented by the general public license that provides each developer a cite and hence the social recognition of its contribution, plays a crucial role. Specifically it seems that the free access to software made available by the software expert cum its social recognition is compensated by the increase of reputation and its direct valorization in the adjacent markets of professional services. The markets for professional services are not only adjacent but strictly complementary to the markets for software: the assistance of the developer in the actual implementation of a new program is in fact absolutely necessary for its effective use. The proximity of the markets for professional services to the markets for software in other words works as a crucial compensating mechanism as it creates complementary rewards that compensate for the lack of direct appropriation. Like in academia, where publications qualified by citations secure chairs and hence long term salaries, each quote carried by the general public license is often worth more than a penny in the working of adjacent professional markets (Trajtenberg, 1990).

The appreciation of the crucial role of the professional rewards to the citations stemming from the general public license limits the possibility of a generalized use of an intellectual property right regime based upon implicit or explicit citations. Where and if adjacent markets -where the professional reputation can be effectively valorized- are missing, the lack of appropriability has negative and direct effects on the incentives to generate new technological knowledge and hence ultimately the supply of new knowledge (Antonelli, 2007).

## 3. COMPULSORY LICENSING AS AN INSTITUTIONAL INNOVATION

Compulsory licensing cum royalties is a major institutional innovation that is being used by a growing number of countries. It is the result of the recombination of the copyright regime with the patent regime. It can be regarded as a new mechanism of knowledge governance that seems able to enable a better allocation of property rights and hence a reduction of social costs (Coase, 1960).

Compulsory licensing has been practiced for quite a long time, since the Paris Convention of 1883. It was regarded as a technical specificity originated in the copyright regime that might be applied to the patent legislation in special circumstances beyond the limits of the Berne Convention for the Protection of Literary and Artistic Works (Merges, 2004).

Its application is now spreading especially under the pressure of the debates upon the TRIPs (Trade Related Intellectual Property Rights. Compulsory licensing is emerging in the international arena stirred by the globalizing economy as the result of a spontaneous and collective bottom-up process of social governance of knowledge commons based upon the implementation of the grafting of the copyright tradition into the patent law able to make possible a new and superior allocation of intellectual property rights. It first applications were found in pharmaceuticals and health care products[4]. It is now spreading in biotechnologies and information and communication technologies. From this viewpoint it shares the characteristics of an emerging and collective process similar to the FLOSS with the specific characteristic that, here, actors are not individual software developers but many small industrializing countries that try and participate into the generation of new technological knowledge (Ostrom, 1990).

Compulsory licensing combines a reduction of the exclusivity of the patent regime with the identification of a royalty for the use of proprietary knowledge. Intellectual property rights on new knowledge are recognized, the use of proprietary knowledge can take place by third parties without authorization, but after registration and the payment of a royalty (Reichman, 2000; Reichman and Maskus, 2005).

A reduction of the exclusivity of intellectual property rights seems useful to reduce the negative effects upon the use of technological knowledge as an input into the generation of new technological knowledge and yet preserving the key role of intellectual property rights to favor the dissemination and social availability of existing technological knowledge. The reduction of exclusivity needs to be balanced by the royalties that the users of patented knowledge should pay to inventors. Royalties are necessary to provide inventors with a reward for undertaking risky

[4] See the Regulation (EC) No 816/2006 of the European Parliament and of the Council of 17 May 2006 on compulsory licensing of patents relating to the manufacture of pharmaceutical products for export to countries with public health problems. See Chien (2003) and Scherer and Watal (2002).

research, development and learning activities and in general to cope with all the costs that are associated with the introduction of technological innovations.

Compulsory licensing differs sharply from compulsory licensing cum royalties. In the former framework knowledge holders are deprived of all economic rights and cannot contrast the free use of their proprietary knowledge from third parties. In the latter framework the users of the patented knowledge are expected to inform the patentee that they are going to use the knowledge and are willing to pay the royalties. Patentees that discover a user that did not declare itself and did not pay the royalties can claim that an infringement has been taking place and ask the judiciary power to act against the clandestine user. On the opposite the patent holder cannot refuse the perspective user the right to access the patented knowledge and can only ask for the payment of the royalty.

