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MODELS OF KNOWLEDGE AND SYSTEMS OF GOVERNANCE

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MODELS OF KNOWLEDGE AND SYSTEMS OF GOVERNANCE[1]

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ABSTRACT. The analysis of the main features of knowledge, in terms of domain, characteristics and processes makes it possible to trace significant shifts in the economics of knowledge. Changing emphasis about the role of knowledge appropriability, divisibility and tradability has provided different solutions to the knowledge trade-off. Three different and rival concepts of technological knowledge can be identified: a) knowledge as a public good, b) knowledge as a proprietary good, c) knowledge as a localized, collective and complex, path dependent activity. Such a shift has relevant implications in terms of governance mechanisms, strategic attitude of agents and public policy making.

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KEY WORDS: Knowledge appropriability, divisibility and tradability, Knowledge externalities, Collective knowledge, Localized technological knowledge, Knowledge interactions, transactions and communication, Path dependent complex systems.

1. INTRODUCTION

The economics of knowledge has gradually emerged as a discipline in a context characterized by a sharp evolution of the analysis as well as of the basic foundations. Such an evolution has made it possible to increase substantially our understanding of the economic characteristics of the generation and use of knowledge in the economic systems. Its evolution is the consequence and the cause of much change in the economic understanding of technological change and more generally in the new thinking about economic growth. This work provides an analysis of the changing foundations of the economics of knowledge and of their effects upon the assessment of the design, the characteristics and the performances of the institutions and processes that shape the generation and distribution of technological knowledge. The ongoing debates on science and technology policy often reveal that inappropriate analytical conceptions can lead to significant errors in terms of institutional design.

2. KNOWLEDGE AS A PUBLIC GOOD

The seminal contributions of Kenneth Arrow and Richard Nelson have marked for more than twenty years the economics of knowledge, since the late 50s. The Arrovian frame shaped the debate about the economic organization for the supply of knowledge and provided the theoretical foundations for the build-up of the public knowledge commons.

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In the Arrovian approach technological knowledge was seen as a public good for the high levels of indivisibility, non-excludability, non-exhaustibility, non-appropriability and hence non-tradability. In this context markets fail to provide the necessary coordination and the case for undersupply takes place. Markets are not able to provide the appropriate levels of knowledge because of the lack of incentives, and the opportunities for implementing the division of labor and hence achieving adequate levels of specialization (See table 1 for a synthesis of the main arguments).

The public provision of technological knowledge, and especially scientific knowledge has long been regarded as the basic remedy to under-provision. This led to the actual build-up and the systematic implementation of public knowledge commons. The legacy of patronage, such as universities and other public research centers received new endorsement and support (Arrow, 1962; Nelson, 1959).

The key role of the public knowledge commons, based upon the public funding of universities and other public research centers was also consistent with the top-down view about the generation of technological knowledge. In the linear approach in fact technological knowledge was the eventual result of the application of new scientific discoveries. In the linear model a clear division of labor could be articulated between the role of universities and corporations. Universities and public research centers were better equipped to perform scientific research. The eventual application of scientific discoveries for the actual generation of technological knowledge and the introduction of technological innovations was instead assigned to corporations.

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 was the third basic tool to increase the production of knowledge. The demand for weapons especially was regarded as 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 – was expected to feed the levels of technological opportunity for the rest of the system.

The Arrovian approach was consistent with the neoclassical views about the exogeneity of technological change. New scientific discoveries and eventual advances in technological knowledge could not be regarded as the endogenous product of economic decision making, but as the result of a sphere of human activity that could not be approached with the tools and the instruments of economic analysis. Actually the Arrovian approach provided good economic foundations to the neoclassical assumptions about exogeneity. The limitations of knowledge as an economic good were such that economics could not provide basic assistance in understanding the process by means of which scientific knowledge was produced.

The notion of technological opportunities easily integrated also 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 stemming from new technological opportunities. Because of the low levels of natural appropriability, financial markets perform poorly in providing the necessary amount of external funds to firms undertaking research activities. Financial markets and specifically banks are most likely to ration the credit to innovation both because of radical uncertainty and low appropriability. Even when a research project finally generates a new bit of knowledge, the risks that the inventor, and hence the banker who provided the funds, is able to reap the benefits are put at stake by non-appropriability. Non-appropriability leads to non-fundability (Stiglitz and Weiss, 1981).

