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THE GOVERNANCE OF LOCALIZED TECHNOLOGICAL KNOWLEDGE AND THE EVOLUTION OF INTELLECTUAL PROPERTY RIGHTS

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Introduction

The economics of intellectual property rights has been characterized by an evolution that parallels and reflects the major shifts in the economics of technological knowledge that have occurred in the recent years. This work provides an analysis of the effects of the changing foundations of the economics of knowledge upon the assessment of the design and the characteristics of intellectual property rights.

To do this, the paper relies on a systemic approach to understanding the mechanisms of the institutional set up that are most conducive to foster the rate of introduction of technological knowledge and hence technological change. The systemic analysis of the interdependent and complementary conditions of access and exclusion to the flows of technological interactions, transactions, coordination and communication that are specifically designed to organize the generation and the distribution of technological knowledge provides the appropriate context into which the role of each mechanism and specifically intellectual property rights can be assessed (Jaffe 2000).

Major changes have occurred in the economic understanding of knowledge in the second part of the 20th century. Knowledge has been first regarded as a typical public good that markets and profit-seeking agents could not produce in the appropriate quantities and with the

appropriate characteristics. These theoretical ingredients paved the way to the build-up of the infrastructure for the public provision of knowledge. Consensus on the analysis of the public good characters of knowledge has been first contrasted and eventually substituted by the new argument about the quasi-private nature of technological knowledge. The identification of the central role of external knowledge in the production of new knowledge marks the second step. The identification of the knowledge trade-off stressed the limitations of the intellectual property rights. Eventually a more balanced view based upon a deeper analysis of the generation and distribution of knowledge as a localized process and a closer analysis of the role of knowledge interactions and transactions as a part of a broader governance problem have been elaborated. This evolution had important consequences on the analysis and the implementation of institutional design for the

organization of the production and distribution of knowledge (Machlup and Penrose 1950; Alchian and Demsetz 1973).

In the new analysis of the governance of the production and distribution of knowledge, intellectual property rights as signaling devices and the new understanding of the implications of knowledge as an essential facility play a major role[1].

Knowledge as a public good

The seminal contributions of Kenneth Arrow marked for a long time the economics of knowledge and provided the theoretical foundations for the build up of the public knowledge common. In this approach technological knowledge is seen as a public good because of its intrinsic limitations due to the high levels of indivisibility, non-excludability, non-appropriability and hence non-

tradability. In this context markets are not able to provide the appropriate levels of knowledge because of the lack of incentives, and the missing opportunities for implementing the division of labor and hence achieving adequate levels of specialization.

The public provision of scientific and technological knowledge by means of the funding to Universities and other public research bodies, as well as directly to firms willing to undertake research programs of general interest, found in this argument a rationale. This led to the actual build-up and the systematic implementation of public knowledge commons.

The Arrovian approach impinged upon a second leg. The provision of public subsidies to firms undertaking research and development activities was regarded as a necessary condition to remedy the low appropriability conditions and hence the lack of incentives.

Public procurement is the third basic tool to increase the production of knowledge. The demand for weapons especially becomes a major instrument to focus resources and identify research direction and objectives with a broader and general scope for derivative technological applications at the system level and relevant from the viewpoint of the general production of new scientific and technological knowledge. The natural leakage of technological knowledge from the military sector - often within the same corporations - feeds the levels of technological opportunity for the rest of the system. The spillover from the high-tech military activities provides unique opportunities for the introduction of product and process innovations in all the other sectors of the economy.

The Arrovian approach easily integrated into the Schumpeterian legacy according to which the large

corporation with substantial market power was the appropriate institution to accelerate the rate of introduction of technological change. Because of the low levels of natural appropriability only large incumbents in product markets characterized by barriers to entry, could fund internally research and development activities, with their own money. Ex-ante monopolistic market power based upon barriers to entry in existing product markets would provide extraprofits and hence secure the financial resources to fund research and development expenditures and, most importantly, reduce the risks of uncontrolled leakage and imitation. Competitors have yet to enter and entry is barred by substantial cost disadvantages. Appropriability is provided by barriers to entry rather than by barriers to imitation. The large corporation is also considered the appropriate tool to increase the rate of introduction of innovations as it provides internal markets

for financial resources and competence: because of low appropriability regimes, arms' length transactions in external markets cannot be used to coordinate neither the allocation of financial resources into research activities and their selection, nor the necessary division of scientific and technological labor.

The creation of intellectual property rights was regarded as the complementary institutional set-up, parallel to the public provision of scientific knowledge and the benign neglect to monopolistic market power. Patents and copyrights, if properly implemented, could reduce non-excludability and non-appropriability. In a proper institutional design, intellectual property rights may also favor tradability and hence lead to higher levels of specialization and division of labor in the technological applications of new scientific discoveries, made possible by the public support. Intellectual property rights can help

increasing the incentives to the production of incremental technological knowledge, but only in a broader context shaped by the role of the State (Kingston 2001).