The introduction of compulsory licensing cum royalties can be regarded as a major institutional innovation. Its introduction can be advocated as a tool to contrast the creation of barriers to entry and monopoly especially in sensitive product markets such as health care and pharmaceuticals. As a matter of fact compulsory licensing should be used not only to favor competition in the product markets, but also to foster the generation of new technological knowledge.

From this specific viewpoint it seems clear that the negative consequences of exclusive intellectual property rights are all the stronger the larger is the scope of application of technological knowledge. Barriers and delays to the use of technological knowledge that has a limited scope of application have smaller negative consequences than barriers and delays to the use of technological knowledge that has a wide scope of application. In the latter case in fact intellectual property rights with high levels of exclusivity slow down and may actually impede the advances of a large portion of the scientific and technological frontier (Antonelli, 2007).

The introduction of compulsory licensing cum royalties seems most promising for general-purpose technologies and technological knowledge with high levels of fungibility. The negative effects of the exclusivity of intellectual property rights are all the stronger the wider is their scope of application. The new understanding of the mechanisms underlying the generation of technological knowledge enable to grasp that the reduced availability of existing knowledge has negative consequences that are stronger the larger of products and derivative advances in technological knowledge that rest upon its un-limited imitation and use as an intermediary input into the generation of new technological knowledge (Reitzig, 2004).

Compulsory licensing cum royalties should combine the positive effects of the rewards to the generation of technological knowledge and the introduction of technological innovations with the positive effects of the reduction of monopolistic power in product markets and of access and actual use of technological knowledge once generated. Compulsory licensing cum royalties deprives inventors from the exclusive property right so that they can no longer impede the imitation of innovations and the use of technological knowledge but entitles them with royalties based upon the actual use of their new technology and innovation (Barton, 2000; Penin, 2005).

## 4. THE ECONOMICS OF COMPULSORY LICENSING IN PRODUCT MARKETS

The economics of compulsory licensing, so far, has focused exclusively the effects on both users and producers of technological knowledge in the markets for the products that embody technological knowledge (Tandon, 1982).

The modeling exercises based upon the analysis of the downstream product markets show how the introduction of an institutional innovation based on the fine tuning of the characteristics of intellectual property rights can help fostering the rate of technological advance that is put at risk both by the uncontrolled weakening of patents and by the intentional creation of new fences and limitations to the use of existing technological knowledge.

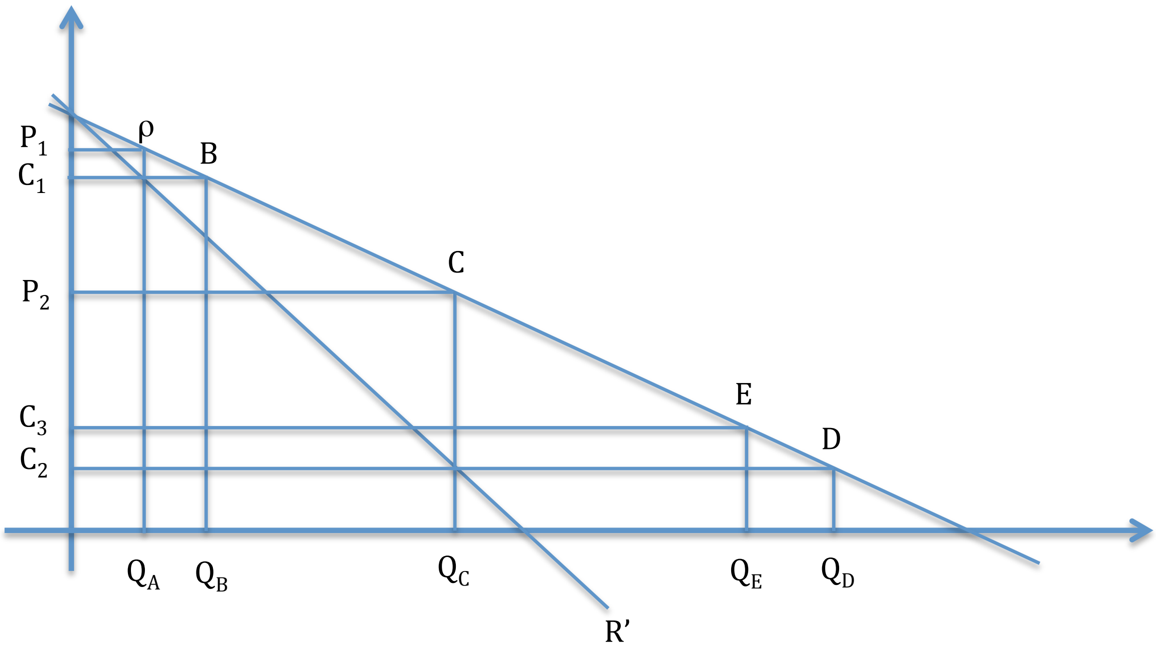
Compulsory licensing cum royalties enables to reduce the levels of exclusivity of intellectual property rights with positive effects both in the markets for products that embody new technological innovations and in the markets for knowledge. Compulsory licensing has positive effects in terms of: a) a reduction of monopolistic power in product markets that is compatible with the identification of the rewards for inventors that are necessary to avoid the use of secrecy and b) the dissemination of knowledge that is necessary to foster the generation of new technological knowledge.