Nelson (1959) stresses the positive role of large corporations for their higher scope of action across product markets. High levels of unpredictability of the results of research activities and even lower levels of predictability about the specific applications of the new knowledge characterize the production of knowledge. Large firms can better exploit the results of scientific and technological knowledge by means of diversification strategies in markets where the knowledge generated happens to command larger rewards. From this viewpoint the notion of barriers to mobility, introduced by Caves and Porter (1977), is especially relevant. Large corporations, as incumbents in adjacent markets, have much lower barriers to mobility across product markets.

KNOWLEDGE AS A PUBLIC GOOD (TABLE 1)

CHARACTERISTICS	**NON-APPROPRIABILITY** **NON-EXCLUDABILITY** **NON-PREDICTABILITY OF RESULTS AND APPLICATIONS** **NON-RIVALITY IN USE** **NON-DIVISIBILITY** **NON-EXHAUSTIBILITY** **NON-TRADABILITY** **NON-FUNDABILITY**
PROCESSES	**DEDUCTIVE PROCESS** **LINEAR SYSTEM** **TOP-DOWN** **RESEARCH&DEVELOPMENT**
CORPORATE GOVERNANCE	**LARGE CORPORATION** **EX-ANTE BARRIERS TO ENTRY** **INTERNAL FINANCIAL MARKETS**
POLICY	**KNOWLEDGE COMMONS** **PUBLIC PROCUREMENT** **PUBLIC SUBSIDIES** **NARROW SCOPE PATENTS**
DOMAIN	**NATION STATE**
LIMITATIONS	**POOR INCENTIVES** **LOW TRANSPARENCY** **POOR ALLOCATION** **POOR MONITORING** **POOR DISSEMINATION** **INTERNATIONAL FREERIDING**

The foundations of the well-known Schumpeterian trade-off between static and dynamic efficiency are laid down in this context. Monopoly reduces static efficiency, but makes it possible, via extra profits and increased ex-post appropriability based on barriers to entry and hence imitation, the dynamic efficiency engendered by the increased amount of knowledge generated and hence the augmented flow of innovations.

The creation of intellectual property rights was regarded as a complementary institutional set-up, parallel to the public provision of scientific knowledge and the benign neglect to monopolistic market power. Patents and copyrights 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).

At this time in fact intellectual property rights are not considered as 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 (Machlup and Penrose, 1950; Alchian and Demsetz, 1973).

3. 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 (Nelson and Winter, 1982).

In this new approach, the distinctions between science and technology are blurred and the traditional sequence is actually reversed. Scientific knowledge can be considered as the ultimate result of an inductive process of articulation and codification of knowledge originated in a tacit form and acquired by means of learning processes. Here the work of Polanyi becomes a basic reference. The distinction between tacit and codified knowledge provides in fact the foundation to the new approach to technological knowledge (See table 2 for a synthesis of the main arguments).

Tacit knowledge is the result of learning processes: it is not easy to articulate it and to make it explicit. It cannot be shared and applied outside from its original 'locus' of generation. The eventual articulation makes generalization possible. The final end-outcome of a bottom-up process of systematization and generalization is the full codification and hence the generation of scientific knowledge. Scientific knowledge follows technological knowledge rather than preceding it. Knowledge emerges out of the inductive process of abstraction and generalization rather than from the deductive process of application of general ideas to specific circumstances. Because technological knowledge is now viewed as the sticky joint product of internal learning, it cannot spill freely in the air: appropriability is de-facto secured by high levels of stickiness in routines and procedures. 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 not-invented-here syndrome is much more effective than assumed in the public good tradition (Mansfield, Schwartz, Wagner, 1981; Von Hippel, 1988; Harabi, 1995).

The theory of the firm is deeply affected by the new approach. The accumulation of competence, technological and organizational knowledge and the eventual introduction of technological and organizational innovations are now considered the essential role of the firm. The firm does not coincide with the production function and cannot be reduced to a production function. 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. Edith Penrose marks an important contribution to implementing this approach with the identification of the sequence of developing new knowledge as a resource, conceiving of new services which it could deliver and imagining new productive opportunities. In so doing Penrose provides a direct link between the notion of learning and the emergence of novelty within firms (Penrose, 1959).

The resource-based theory of the firm focuses the attention 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 system. In this context the firm is the primary, if not the single, 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. Firms, especially large corporations, are considered, in this approach, primarily as a depository and a generator of competence and eventually knowledge (Chandler, 1990).