Nevertheless, at this time intellectual property rights are not considered the major tool to improve the static and dynamic efficiency of the economic system in the production of knowledge. Patents are mainly viewed as an instrument designed to increase the incentives of firms to introduce minor technological innovations. Public subsidies, public direct participation in the production and demand for knowledge are regarded as the basic instruments to push the introduction of radical technological innovations.

Knowledge as a proprietary good

The first major shift in the economics of knowledge takes place when the notion of knowledge as a public good is

challenged and knowledge is regarded as a quasi-private good with higher levels of natural appropriability and exclusivity and hence tradability (Nelson and Winter 1982).

Technological knowledge is now viewed as the result of a bottom-up process of learning, which takes place mainly within the borders of firms. Technological knowledge is based upon tacit knowledge accumulated by means of learning process. Eventually tacit knowledge can be articulated and finally it translates into its codified form. Only when knowledge is fully codified and systematic effort of articulation have been made, it can be diffused without the intentional assistance of the original holder (David 1993; Cowan and Foray 1997; Cowan, David and Foray 2000; Ancori, Bureth and Cohendet 2000).

Imitation is hampered by major information and adaptation costs, appropriability is de-facto secured by high levels of stickiness in routines and procedures: the not-invented-here syndrome is much more effective than assumed in the public good tradition (Mansfield, Schwartz, Wagner 1981; Harabi 1995).

In the resource-based theory of the firm, the generation of technological knowledge is regarded as the distinctive feature of the firm. The firm does not coincide with the production function and cannot be reduced to a production function because its essential role is the accumulation of competence, technological and organizational knowledge and the eventual introduction of technological and organizational innovations. From this viewpoint the firm precedes the production function: the technology is in fact the result of the accumulation of

knowledge and its application to a specific economic activity (Penrose 1959; Foss 1997).

The resource-based theory of the firm has grown as a development and an application of the economics of learning (Loasby 1999). It focuses on the characteristics of the process of accumulation of competence, the generation of technological knowledge and the introduction of technological and organizational innovations, not only as key factors to understanding the firm, but also as the relevant characteristics in the general production of technological knowledge.

In this context the firm is the primary actor in the production of knowledge for the whole economic system. The firm is viewed as the privileged locus where technological and organizational knowledge is generated by means of the integration of learning processes and formal research and development activities. The firm is

considered in this approach primarily as a depository and a generator of competence and eventually knowledge (Foss 1997; Nooteboom 2000).

Because technological knowledge is now viewed as the sticky joint product of internal learning, it cannot spill freely in the air. Relevant absorption costs for potential users should be taken into account and qualified interactions between producers and users of new knowledge are necessary for technological knowledge to be actually transferred from one organization to another. The explicit and intentional assistance of original knowledge holders to perspective users is relevant, if not necessary.

The role of the public knowledge commons is now questioned on two counts: first the firm is now viewed as the key actor in the production of knowledge and second, knowledge can circulate only if a dedicated framework of

systematic interactions, which involve directly inventors, is put in place.

This new approach paved the way to significant steps towards the privatization of public knowledge commons. The public provision of subsidies to firms undertaking research and development activities and the direct role of the State in the production of knowledge comes under a closer scrutiny. The role of university as the single provider of externalities to the economic system is questioned (Henderson, Jaffe and Trajtenberg 1998)[2].

The new enclosures substitute the knowledge commons. Public research centers and Universities were solicited to patent their discoveries and often forced to enter the markets for the technological outsourcing of large corporations. The conditions for the effective appropriation of knowledge are enforced both at the firm level and in public organizations: the mobility of human

capital is more and more regarded as a sensitive issue (May 2000; Mowery, Nelson, Sampat, Ziedonis 2001).

At the same time, the role of intellectual property rights is reconsidered. Intellectual property rights can complement and integrate the appropriability of technological knowledge, so that actual markets for knowledge, now much closer to traditional economic goods, can be developed. Intellectual property rights are now regarded as a complementary condition to increase the tradability and consequently to achieve the standard conditions for equilibrium supply of knowledge in the economic system. The extension of patent protection to new forms of knowledge such as software, algorithms and genetic entities finds here its foundations (Merges and Nelson 1994; Sakahibara and Bransletter 2001).