Compulsory licensing enables to solve the arrovian paradox according to which it is at the same true that the social surplus of innovation is larger in competitive markets than in monopolistic ones, but the incentives to innovate are stronger in the latter than in the former. The identification of the correct levels of royalties however is crucial to substantiate the effective use of this important institutional innovation.

Figure 2 helps grasping the point. Let us assume that $C_1$ are the costs of a good sold in a monopolistic market at price $P_1$. Before innovation the equilibrium quantity is $Q_A$. The introduction of an innovation reduces the costs to $C_2$. These new costs include the innovation costs but no rewards for the innovator. In monopoly the new price would be $P_2$ and the new equilibrium quantity $Q_B$. In a competitive market the price would coincide with $C_2$ and the new equilibrium quantity would be $Q_D$.

INSERT FIGURE 2 ABOUT HERE

Figure 2: Compulsory licensing in products markets




The inspection of Figure 2 confirms that in monopolistic product markets the consumer surplus is lower than in the competitive market, but in the competitive market there are no profits. Yet the competitive market enables to maximize the social surplus defined as the sum of profits and consumer surplus. From the social viewpoint the competitive market is clearly superior, but there are no rewards for the innovator and hence the incentives to innovate are completely missing. The economic system risks a dramatic undersupply of the technological knowledge that is necessary to introduce the innovation than enables to reduce the costs from $C_1$ to $C_2$.

From an ex-post perspective, assuming that the profits stemming from the introduction of an innovation do incentive their introduction, it seems clear that competitive markets are superior in terms of static efficiency, but absolutely inferior in terms of dynamic efficiency (Schumpeter, 1942).

Let us now consider the case that compulsory licensing is introduced with royalties that are fixed at the level R. Royalties are a cost for the producer and a revenue for producers of the technological knowledge that is necessary for the introduction of innovations. Hence costs increase from $C_2$ to $C_3$. $C_3$ include both the costs of the product after the innovation and the rewards for the activities that have made possible the generation of technological change and the introduction of the innovation. Compulsory licensing implies that there are no barriers to entry to imitators: competitive markets can substitute monopolies. In a competitive market, where all firms can use the new technology, the price would coincide with the new costs. The new equilibrium is found in E and the system would produce the quantity $Q_E$.

The equilibrium in E combines royalties with consumer surplus. Royalties indeed provide incentives to innovate. The key question concerns their correct levels: too high royalties create static inefficiency while too low ones end up in dynamic inefficiency.

E solution the consumer surplus is larger than the monopolistic solution identified by point C. As a result the social surplus of compulsory licensing with royalties is larger than in the monopolistic product markets and yet provides the appropriability that is necessary to yield incentives. Compulsory licensing enables to combine the benefits of incentives for 'inventors' and hence for innovators with the social goal to increase as much as possible the social surplus stemming from the generation of technological knowledge and the ensuing introduction of innovations. The E solution, however, does not provide any hint that the future consumers' surplus is actually maximized by the current levels of the royalties.