The new growth theory builds upon the new appreciation of de-facto appropriability arguing that the economic rents of knowledge can be substantially appropriated, at least to such an extent that firms can fund correct levels of research and development expenditures. According to much new theorizing, the characteristics of knowledge are no longer regarded as conducive to market failure. Markets are able to allocate viable amounts of resources to fund the generation of knowledge. The optimum however cannot be identified by market forces (Romer, 1986; Aghion and Tirole, 1994).

On a parallel and complementary ground, evolutionary theory stresses not only the role of the firms as the locus of accumulation and generation of technological knowledge, but also the market place as the proper selection mechanism. The selection in the market place among competing bits of knowledge and related innovations that impinge upon them makes it possible to fully endogenize the rate and the direction of technological knowledge. The supply of knowledge and its selection can be considered as two different and yet related steps.

In this context, intellectual property rights play an important role to create the institutional conditions to secure appropriability and hence to increase the levels of incentives to fund research activities by firms. Intellectual property rights, if properly designed, may also favour tradability and hence lead to higher levels of specialization and division of labour. Trade in knowledge is now regarded as a major opportunity to achieving the well known advantages of market coordination in terms of division of labour, specialization and selection. A huge literature explores the evidence about the growing flows of trade in patents and licences both in international and domestic markets (Geroski, 1995; Arora, Fosfuri and Gambardella, 2001).

The new approach is also fed by growing concern about the limitations in the governance of the model based upon the knowledge as a public good. In that context, in fact, such issues as the criteria for the allocation of resources, the methodology for the correct monitoring of their use and the assessment of their results were missing. The case for 'government failure' is now applied to science policy as well: the risks of government failure in selecting, conducting and funding research activities are now regarded as non trivial (Buchanan, 1965). Fundamental questions were left without an answer and even worse without a methodological clue to address them. How should the levels of public funds to scientific activities be fixed? How should they be distributed among universities and scientific disciplines? How should they be delivered? How the results of the public funding should be assessed? (Kealey, 1996). The dissemination of the results of the scientific research were left to publications in scientific journals and the hiring of PhDs from the business community with little understanding of the problems of scientific dissemination and of the serious limitations to the spontaneous communication of the new scientific discoveries to the community of potential users.

The perverse effects of international free riding have been much emphasized. The international uncontrolled leakage and spillover of technological knowledge would benefit the technological strategy of laggard countries based upon fast imitation and re-engineering.

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. The general reversal of policy emphasis –which gained consensus in the 90s- from the role of public policy to the privatization of public provision inspired by the swing from the presumption that governments cam do everything that markets do and more besides to the new presumption of market efficiency, associated with rational expectations, together with the new theory about knowledge as a proprietary quasi-private good provided theoretical support to a new -problematic- understanding upon the role of public research.

As a consequence, a wave of privatizations has been taking place: Universities have been pushed to enter the markets for knowledge and knowledge outsourcing. 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 (Geuna, 1999: Geuna, Salter and Steinmueller, 2003).

Academic patenting and scientific entrepreneurship have been praised as new effective tools to stimulate the distribution of knowledge and to increase the incentives to its production. Much analysis has been carried out on the regional aspects of the interplay between the research system and the business community: geographical distance has proved a relevant factor in this context (Feldman, 1994 and 1999; Audretsch and Stephan, 1996; Audretsch and Feldman, 1996; Geuna, 1999).

The large corporation firm and its evolution into the global corporation emerge as the most appropriate tool to foster the levels of access to scientific knowledge and the rate of accumulation of technological knowledge by means of the capability to combine the selection of a few sites worldwide for the location of research facilities with a portfolio of production and commercial activities scattered in the global economy. The global corporation is able, at the same time, to generate and disseminate technological knowledge by means of the powerful internal markets, into which the international transfer of technological knowledge can take place with reduced risks of dissipation and opportunistic behaviour. Enhanced internal tradability favours the division of labour and makes it possible to reap the benefit of specialization (Cantwell and Iammarino, 2003)

Special attention is paid to the opportunities provided by financial market as an institution for the exchange of property rights of new innovative companies. The role of IPO (Initial Public Offerings) as a way to convey financial resources into new ventures and at the same time to assess and select the choices of venture capital receives much attention (Gompers and Lerner, 2003).