The discovery of the knowledge trade-off

The second major swing takes place when a closer analysis of knowledge appropriability made it possible to understand, next to its negative effects in terms of missing incentives and hence undersupply, the positive effects of technological spill-over and the key role of technological externalities. The discovery of external knowledge, available not only by means of transactions in the markets for knowledge, but also by means of technological interactions, marks a new important step in the debate. External knowledge is an important input in the production process of new knowledge. The appreciation of external knowledge, as an essential input in the production of new knowledge, was later articulated in the systems of innovation approach, where the production of knowledge is viewed as the result of the cooperative behavior of

agents undertaking complementary research activities (Eisenberg 1989; Scotchmer 1991).

The costs of exclusion associated to intellectual property rights, as a consequence, should be taken into account. Monopolistic control of relevant bits of knowledge, provided both ex-ante and ex-post by patents and barriers to entry in the products markets respectively, can prevent not only its uncontrolled leakage and hence its dissemination but also further recombination, at least for a relevant stretch of time (Arrow 1969; Dasgupta and David 1987 and 1994; David 1993; Shavell and Ypersele 2001)[3].

The advantages of the intellectual property right regime, in terms of increased incentives to the market provision of technological knowledge are now balanced by the costs in terms of delayed usage and incremental enrichment. The vertical and horizontal effects of indivisibility display their powerful effects in terms of

cumulability. Indivisibility of knowledge translates into the basic cumulative complementarity among bits of knowledge. Complementarity and cumulability in turn imply that new bits of knowledge can be better introduced building upon other bits already acquired, both in the same specific context and in other adjacent ones. The access exclusion from the knowledge already acquired reduces the prospect for new acquisitions and in any event has a strong social cost in terms of duplication expenses (O' Donoghue 2001).

The duration of exclusive property rights assigned by patents and the conditions for their renewal become a central issue for the possible negative drawbacks in slowing the rate of generation of new knowledge, especially when general purpose knowledge with a wide scope of applications is concerned (Scotchmer, 2001; Shankerman and Scotchmer, 2001).

The breadth of patents is also questioned: when the breadth is large the protection is not specific and the negative effects in terms of foreclosure can easily exceed the advantages in terms of increased incentives. A narrow definition of the scope of application of intellectual property rights is thus recommended (Klemperer 1990; Merges and Nelson 1994; Hopenhayn and Mitchell 2001).

The introduction of a prize system has been advocated in this context as a possible alternative to patents. Prizes are seen as the proper incentive to the generation of technological knowledge because they combine the reward to innovators with informational advantages of patents in signaling the new relevant knowledge, which becomes available, but they do not impede the circulation of the new knowledge. The limitations of the prize system however are easily found on the screening and assignment procedure whereby a

committee of scientist and technologists might easily assign the rewards to the wrong technological knowledge. An issue of bureaucratic coordination failure based upon bounded rationality clearly emerges (Wright 1983; Shavell and Ypersele 2001).

Here in the economics of technological knowledge the issues of externalities on the demand side become relevant and evident. The generation of technological knowledge is now characterized by technical and pecuniary externalities. The notion of user-interdependence makes its foray into the scene when agents value the levels of usage of other agents of certain goods. As far as scientific and technological knowledge is concerned, interdependence among users, hence on the demand side, is very strong. The actual chances of generating a new relevant bit of knowledge for each agent depend upon the levels of accumulation of skills and

competence, education and access to information of the other agents in the community.

The issues of the distribution of knowledge become central in the debate and the notion of an actual knowledge trade-off is articulated. Uncontrolled leakage and low appropriability regimes reduce incentives, but may not necessarily lead to under-provision. Low appropriability engenders technological externalities and spillovers that are the prime factor in increasing the efficiency of generation of new knowledge, at the system level: the growth of efficiency can compensate for lower inputs (Griliches 1992).

Excess appropriability, both ex-ante and ex-post, based upon barriers to entry or on intellectual property rights, may slow down if not impede the working of knowledge complementarity, cumulability and fungibility. Intellectual property rights are now questioned as it seems

evident that too strong a regime of protection may have positive effects in terms of increased incentives to the generation of knowledge, but has clearly negative effects in terms of delayed and slower circulation and distribution of the new knowledge available (Mazzoleni and Nelson 1998).

The governance of the generation and distribution of localized technological knowledge

A new step is made with the full appreciation of the notion of localized technological knowledge, which stresses the role of knowledge as a joint-product of the economic and production activity. Agents learn how, when, where and what, also and mainly, out of their experience, accumulated in daily routines. The introduction of new technologies is heavily constrained by the amount of competence and experience accumulated by means of

learning processes in specific technical and contextual procedures. Agents, in this approach, can generate new knowledge, only in limited domains and fields where they have accumulated sufficient levels of competence and experience. A strong complementarity must be assumed between learning, as knowledge input, and other knowledge inputs such as R&D laboratories, within each firm.