The E solution has been selected with a rule of thumb procedure that does not necessarily lead to the maximization of dynamic efficiency. The maximum levels of dynamic efficiency would be actually identified only if it were possible to select the 'correct' amount of royalties that combine the optimum incentive to introduce innovations with the maximum levels of consumers' surplus at time t and in the following periods.

The analysis has focused the markets for the products that embody new technological knowledge in the attempt to identify the correct level of royalties starting from the analysis of their characteristics. The levels of royalties affect at least three categories of agents: the holders of patents or the innovators, the users of the patent or the imitators and finally the customers of the products that have been produced with the innovation.

Scherer (1977) with a path-breaking empirical study on the propensity of firms to fund R&D activities after compulsory licensing and to innovate found that the consequences were negative but only to limited extent. This result is important but does not shed any light on the actual optimum levels of the royalties. More recently Moser and Voena (2012) provide interesting evidence on the effects of compulsory licensing on the users of knowledge. The effects were absolutely positive with an increase of innovation activities for users estimated around the 20%. In this case however compulsory licensing was enforced without royalties as a part of the Trading with the Enemy Act enforced in 1917 by the US against German patents. The positive effects on US users should be confronted with the negative effects on patent holders in order to assess the general effects of compulsory licensing.

The main result of this approach consist in the identification of the characteristics of the markets for the products such as the price and revenue elasticity of the demand, the type of rivalry on the supply side, the extent to which barriers to entry prevent imitation that affect the conduct of both innovators and imitators. This approach however has not provided any clear-cut definition of the optimum level of the royalties that are associated to compulsory licensing (Lanjouw, Lerner, 1997).

So far the identification of the correct level of royalties remains unsettled. The limits of this approach are more and more evident with: a) the failure of patent pools where the literature has not been able to elaborate a coherent methodology for the identification of the levels of royalties undermining their practical application (Lerner and Tirole, 2004; Lerner, Strojwas, Tirole, 2007); b) the spreading of patent thicketing as a strategic tool to reduce the risks of non-appropriability and the increasing limits to the use of technological knowledge to generate new technological knowledge (Shapiro, 2001); d) the increasing levels of litigation and legal costs (Hall, 2007), e) the spreading of 'trolls' that try and maximize the benefits stemming from knowledge indivisibility in terms of complementarity among patents (Chien, 2008 and 2011) . The lack of a correct methodological approach to identify the correct levels of royalties limits the application of compulsory licensing to the field of drugs and medical products, typically in developing countries (Chien, 2003).

The identification of the correct level of royalties is crucial (Scherer and Watal, 2002). Non exclusive property rights with no rules about the correct level of royalties would give patentees the right to ask huge royalties that would vanish the actual non-exclusivity with the well-known negative effects that are all the stronger when innovation is cumulative (Shapiro, 2001; 2010, Llobet, 2002).

A step forward is necessary towards the identification and implementation of a methodology to identify the correct level of royalties to which all parties involved in non exclusive property rights –sellers and customers- should stick to. This implies a shift of intellectual property rights away from the property rule towards the liability rule. The distinction is important as with an entitlement protected by property rule, a collective decision can be made with respect to the content of an entitlement, but not upon the value of the entitlement. An entitlement protected by a liability rule, instead, involves a collective decision on the value of the entitlement (Calabresi and Melamed, 1972).

The analysis of the upstream generation of knowledge as a good per se that is not yet embodied in new products but is strictly necessary to introduce product or process innovations seems to offer a promising opportunity to solve the problem.

## 5. OPTIMUM ROYALTY IN THE GENERATION OF KNOWLEDGE

The economics of knowledge by now provides a large set of analytical tools and ammunitions to try and identify the crucial level of royalties analyzing directly the knowledge generation activity rather than the markets for products that embody new technological knowledge. Knowledge is a collective activity that uses knowledge as a necessary input for the generation of new knowledge as an output.

More specifically the rich literature of the economics of knowledge shows that each firm can generate new knowledge as long as it can rely upon the knowledge activity implemented at each point in time by all the other firms with which it can interact. External knowledge is acquired by means of transactions enriched by interactions. The mix of transactions-cum-interactions is made necessary by the tacit component of knowledge. At the same time external knowledge cannot be considered as a stock. Knowledge exists as long it consists of an ongoing activity. External knowledge is always and necessarily a flow of competences practiced by other agents in the system.