This evolution of financial markets marks a major shift with respect to the traditional emphasis on the limits of financial markets. In the previous approach the stock exchange did not play a role and only credit was considered. Bankers were supposed to be reluctant in providing credit to risky ventures based on research activities and innovation. The case for credit rationing emerged as a major problem to fund innovation activities. In turn, targeted credit rationing in financial markets stressed the role of internal financial markets and extra profits to fund internally research activities that bankers could not properly fund because of the lack of instruments able to generate and assess the necessary information on the risks and the eventual pay-off of investments in research activities (Stiglitz and Weiss, 1981).

KNOWLEDGE AS A PROPRIETARY GOOD (TABLE 2)	
CHARACTERISTICS	**-FROM TACIT TO CODIFIED** **-STICKINESS** **-LIMITED APPROPRIABILITY** **-MODULAR DIVISIBILITY** **-FUNDABILITY BY PRIVATE EQUITY** **-LIMITED TRADABILITY**
PROCESSES	**INDUCTIVE PROCESS** **BOTTOM-UP** **LEARNING** **SPILLOVER AS A FREE GOOD**
CORPORATE GOVERNANCE	**-GLOBAL COMPANIES** **-FINANCIAL MARKETS: VENTURE CAPITAL + IPO + M&A** **-KNOWLEDGE OUTSOURCING** **-MARKETS FOR KNOWLEDGE** **-UNIVERSITY AS A KNOWLEDGE SERVICES SUPPLIER**
POLICY	**-PRIVATIZATION OF THE KNOWLEDGE COMMONS** **-STRONG&BROAD IPR**
DOMAIN	**GLOBAL MARKETS**
LIMITATIONS	**-KNOWLEDGE TRADE-OFF** **-EXCLUSION** **-CONCENTRATION**

The new emphasis on the working of financial markets as an effective and efficient tool to provide funds to innovative undertaking leads to a new assessment about the role of scientific entrepreneurship. Scientific entrepreneurship grows into a fully-fledged new viable mechanism to incentive, generate and disseminate technological knowledge in economic systems (Etzkowitz, 2002). The role of new science-based firms as converters of technological opportunities, available in science rich environments, such as Universities and large corporations, into actual market experiments is now better recognized. The dynamics of spin-off from research laboratories and the supply of funds and managerial competence by venture capitalists are now regarded as complementary tools for the eventual creation of new science-based firms. Next to the size of firms, new attention is given to their age. The complementarity between new and small and large firms is now advocated: small startups are seen as the best way for new technologies to enter the market place. Eventual mergers and takeover by larger firms will lead to the integration and dissemination of the new technologies into larger corporations.

Scientific capitalism is based upon scientific entrepreneurship, effective intellectual property rights systems, academic patenting, venture capitalism, initial public offering and financial institutions, including dedicated stock exchange systems (Nasdaq) where the new ventures can be assessed and possibly recombined with existing companies, by means of mergers and acquisitions. Technological knowledge can flow within the economic system embedded in new companies.

But, once again, the trade-off between static and dynamic efficiency emerges.

4. KNOWLEDGE AS A COLLECTIVE AND COMPLEX DYNAMIC PROCESS.

4.1. THE DISCOVERY OF THE KNOWLEDGE TRADE-OFF

The new approach is based upon the re-discovery through the 90s of external knowledge as an essential intermediary input in the production process of new knowledge. 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. This major progress is made when the special character of knowledge as a non-exhaustible good that is at the same time an output and an input into the production of other knowledge is grasped and retained at the core of the analysis. Here the derivation from the Arrovian notions of the non-excludability and non-divisibility of knowledge is clear (Griliches, 1992; David, 1993; Cooke, 2002).

The core of the new analysis is now centered upon the exploration and identification of the conditions into which external knowledge, as an essential input in the production of new knowledge and new technologies, is effectively disseminated in the economic system. This line of enquiry contributes the founding of the systems of innovation approach, where the production of knowledge is viewed as the result of both knowledge transactions and the cooperative interactions, mainly rooted in regional space, of agents undertaking complementary research activities.

The focus is now more and more centered upon the analysis of the mechanisms of governance of the broad array of knowledge interactions among agents, including coordinated division of labor and market transactions, and their effects in terms of generation and dissemination of new knowledge. An array of specific institutional arrangements emerges eventually as indispensable conditions that are necessary for the trade of such a idiosyncratic and heterogeneous good to take place in order to handle the difficulties in understanding and using the differentiated set of new knowledge modules supplied in the markets place (Menard, 2000; Guilhon, 2004). Regional economic contributes significantly the new approach highlighting effectively the role of geographic space in the distribution and circulation of knowledge and at the same time regional analysis is deeply affected by the new understanding of knowledge as a way to understand the role of geographic space (Feldman, 1994).