A second and most important complementarity takes place between internal and external knowledge. Firms can generate new knowledge and eventually introduce new technologies only when and if they are able to take advantage of external knowledge. No firm can rely exclusively on its own internal knowledge, either tacit or codified, whether it is the result of learning processes or formal research and development activities. The complementarity between external and internal knowledge

and the cumulability between different vintages of knowledge, both internal and external, become a key issue. Neither can firms generate new knowledge relying only on external or internal knowledge as input. With an appropriate ratio of internal to external knowledge instead internal knowledge and external knowledge inputs enter into a multiplicative production function. Both below and above the threshold of the appropriate combination of the complementary inputs the firm cannot achieve the maximum output.

Localized technological knowledge can be understood as a collective activity characterized by the complementarity both between external and internal knowledge and the stock of existing knowledge and the flows of new knowledge. Markets appear to provide a unique set for incentive mechanisms to work swiftly: the result of such market interactions however may or may not

lead the system towards stable and fair solutions. Tradability is a necessary but not sufficient condition for dynamic efficiency to be achieved. The aggregate outcomes of the governance mechanisms at the firm level are far from being attracted by a single equilibrium point.

Because of the complementarity, between internal and external knowledge, especially if it is specified in terms of a multiplicative relationship, the aggregate outcome of both market transactions and interactions is unstable and sensitive to interactions and subjective decision-making. When both demand and supply schedules are influenced by externalities, multiple equilibria exist (Marmolo 1999).

Inclusion needs to be coordinated and managed. Free riding can take place, although reciprocity and mutuality in interactions based upon knowledge barters, implemented by repeated and long-lasting exchanges, can

help reducing the extent and the effect. Exclusion is dangerous for the risks of missing the relevant complementary input, which characterizes the generation of new technologies.

The organization of the systems of innovation appears to be influenced by the need to implement and valorize the complementarity of the bits of knowledge possessed and accumulated in the diverse units, in a context characterized by relevant governance costs.

The full identification of the notions of knowledge complexity, knowledge cumulability and knowledge fungibility is the major result of much empirical and theoretical work. The analysis of the intrinsic indivisibility of knowledge makes it possible to distinguish between cumulability when it applies more precisely to the complementarity between the stocks of knowledge and the new flows, complexity when it applies to the variety of

diverse elements of knowledge that are necessary to generate a new element of knowledge by means of recombination, and fungibility, when it consists of the variety of possible uses and applications of a given unit of knowledge that can be replicated with little incremental and variable costs.

The distinctive notions of knowledge transactions and interactions costs can also be identified and defined in terms of the costs of all the activities such as search, screening, processing, contracting that are necessary to exchange bits of knowledge among independent parties. The trade-off between knowledge coordination costs, internal to firms, and knowledge transaction and interaction costs contributes the understanding of the bundle of governance mechanisms at work (Antonelli 2001; Antonelli and Quèrè 2002; Antonelli 2003 and 2003a).

The analysis of the fabric of governance mechanisms of the production and distribution of scientific and technological knowledge emerges as the appropriate analytical framework. In the governance of knowledge not only the traditional 'make or buy' trade-off is relevant, but also a 'make or sell' choice has to be considered. The firm in fact needs to assess not only whether to rely upon external or internal knowledge in the production of new knowledge one, but also whether to try and valorize the knowledge available internally as a good itself and sell it disembodied in the markets for technological knowledge, or to use it as an input in the production of other goods. Technological strategies can be implemented by means of intentional learning procedures, internal research and development laboratories, technological outsourcing, location of research and development centers into technological districts, technological alliances and

research joint-ventures and finally actual mergers and acquisition. Intellectual property rights play an important role within such a systemic context, together with other complementary and interdependent characteristics of economics systems such as the distribution of firms in regional space, the quality of financial markets and especially of the stock exchange, and needless to say, the organization of academic research.

A wide range of choices in terms of governance can be analyzed and understood also with respect to the characteristics of the processes of knowledge generation and usage. Different governance mechanisms and governance choices emerge according to the characteristics of technological knowledge and to the related levels of knowledge transaction costs (Dasgupta and David, 1987; Antonelli, 2003 and 2003a).

The markets for knowledge: to sell or to make technological knowledge

Markets for technological knowledge are spreading in the economic systems. The use of the market place to exchange technological knowledge is more and more common. Technological knowledge can be traded embodied in new intermediary and capital goods that enter into the production of other goods. It can be traded as a knowledge intensive business service. It can be traded incorporated in weightless products such as software[4]. Technological knowledge can be traded as patent or a license. Finally, technological knowledge can be traded embodied in financial property rights after a new company has been created (Geroski 1995; Arora, Fosfuri and Gambardella 2001).

The characteristics of technological knowledge, its forms and the typology of the process by means of which

new technological knowledge is generated matter in assessing the appropriate mechanisms of governance and the weight of knowledge transaction costs, that is the costs for using the markets for technological knowledge.