The analysis of the knowledge generation function, as distinct from the knowledge production function that includes knowledge as an input, enables to make an important step forward. Following Griliches (1979) the knowledge production function applies to all the other goods and includes explicitly knowledge an input, next to the traditional inputs such as capital and labor. The knowledge generation function applies only to the upstream activities that make it possible to generate new knowledge (Nelson, 1982). Building upon Weitzman (1996 and 1998) the generation of knowledge can be considered as the result of a recombination activity of all existing knowledge available at each point in time. The diverse knowledge items that exist at each point in time are dispersed in a myriad of possessors and used in a variety of activities. The stock of knowledge does not exist independently of the learning activity of the agents that posses and use it. A bit of knowledge that is not used is lost. External knowledge is the basic indispensable and non-disposable input that feeds the eventual generation of new knowledge. The knowledge possessed by all the other agents is external to each agent and yet is a crucial input into the recombinant generation of new knowledge. Research and development activities together with learning processes enable to recombine the existing knowledge items into new knowledge. No generation of new knowledge is possible without the access to and the use of existing knowledge.

The access to external knowledge by each agent requires a complex set of transactions cum interactions. Because of the tacit component of knowledge perfect, impersonal, spot transactions are not sufficient to transfer knowledge. Dedicated, personal interactions are necessary. The price of knowledge plays an important although not exhaustive role in the actual acquisition of external knowledge and its effective use in the recombinant generation of new knowledge.

The specification of a knowledge generation function and the appreciation of the dual role of knowledge as both an input and an output provide the opportunity to identify the correct price for knowledge. The identification of the correct levels of royalties is in fact possible as soon as we consider jointly their positive and negative effects on the economics of the generation of technological knowledge. High levels of royalties engender high revenues for the knowledge producer as well as higher costs. Technological knowledge, in fact, is both an output and an input, more specifically, a necessary and indispensable input for the production of new technological knowledge. Hence technological knowledge is found twice in the generation function of the inventor, both on the revenue and the cost side. This frame enables to identify an optimum level of royalties.

Let us assume that, at the system level, it is possible to identify the amount of new knowledge Y that the system is willing to use. Y is generated with the following Cobb-Douglas production function:

(1) $F(R\&D, K_n) = R\&D^{\alpha} K_n^{1-\alpha}$
where $0 < \alpha < 1$.

In particular, $F(R\&D, K_n)$ represent the additional level of knowledge produced, Y, given the two productive factors employed: research and development (R&D) and initial quantity of knowledge ($K_n$). As in the standard Cobb-Douglas we assume that the two productive factors are complements with a certain degree of substitutability. In other words, the production of knowledge requires a minimum amount of the productive factors R&D and $K_n$, so that even if royalties are very large, the production cannot rely exclusively on the factor R&D, and some minimum amount of $K_n$ must be used in any case. Let us call this minimum amount $K_{n\,min}$.

Assuming linear costs g of R&D and $K_n$, and a price for the royalties R, the profit function is the following:

(2) $\Pi(R\&D, K_n) = R\, F(R\&D, K_n) - g\, R\&D - R\, K_n$.

In the range of substitutability, the firm chooses the level of R&D that maximizes her profits:

(3)

$$\frac{d\,\Pi}{dR\&D} = 0 \Rightarrow R \cdot \alpha \cdot R\&D^{\alpha-1} K_n^{1-\alpha} - g = 0 \Rightarrow R\&D^* = \left(\frac{\alpha R}{g}\right)^{\frac{1}{1-\alpha}} K_n^*$$

Similarly, the level of $K_n$ that maximizes the firm's profits is

(4)

$$\frac{d\,\Pi}{dK_n} = 0 \Rightarrow R \cdot (1-\alpha) \cdot R\&D^{\alpha} K_n^{-\alpha} - R = 0 \Rightarrow K_n^* = (1-\alpha)^{\frac{1}{\alpha}} R\&D^*$$