Here in the economics of knowledge the issues of externalities on the demand side become relevant and evident. The generation of technological knowledge is now characterized by relevant end actually necessary externalities, both technical and pecuniary. The notion of user-interdependence makes its foray into the scene when agents value the levels of usage of other agents of certain goods

(Von Hippel, 1988). 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 evidence especially in new information and communication technologies confirms that proximity matters in assessing the rates of introduction of innovation (Foray, 2004).

An important contribution to understanding the role of external knowledge is provided by an extension and implementation of the approach based upon learning processes. The competence and experience that is necessary to innovate is acquired not only in the repeated usage of a given set of capital goods and intermediary products and in the production of well-identified products. Also the experience accumulated in marketing and interacting with a well-defined set of consumers and competitors in a limited range of products, is necessary in order to generate new knowledge and eventually introduce new products. Interactions between users and producers are a primary source of tacit knowledge about the actual needs and preferences of customers (Lundvall, 1985). No successful product innovation can be effectively and successfully introduced without some dedicated competence about the market place. The distance, in the product space, from the products being traditionally delivered to the market place, can be considered a strong factor of increasing innovation costs and decreasing efficiency in the generation of innovations.

The amount of external technological knowledge, available in a given context, industrial, technological or regional, and its conditions of accessibility and proximity, becomes an important endowment, as well as the conditions of access to it and the characteristics of the relational set-up. 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).

The advantages of the intellectual property rights 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 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; David, 1993).

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). Murmann (2003) provides a fascinating account of the perverse effects of the patenting strategy pursued by Bayer on the technological development of competitors. 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, 2004).

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 (Scotchmer, 2004).

The understanding of the knowledge trade-off contributes the parallel development of a systemic approach to the understanding of the economics of technological change. In this approach the characteristics of the regional, industrial, professional and national systems play a major role in determining the rate and the direction of technological change. Technological knowledge is endogenous to the system into which each agent is rooted.

4. 2. LOCALIZED TECHNOLOGICAL KNOWLEDGE

Technological knowledge is now viewed as the outcome of the localized interactions of a variety of learning and heterogeneous agents, able to learn and to establish network relations, although in a limited range of activities, rooted in a limited technical and product space where each firm has accumulated competence by means of process of learning by doing and by using (Atkinson and Stiglitz, 1969; David, 1975; Antonelli, 1999, 2001) (See table 2 for a synthesis of the main arguments).

The retrieval of the Austrian tradition, as articulated by Hayek (1945) about the dispersion of knowledge and the complementarity of the bits of knowledge possessed by each agent as a key characteristic of economic systems, even in static conditions where technological change is not considered, contributes this line of analysis. Technological knowledge is now viewed as dispersed and fragmented into a variety of specific and idiosyncratic applications and contexts. Yet the variety of agents and of their competence is crucial for generating new knowledge. This view contrasts sharply the centralized and top-down understanding of knowledge built around the Arrovian tradition.

Firms are viewed as creative agents, who are not limited to adjusting prices to quantities and vice versa. They are also able to learn and change their technology, as well as their strategies. When actual market conditions do not match the plans and irreversibility and limited knowledge make sheer technical substitution expensive, firms are induced to introduce technological innovations. The generation of new technological knowledge is activated. The search for new knowledge takes place locally in the close surroundings of the existing activities bounded by relevant switching costs: the tacit knowledge accumulated by means of learning process is eventually valorized and articulated both internally and externally by means of network relations. More generally the generation of new technological knowledge is the result of four specific activities: learning, socialization, recombination and research and development, where both general the process and each activity is localized by the effects of bounded rationality and proximity.

These activities are complementary and none can be disposed of. A limited substitution can take place among them. In the localized technological knowledge approach, firms generate new knowledge relying on both external and internal knowledge as complementary inputs. Essential inputs of tacit, codified, internal and external knowledge all enter into a multiplicative relationship within the knowledge production function. External knowledge is strictly necessary to generate new knowledge both when it concerns the same module of knowledge and when it belongs to other knowledge modules: intra-technological and inter-technological flows of knowledge are both necessary, in varying levels according to the character of the knowledge being generated whether mainly analytical or synthetic (Laestadius, 1998). In some cases, substitution between the four different knowledge inputs is possible, but only above minimum thresholds[2].