Such knowledge transaction costs are relevant both on the demand and the supply side. On the demand side the identification of the agents holding specific bits of knowledge and the assessment of their quality is expensive in terms of search and screening costs including the resources to evaluate the scope for incremental advance.

On the supply side, knowledge transaction costs arise mainly because of the high risks of opportunistic behavior of the customers. Uncontrolled usage of the knowledge can take place with evident damages for the vendor. Derivative knowledge also matters: the vendor of the knowledge bears the risks of non-appropriation of the

results of the efforts of implementation of the knowledge, which has been sold (Scotchmer, 1996).

The costs of writing proper contracts are relevant and the variety of contingencies, which must be taken into account, is very large. A strong intellectual property right regime and favorable conditions for its actual implementation in the markets for technological knowledge clearly favor the reduction of knowledge transaction costs. The role of the judiciary system with respect to the enforcement conditions of the contracts for disembodied technological knowledge is also most relevant (Anand and Tarun, 2000; Kingston, 2001).

The main characteristics of knowledge, identified so far, are: a) appropriability, defined in terms of the possibility of inventors to be the single beneficiary of the stream of profits associated with the introduction of a new

bit of knowledge; b) fungibility, defined by the scope of possible applications of a given unit of knowledge, c) complexity, defined by the variety of complementary unit of knowledge that are used to generate a new unit, d) cumulability, defined by the vertical and diachronic complementarity between the stock of existing knowledge and the flow of new knowledge, e) stickiness of knowledge in human capital and routines and finally. These characteristics of knowledge have a direct bearing on its tradability, defined by the extent to which knowledge can be traded as a disembodied good in the market place.

The process by means of which technological knowledge is generated also matter in this context. Four different processes have been identified: learning, research and development, socialization and recombination. When recombination is the primary source of new knowledge

and hence external codified knowledge matters, the access conditions to external codified knowledge are essential and intellectual property rights exert a key role. When socialization, i.e. the exchanges of tacit knowledge in an informal context, qualified in terms of reciprocity and gift-exchange, matters, interactions in the knowledge communities is the primary vector. The social codes of conduct and the tacit laws of inclusion, exclusion and stratification in the knowledge community are the basic mechanisms of governance. When learning is the primary vector of tacit knowledge and the latter is the primary source of new knowledge, the institutions of labor markets play a central role together with the organization of financial markets for the exchange of the property rights that embody the new knowledge in the form of new companies. When R&D activities, leading to new codified knowledge, that cannot be easily appropriated, are the key

mean of generation of new knowledge, intellectual property rights are again in a central position.

The forms of technological knowledge matter: whether technological knowledge is more tacit, articulable or codified has a direct bearing on the governance of knowledge production. The exchange of tacit scientific and technological knowledge seems easier within research communities based upon repeated interactions and closed reciprocity in communication. Random inclusion can take place with positive effects, provided newcomers are properly selected. The incentives to the creation of informal interaction procedures, often implemented by co-localization within technological districts, are very strong in this case. Geographical proximity emerges as a major factor conducive to closer knowledge interactions and exchanges: proximity reduces the scope for opportunistic behavior because of the exposure to repeated interactions

and also reduces the costs of communication. Collective bodies such as industrial associations emerge as important governance structures especially when technological knowledge is tacit and articulation requires complex procedures.

The exchanges of articulable knowledge take place more easily within vertical technological clubs and coalitions formed between vendors and customers-users. Vertical technological clubs differ from horizontal ones where all parties are involved in a shared research activity. Vertical technological clubs complement the sale of patents and licenses and are based upon the close inspection of the activities of the customers and users of the patents. The relationship between the vendors and the customers takes place within long-term contracts, which include the assistance and the active cooperation of the two parties. The reputation of the fellows in the club plays

an important role in building vertical technological clubs. The major goal here is the reduction of transaction costs stemming from the prospects for future knowledge: the vendors can retain the rights to participate into the appropriation of the derivative knowledge stemming from its implementation and incremental accumulation conducted by the customers. When technological knowledge is more articulable, the contractual interaction among partners within technological clubs can be better implemented. Here knowledge transaction costs include high levels of monitoring and assessment of the actual conduct of the partners in the club[5].

Codified technological knowledge better meets the conditions for tradability when implemented by an appropriate intellectual property right regime and when the assistance of innovators is necessary and useful to reduce adoption and adaptation costs of perspective users.

Codified knowledge is often found in fields where technological opportunities are slowing down and the levels of knowledge cumulability are lower (Cowan, David and Foray 2000).

When technological knowledge can be easily appropriated by the innovator, either because of its complexity and hence natural levels of high appropriability, or because the regime of intellectual property rights is effective and easily enforced, firms may prefer to sell directly the technological knowledge as a good per se in the markets for knowledge.