Considering that $Y = R\&D^{\alpha} K_n^{1-\alpha}$,

(5)

$$Y = \left(\frac{\alpha R}{g}\right)^{\frac{\alpha}{1-\alpha}} K_n^{*\alpha} K_n^{*(1-\alpha)} = \left(\frac{\alpha R}{g}\right)^{\frac{\alpha}{1-\alpha}} K_n^* \Rightarrow K_n^* = Y \left(\frac{g}{\alpha R}\right)^{\frac{\alpha}{1-\alpha}}$$

and, by substituting (5) in (3)

(6)

$$R\&D^* = Y\left(\frac{\alpha R}{g}\right)$$

The revenue function is:

(7)

$$RV(R) = R \cdot Y$$

From expression (7), the revenue function is linear with respect to R as shown in Fig. 3 with the bold straight line increasing from the origin.

The total costs are the sum of the cost component related to R&D and the cost component related to $K_n$:

(8)

$$C = C_{R\&D} + C_{K_n}.$$

In the substitutability range (namely when $K_n > K_{n\ min}$), both cost components depend on R, as expressed by (5) and (6). The cost components in the substitutability range are then:

(9)

$$C_{R\&D}(R) = g \cdot R\&D^* = g \cdot Y \cdot \left(\frac{\alpha R}{g}\right) = \alpha \cdot Y \cdot R$$

and

(10)

$$C_{K_n}(R) = RK_n^* = R \cdot Y \left(\frac{g}{\alpha R}\right)^{\frac{\alpha}{1-\alpha}} = Y \cdot \left(\frac{g}{\alpha}\right)^{\frac{\alpha}{1-\alpha}} \cdot R^{\frac{1-2\alpha}{1-\alpha}}$$

In the substitutability range, the quantity of productive factors used depends on R. Indeed, if R increases, the production of Y relies more on R&D and less on $K_n$. In particular, from the expressions above, we see that the component of cost related to R&D is linear with respect to R, while the convexity with respect to R of the cost component related to $K_n$ depends on the value of $\alpha$. In particular, if $\frac{1-2\alpha}{1-\alpha} < 0$, namely if $\alpha > ½$, the component of cost related to $K_n$, $C_{Kn}$, has the form of a hyperbole.

This case is shown in Fig. 3 where the productive factors are substitutes for R < R*. In this interval, $C_{Kn}$ is represented by the thin hyperbole and $C_{R\&D}$ is represented by the thin line. Their sum is shown by the bold curve C(R).

When R increases beyond a certain value (that we denote R*), $K_n$ cannot further decrease and the combination and amount of productive factors remains constant at $K^*_{n\ min}(R^*)$ and $R\&D^*_{max}(R^*)$. This implies that beyond R* (namely, out of the substitutability range) the component of cost related to R&D remains constant with respect to R, while the component of costs related to $K_n$ increases linearly with R:

(10)

$$C = g \cdot R\&D^*_{max} + RK^*_{n\,min}$$

We thus have that, out of the substitutability range, revenues increase linearly (with the multiplicative factor being the given level of Y), and costs increase linearly (with the multiplicative factor being $K_{n\ min}$). The situation is represented in Fig. 1 for values of R > R*. $C_{R\&D}$ is the thin horizontal line, while $C_{Kn}$ is the thin increasing line. Their sum is shown by the bold increasing line for R > R*.

Assuming that the slope of the revenue curve (Y) is lower than the slope of the cost curve ($K_n$) (namely, that the quantity of additional knowledge produced is lower than the initial level of knowledge used), it is evident from Figure 3 that an optimal level of R exists, where profits are maximized. This level corresponds to R*.