Learning agents are scattered in space and each possesses a bit of knowledge. In turn high levels of potential complementarity characterize such bits of knowledge. The localized context of learning and action affect the chances of generating new technological knowledge because of the key role of external knowledge as an in disposable input. For the same token the similarity and alignment of individual learning processes play an important role in the collective undertaking that leads to the generation of new knowledge: dynamic coordination becomes a central issue (Richardson, 1972).

Because of bounded rationality and switching costs, proximity matters in many different ways. Proximity matters in regional space, as well as in technical, professional and industrial space. Proximity of firms to large research laboratories, and academic centers, is now regarded as a vital condition for the successful introduction of new technologies. Proximity in product space matters as the prime source of information about the tastes of customers and their potential interests. Proximity matters in the product space as a factor, which makes the acquisition of information and eventually knowledge easier with respect not only to the habits and preferences of customers but also to the capabilities of competitors and their strategic attitude. The introduction of product innovations in market niches that are far away from the source of the experience of each firm is put at risk by the lack of specific competence and relevant, additional costs should be recognized (Boschma, 2005).

Variety is the second key factor in enhancing the chances of generation of new knowledge. Too much cognitive proximity among learning agents can affect the capability of the system to engender successful innovation. Variety of complementary competence is key in assessing the innovation capabilities both at the firm and the system level (Nooteboom, 2000).

The key distinction between receptivity and absorptive capabilities as distinct from the strength and intensity of the message plays a key role in this context. The topological structure of economic systems from the viewpoint of the knowledge communication flows and interaction networks receives much attention: the structure of the communication channels is analyzed and the organization of communication flows within the networks of relations appreciated (Cohen and Levinthal, 1990).

The role of communication and transmission of knowledge is more and more appreciated. Communication theory is applied successfully to the analysis of knowledge communication processes. The density of communication channels and their duration are considered as relevant structural elements of an economic system. The role of business interactions is now appreciated from the viewpoint of their communication role. Prices, of course, are no longer viewed as the single vectors of all relevant information for economic decision making. Next to prices in fact, vital information is transferred and contributes the generation of knowledge by each economic agent. The communication of bits of knowledge in other words is not considered as obvious and spontaneous, but on the opposite, it is viewed as the result of intentional efforts both in terms of connectivity and receptivity. Systems differ with respect to the speed and capillarity of the flows of knowledge communication. In turn the rate of generation of new knowledge and introduction of

[2] This approach differs from that of Nonaka and Takeuchi (1995) also shared by Cowan, Foray and David (2000) according to which tacit knowledge eventually coverts fully into codified knowledge. On the opposite it is argued here that tacit knowledge remains an essential and non-disposable input which can be never fully codified.

new technologies is clearly influenced by the permeability of the system. Percolation analysis borrowed from physics and communication theory is introduced in the economics of knowledge so as to provide tools to appreciate the distinctive role of receptivity and connectivity in knowledge communication processes. According to the acquisitions of the localized approach, the firm cannot be seen as the single actor in the process of generation of new knowledge. The assumptions about the complementarity between internal and external knowledge play a key role in this context. The variety of firms and learning institutions is most important in the generation and circulation of knowledge when the latter is viewed as a collective good, with varying degrees of appropriability, dispersed and fragmented in the economic system, the result of both top down and bottom up processes, where learning by doing, learning by using and learning by interacting with suppliers, customers and rivals play an essential role, together with research and development activities (Antonelli, 1999).

Knowledge is now, more and more, viewed as a collective process activity made possible by the continual efforts of accumulation of the highly differentiated competence and technological knowledge, based upon localized learning processes and the eventual introduction of innovations, of a myriad of heterogeneous and interacting agents rooted in a well defined set of scientific, technical, geographic, economic and commercial circumstances. The capability to generate knowledge is embedded in a network of qualified relations, limited by relevant switching costs, bounded rationality and limited information. The notion of collective process differs sharply both with respect to the Arrovian tradition of knowledge as a public good and the approach to knowledge as a quasi-private good. Collective processes in fact are characterized not only by partial appropriability and shared property rights but also by the role of the intentional effort, participation and contribution of each agent. Collective knowledge is more than a club good for two important reasons: first knowledge is an activity, rather than a good, for the continual efforts of acquisition and implementation it requires and second because of the increasing returns which can take place when and if the dynamic coordination of stochastic processes make it possible to take advantage of potential knowledge complementarities (Buchanan, 1965; Allen, 1983).