On the contrary, with low levels of appropriability and hence low levels of tradability firms cannot rely on the market place to valorize their intangible outputs. The embodiment of technological knowledge into new products and their eventual sale in the market place becomes necessary. The firm will choose to make and

hence to include within the borders of the portfolio of activities the modules that use the knowledge as an intermediary input when the tradability and appropriability conditions are low. Here the governance choice for the firm is clearly between making and selling rather than between making and buying (Teece 1986, 2000; Antonelli 2001).

For the same token, the larger is the cumulability of the technological knowledge, specific to the products and the production process of a firm, and the larger are the incentives towards the internalization of the knowledge generation process. The sale of technological knowledge in fact has high costs in terms of missed opportunities for further advances. The same argument applies when learning plays a key role in the generation of new knowledge: the full control of the production process is

likely to yield important benefits in terms of increased rates of accumulation of new technological knowledge.

Knowledge fungibility has a direct bearing in this context. When the generation of new knowledge in operating downstream modules is directly influenced by the competence and the knowledge acquired in operating the module upstream, the firm has an incentive to make rather than to sell. This is true also when knowledge complexity applies and the operation of downstream modules has positive effects on the generation of new knowledge in the module upstream. Although the two modules are technically separated, high levels of indivisibility are found with respect to the generation of new technological knowledge and hence with respect to the introduction of new technologies.

When knowledge complexity and fungibility are weak, and knowledge transaction costs are low, the choice

of the firm may be directed towards specialization: the modules are effectively separated both from the technical and the technological viewpoint.

Finally when fungibility is high as well as transaction costs in the markets for technology are high, the firms has a strong incentive to use internally the technological knowledge by means of downstream diversification in a wide range of products. When complexity and knowledge transaction costs are high, the firm has an incentive to integrate vertically in upstream activities.

Both downstream diversification and upstream integration in turn lead to an increase of coordination costs[6] and hence induce the use of the markets to sell knowledge, at least for a subset of applications. Here the costs of using both the market and the internal organization may be so high that the scope for a broad array of applications is lost. Information costs impede to

take advantage of the full basket of technological opportunities stemming from the availability of technological knowledge with high levels of fungibility and complexity (Foray and Steinmueller 2003).

When technological knowledge is embedded in the learning routines of the firm, a strong intellectual property right regime favors the use of financial markets as the appropriate governance mechanism. When technological knowledge cannot be separated from the organizational structures and human capital that characterize the localized learning process, the trade of the property rights of the company where the knowledge has been implemented become an effective mechanism which favors the division of intellectual labor as well as the distribution of knowledge and its appropriation (Gompers and Lerner 1999).

Patents as signals

The debates about the knowledge trade-off have concentrated upon the positive and negative effects of the creation of intellectual property rights. Little attention has been paid to the informational role of intellectual property rights

First, patents play a major role as signaling devices, which help the identification of the available bits of complementary knowledge and their owners so as to reduce search costs. Secrecy, the alternative to intellectual property right, to secure exclusive ownership can have dramatic effects generally in terms of networking costs and specifically in the form of technological communication costs, and hence upon the amount of knowledge complementarities that can be effectively activated (Arundel 2001; Oxley 1999; Teece, 2000).

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 seems 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.

Finally, intellectual property rights can provide not only a remedy to the public good nature of technological knowledge. They 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 does not necessarily leads 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 generate the appropriate quantities of knowledge.

Effective property right systems can rather 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 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.

Intellectual property rights reduce the incentive to internalize the valorization of technological knowledge by means of downward vertical integration. They can favor the creation of markets for technological knowledge and hence favor the distribution of fungible technological knowledge to a wider range of economic activities But they do not necessarily increase the incentive to generate new knowledge, because of the sheer appropriability.

Third, 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, Gambardella and Fosfuri 2001).

Following the resource-based theory of the firm, technological knowledge is the primary output of the firm: the firm exists because it is a depository of knowledge. The choice whether to sell it or to use and make with it is especially relevant. This approach can contribute the debate on the economic organization for the supply of knowledge.

The new appreciation of the role of intellectual property rights is now found in the assessment of their positive effects in terms of higher levels of specialization and division of labor. 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.

The systematic use of patents because helps the identification of bits of relevant knowledge for perspective users, is essential to reducing the waste of duplication and to make easier the working of cumulability in the production of new knowledge. Patents can make knowledge interactions easier, provided the exclusivity of ownership is properly tuned. The basic problems of the knowledge trade-off emerge again and yet can be tackled in a different way.

Complementarities and property rights

The introduction and eventual implementation of new technological system based upon new information and communication technologies have characterized the last decades of the 20th century with important implications for the governance of knowledge commons and the economics of property rights.