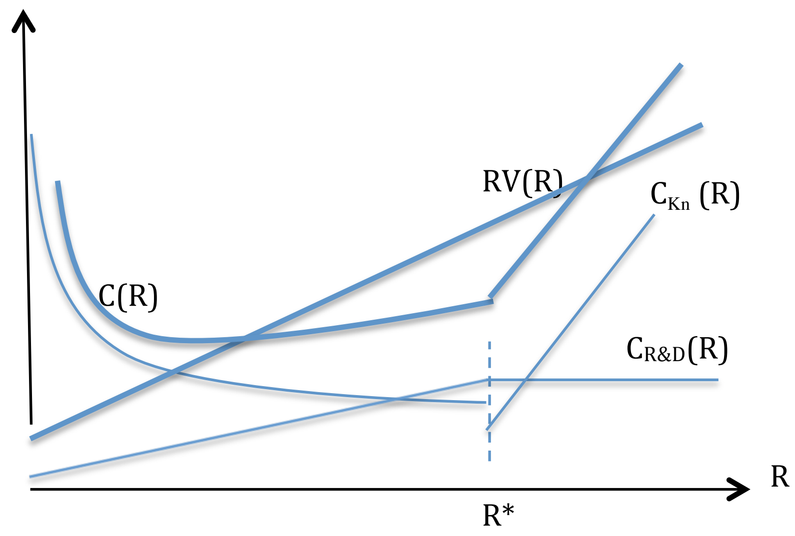



Fig. 3: Cost and revenue function for α > ½ and complementary productive factors, with $Y<K_n$

The model has shown the strict interdependence between active and passive royalties when the stock of technological knowledge is considered as an input into the production of new technological knowledge.

From a regulatory viewpoint the implications of this analysis are straightforward and consist in the direct extension of the existing regulatory body on essential physical facilities such as telecommunications, energy, transportation. Existing knowledge is an essential facility. At the same time intellectual property rights should be enforced. Their use and access should be implemented with a shift of intellectual property rights away from the property rule towards the liability rule that implies a collective decision valid *erga omnes* on their value and access conditions (Antonelli, 2007; Choi, 2010).

Applications for patents should be integrated by the identification of the research costs that have been expensed to generate the new technological knowledge. The declaration of the costs incurred should be supported by appropriate accounting evidence. Patent offices are expected to acquire the competence that is necessary to assess the congruence of the costs declaration so as to limit the drawbacks of inefficiency in knowledge generation and/or opportunistic behavior in declaration. Moreover, in order to counterweight the creation of spurious incentives to opportunistic behavior of inefficient inventors, renewal fees will be calculated as a share of the costs that have been admitted by the patent office.

Once the patent is granted, compulsory licensing applies and the use of patents by third parties cannot be limited, provided the request for license is registered and royalties are paid.

The royalties will be calculated as a share of the costs. The level of the royalty for the perspective user should be lower than the costs incurred by the inventor. The royalty should be fixed at a level that prevents the substitution by users involved in the generation of new knowledge, of current R&D expenses to existing knowledge. If the royalty is fixed at 50% of the costs, patents with a number of requested licenses below 2 would incur losses. When the number of licenses, however, is larger than 2 inventors make profits. The actual levels of the inventor's profits will be influenced by the relevance of the patent. Because the costs incurred for the generation of new technological knowledge are fixed, the average costs of patents with a wide application will decrease overtime favoring the increase of the profits.

On the demand side knowledge generators will try and identify the best mix of knowledge inputs according to their content and their costs. On the supply side the generation of technological knowledge can became a specialized industry where firms compete in the generation of useful knowledge that can be patented and used with no exclusivity by third parties. The identification of mark-ups can help fostering the entry of new competitors in specific domains. Inventors of minor inventions will barely cover costs. Inventors of radical inventions will gain major profits stemming from the difference between the fixed royalty and the declining average costs of the patent[5]. The entry in the knowledge generation industry however is open as there are no barriers to entry determined by exclusive intellectual property rights. High profits is specific domains are likely to attract the entry of new competitors while inventors might want to exit from scientific and technological domains with low demand for licenses [6].

Because of compulsory licensing and the consequent right to use the existing knowledge although at a price paid to the possessor of its patent we can assume that Schumpeterian competition takes place in both product and knowledge markets with a plurality of firms both upstream and downstream that enter and exit. Many firms try and generate new technological knowledge using the stock of existing knowledge as much as many firms try and introduce technological innovations in the product markets.

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[5] Patent offices might be given regulatory powers that enable to reduce the unit royalty for patents that register very high levels of licenses.