New information and communication technologies are characterized by the pervasive role of complementarities, with respect to the infrastructure and the goods produced and delivered. Moreover, high levels of complexity and interdependence also characterize the bundle of technological knowledge upon which new information and communication technologies build. Each advance in this field is strongly influenced by the access conditions to the others, both diachronically and synchronically.

The telecommunications industry provides clear empirical and analytical evidence on such dynamics. Intrinsic complementarity among bits of networks as well as functions within the telecommunications networks is well known. Telecommunications networks are characterized on the supply side by the complementarity between existing trunks of each network and incremental

portions: this leads to economies of incremental costs. Important complementarities, in terms of differentiated economies of density, take also place between functions within the network in terms of transmission, switching, distribution, and signaling. Because of the differences in the minimum efficient size, in the duration and in the capacity of the different segments of the network, their combination into an integrated system, yields important economies of scope. Finally, high levels of complementarity on the demand side with the well-known effects of network externalities characterize telecommunication networks.

The notion of essential facility has been elaborated upon these bases. When a piece of property acquires the characteristics of an essential facility, the rights to 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 Sidak 1994).

As it is well known, competition in the telecommunication industry has been made possible by mandated interconnection. Mandated interconnection is 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 rights, 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 telecommunication 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 both appropriate returns on the investments for the owners as well as viable conditions of entry to new competitors. Newcomers must be put in conditions of actual competition 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 complementarities and the dual effects of economies of scope and externalities 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 generalization can be drawn. The separation between ownership and rights of exclusive use is necessary within economic and physical systems where and when complementarities matter in order to restore and enforce the conditions for competitive markets. The evolution of the property rights regime in the

telecommunications industry is directly pertinent to the case of knowledge complementarities.

Indeed 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.

The separation between ownership and usage conditions experienced in the case of the telecommunications industry can apply with success to intellectual property rights. The monopolistic rights delivered to inventors can however reduce the circulation

of knowledge protected by intellectual property rights. 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.

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 to this central and strategic area as well, where the reduction of the exclusivity of intellectual property rights can be realized by means of compulsory licensing and the liability rule. Compulsory licensing is more and more associated to the authorization to mergers and acquisitions by Antitrust Authorities. Mergers are authorized provided that the firms agree to grant the licenses of their patents to

all perspective users. The ex-ante definition of the appropriate levels of the royalties can become a problem however.

The transition towards the liability rule in intellectual property rights can be considered a useful device to implement mandated interconnection in intellectual property rights. Liability rule consists in the right of the owner of intellectual property to claim for appropriate payments for the usage of her rights (Kingston 2001).

In this context, the right of exclusive use is no longer associated to the rights of ownership of any intellectual property. Like in telecommunications networks, ownership is recognized as well as the right of other parties to take advantage of it for their own transmission needs.

In the case of intellectual property rights the ex-ante definition of the equivalent of interconnection tariffs

seems difficult on many counts. First of all research activities are characterized by high levels of risk and intrinsic uncertainty, both in terms of the chances of generating an output and with respect to the possible field of application of any novelty. Ex-ante definition of the costs of each new piece of knowledge is problematic. Much less difficult is the ex-post identification of the economic value stemming from the application of a given specific piece of new knowledge.

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 liability rule 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 can come closer to market transactions and hence increase the scope for the valorization of knowledge complementarities.

Conclusions

A long process has been taking place, since the old days of knowledge as a public good. A better understanding of the dynamics of knowledge

accumulation has been elaborated. Appropriability conditions seem now less relevant. Today demand and network externalities play a much stronger role. Transactions in knowledge do take place in markets characterized by knowledge transaction costs and governance mechanisms.

The better understanding of the generation of technological knowledge, made possible by the localized approach, and the results of the new enquiry in the economics of knowledge calls the attention on the economic characteristics of knowledge in terms of levels of fungibility, cumulability, complexity, stickiness and appropriability and its forms - tacit, articulated or codified. The analysis of the conditions for tradability is the ultimate result of all these advances. Tradability however is a not a sufficient condition for dynamic efficiency to be assured in the market place.

When increasing returns matter, as in the case of technological externalities, and the price mechanism is unable to convey all the relevant information, the markets are unable to set the right incentives and hence move in the right direction. Governance mechanisms at the microeconomic level and economic policy at the system level are necessary in order to provide the necessary coordination.

The systemic approach to understanding the mechanisms of the institutional set up that are most conducive to foster the rate of accumulation of technological knowledge and its distribution and hence of introduction of technological innovations proves to be the appropriate analytical framework. The systemic analysis of the interdependent and complementary conditions of access and exclusion to the flows of technological interactions, transactions, coordination and

communication that are specifically designed to organize the generation and the distribution of technological knowledge emerges as a area of investigation and enquiry. All mechanisms and specifically intellectual property rights need to be assessed and considered into this broader framework.

The informational role of patents as carriers of relevant information about the actual levels of technological competence of agents and the availability of new bit of knowledge is now more and more appreciated (Stiglitz 2000).

The identification of each bit of complementary and useful knowledge as well as of the agents holding specific bits of knowledge and the assessment of their complementarity becomes an important function. This is expensive both in terms of search and opportunity costs: the costs of interacting with the wrong agents in terms of

low opportunities. The selection of the firms and agents with whom technological cooperation and technological communication can take place is a relevant aspect of the governance mechanism and of the governance process. The creation of technological clubs and research joint ventures as institutional organizations designed to carry on collective research within selective coalitions can take place, only if appropriate information is available on the technological competence of perspective partners.

Technological signaling becomes relevant in this context as a device to reduce knowledge transaction costs. Patents are essential tools to signal the levels and the characteristics of the knowledge embodied in each organization. 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 transactions.

This approach shows that intellectual property rights increase i) the incentives to the specialization in the generation of knowledge, ii) the creation of markets for technological knowledge as a good in itself, and iii) the production of knowledge.

A strong intellectual property right regime associated with high levels of natural appropriability and codification and low levels of embeddness in the routines of the innovative firm can favor the use of markets as the appropriate governance mechanism to trade disembodied knowledge. When technological knowledge is sticky, embedded in learning process and organizational structures, and as such it is difficult to trade as a disembodied good, the trade of the property rights of the company where the knowledge has been implemented becomes an effective mechanism which favors the

division of intellectual labor as well as the distribution of knowledge and its appropriation.

A weak intellectual property right regime favors the internal usage of technological knowledge within the borders of the corporation as an intermediary input. When ex-ante and ex-post appropriability is low, firms try and valorize technological knowledge as an intermediary input. When appropriability is high, firms may specialize in the direct generation and sale of technological knowledge. When technological knowledge has high levels of fungibility, and as such applies to a wide range of products and other technologies, a strong intellectual property right regime may favor the distribution of technological knowledge. Vertical integration of technological knowledge with high levels of fungibility can lead to a reduced spectrum of applications because of fast-increasing internal coordination costs

The new assessment of the informational role of intellectual property rights in terms of increased incentives to the production and trade of knowledge 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 20th century, is fruitful in the economics of knowledge and hence in the governance of knowledge commons. 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 liability rule and the ex-post payment of royalties without the preliminary consensus of the patents holders.

The reduction of exclusive rights in the use of intellectual property associated with the effective ex-post enforcement of the liability rule can help the birth of the markets for knowledge. More efficient markets for knowledge can help reducing the costs of interactions among complementary activities. Lower networking costs can increase the scope for the valorization of external knowledge complementarities. Easier access to external knowledge complementarities can increase the amount of externalities and hence the levels of technological knowledge firms can rely upon. The final effect is clearly

the generalized reduction of production costs and hence the increased levels of welfare.

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Endnotes

[1] A preliminary elaboration along these lines can be found in Antonelli (2002) and in the commentaries of the author in Geuna, Salter, Steinmueller (2003)

[2] A closer look to the working of the public commons and the actual need to put under scrutiny the productivity of the resources invested in the public knowledge commons, both at the system and the single units level, is advocated (Jaffe and Lerner, 2001).

[3] The introduction of a prize system has been advocated in this context as a possible alternative to patents as the proper incentive to the generation of technological knowledge

[4] The case of numerical control provides the full range of cases. The technology of numerical control can be sold as a patent or a license. It can be sold embodied in software, in the numerical control itself or finally it can be embodied in a machine tool with numerical control. The machine tool in turn can be sold as such or it can be used as a capital good in the production of car and trucks. The engineering industries and specifically the packaging and textile machinery industry provide similar evidence. The chemical industry is characterized by similar trend with the identification of companies specialized in the supply of the design for chemical plants, as well as by companies that coordinate the competence in the design and the deliver of the plants themselves. Finally important companies in the chemical industries operate the full 'filière' of activities from the design of the plants, to their construction, to their use for delivering the products to the markets.

[5] The distinction between procedural and content contracts is relevant here. Procedural contracts are incomplete contracts designed to specify the modality of the interaction while content contract focus the characteristics of the actual transaction. It is in fact possible to implement and eventually to enforce specific procedural contracts about the process of participation and timing of assignment of property rights, temporary and partial exclusivity, time lags and partial and discriminated domains of

privilege to subsets of contributors, selected according both to the amount of inputs and to the actual results (Menard, 2000).

[6] A notion of decreasing returns to scale in coordination activities with respect to the variety of modules seems plausible from an empirical viewpoint (See Argyres 1995 and Chandler 1990).

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