[6] To increase the levels of actual competition in the markets for products the direct exploitation of a patent by the inventor with the creation of a firm should be impeded. The inventor however can retain the right to use the knowledge generated and patented to generate new knowledge. Clearly the inventor has the incentive to acknowledge the royalties paid to its own knowledge generating activity.

A Marshallian selection process based on entry and exit with the failure of less attractive innovations and firms is likely to take place. At each point in tine a plurality and variety of innovations are being introduced. The Marshallian selection process applies to both firms and innovations and leads to the social optimum in terms of the amount of new technological knowledge identified by the maximum difference between the consumer surplus and the cost of generating new technological knowledge and introducing technological innovations.

Compulsory licensing bears direct effects on patent design and especially on their breadth and duration. Compulsory licensing reduces the relevance of both scope and duration since their implications on the exclusivity of property rights are swept away from the right to use a patent provided that a fee is paid. (Ayres and Klemperer, 1999).

The systematic application of compulsory licensing cum royalties opens new opportunities for knowledge exploitation, favoring the direct valorization of knowledge as a commodity non-embodied neither in goods nor in knowledge intensive property rights, becoming an alternative both to vertical integration in the direct application of new knowledge in the production of other goods and to venture capitalism (Coriat and Weinstein, 2012),

Compulsory licensing cum royalties make possible the working of the markets for knowledge favoring the meeting of the demand and the supply for knowledge. Moreover they can help stirring the interaction between knowledge producers and knowledge users. Knowledge users have a clear interest to purchase technical assistance and support by knowledge producers. At the same time knowledge producers have an interest to assist perspective knowledge users and add to the royalties the revenue stemming from their assistance. Compulsory licensing becomes an incentive to the growth of markets for knowledge transfer services that become strictly adjacent and complementary to the markets for knowledge. From this viewpoint compulsory licensing favors the actual consolidation of a knowledge economy (Arora, Fosfuri, Gambardella, 2001; Shavell, Van Ypersele, 2001).

## 5. CONCLUSIONS

The identification of the dual role of technological knowledge as both the output of a generation process and an essential input into the recombinant generation of new technological knowledge makes it possible to make an important progress towards the identification of the correct price for knowledge.

Knowledge is characterized by the idiosyncratic characteristics of limited natural appropriability, non-exhaustibility, indivisibility and hence cumulability and complementarity. Its efficient generation requires at the same time its unconditioned use as an input and its full exploitation as an output. With too little appropriation, knowledge externalities are very high as much as the efficiency of the knowledge generation process, but the exploitation conditions are so bad and the incentives so low that nobody is willing to engage in the generation of knowledge. Too much appropriation reduces the uncontrolled leakage of knowledge spillovers, limits knowledge externalities and improves exploitation conditions but reduces the viability and the efficiency of the generation process.

In this context intellectual property rights play a central role. Intellectual property rights are necessary to enable the appropriability of technological knowledge, to favor its dissemination in the economic system and to prevent the systematic use of secrecy. The tuning of their characteristics is also necessary in order to reduce their negative consequences both in the product markets and in the knowledge markets. The exclusivity of intellectual property rights and specifically of patents is a crucial characteristic that deserves much attention and analysis. The reduction of the exclusivity of patents by means of the systematic use of compulsory licensing seems to yield positive effects both in product and in knowledge markets.

The identification of the correct level of royalties associated with compulsory licensing is crucial to implement the effective viability of this major institutional innovation and to favor its fast diffusion with widespread adoption.

Compulsory licensing cum royalties enables to combine the need to secure the rewards to innovators with the goal of increasing as much as possible the social surplus stemming from the introduction of innovations. The analysis of the pay-off of the levels of royalties on the economics of knowledge generation enables to identify the correct levels of royalties.

The fine tuning of intellectual property right regimes with their recombination and based upon the reduction of the exclusivity of patent legislation with the enforcement of royalty rights can become a major institutional innovation. The advantages of dynamic efficiency are maximized under the constraints of the appropriate conditions for the implementation of static efficiency. Compulsory licensing gives a new functionality to the patent system as it becomes an essential tool for increasing the dissemination of technological knowledge and hence increasing its repeated use as an intermediary input and at the same time a mechanism that favors the working of the markets for knowledge securing appropriate rents to innovators and inventors.

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