Collective knowledge in other words is a shared activity that can be implemented only by interactive agents that belong to a community of practice and understanding. Collective knowledge pays attention to the consequences of knowledge indivisibility and the role of the complementarity among the localized bits of knowledge possessed by each agent that characterize both the generation and the dissemination of knowledge in the system and value the contribution of external knowledge into the production of new knowledge. The network structure of knowledge communication networks affects deeply the flows of knowledge communication and hence the actual availability of external knowledge. There is an array of possible network architectures. In geodesic networks, i.e. networks where each agent has a direct link to each other agent, communication costs are very high: the dissemination of new knowledge is hampered by relevant communication costs and by the decay of knowledge spillovers associated with distance and heterogeneity among agents. Within centered networks based upon many interconnected and hence competitive hubs, knowledge is disseminated far better than in fragmented networks, where only a few links connect scattered clusters or in networks based upon monopolistic hubs able to exert a control upon knowledge flows and to extract rents out of it.

In this context it is clear that the issue of dynamic coordination of the interdependent activities of the myriad of complementary learning agents involved and the related design of network architecture that shape the flows of communications and the interaction modes, including transactions in the market place, become most relevant (Richardson, 1972).

LOCALIZED KNOWLEDGE AS A COLLECTIVE ACTIVITY (TABLE 3)	
FORMS AND CHARACTERISTICS	**- ARTICULABLE -DISPERSED & FRAGMENTED -MODULAR COMPLEMENTARITY - CUMULABILITY - COMPLEXITY - FUNGIBILITY - KNOWLEDGE PATH DEPEDENCE**
PROCESSES	**-INTERACTION BETWEEN INDUCTION AND DEDUCTION - COMPLEMENTARITY of EXTERNAL INTRATECHNOLOGICAL AND INTERTECHNOLOGICAL, INTERNAL, TACIT, CODIFIED KNOWLEDGE -RESEARCH -LEARNING -EXPLORATION -COMMUNICATION -ABSORPTION -RECOMBINATION -SOCIALIZATION**
CORPORATE GOVERNANCE	**- KNOWLEDGE NETWORKS - EPISTEMIC COMMUNITIES -TECHNOLOGICAL DISTRICTS -JOINT VENTURES -KIBS -OUTSOURCING -TECHNOLOGICAL PLATFORMS -SPONSORED SPIN-OFF -PATENT THICKETING -VENTURE CAPITALISTS AS KNOWLEDGE PROVIDERS -MULTIPLE EXPLOITATION: TO SELL OR TO USE**
PUBLIC POLICY TOWARDS DYNAMIC COORDINATION	**-PUBLIC PROVISION OF FUNGIBLE KNOWLEDGE -CREDIBLE ANNOUNCEMENTS ABOUT LONG TERM RESEARCH GOALS -INTERFACE AGENCIES -KNOWLEDGE AS AN ESSENTIAL FACILITY**

Within knowledge networks localized technological knowledge can be understood as a collective activity characterized by the complementarity between heterogeneous and yet complementary items. Such complementarity takes place especially between external and internal knowledge and the stock of existing knowledge and the flows of new knowledge. The implications of the indivisibility are reconsidered.

A number of key questions is to be addressed in this context: whether economic systems are able to generate and implement the perfect network architecture; whether spontaneous multitask interaction of heterogeneous agents active in a variety of markets and embedded in a variety of contexts can actually lead to the 'perfect' design. The difference in the time scale of the flows of knowledge among the agents within the networks of communication channels existing at each point in time and their duration and the time required for their implementation and incremental construction becomes a relevant factor in assessing the emergence of appropriate network structures.

4.3. KNOWLEDGE AS A PATH DEPENDENT EMERGENT PROPERTY: AN AGENDA FOR A POLICY TOWARDS DYNAMIC COORDINATION

Path dependent complex system dynamics provides a major opportunity to articulate the indeterminacies of the interplay among supply and demand externalities into which traditional economics of knowledge stumbles.

In the localized approach developed so far, four characteristics of knowledge matter:

A) at each point in time knowledge is dispersed and fragmented, scattered among a myriad of learning agents;
B) no agent can possess and control all the knowledge available at each point in time; the complementarity among modules of knowledge possessed by each agent is relevant: its valorization provides the opportunity to generate new radical advances;
C) proximity among agents is relevant for the complementarity among external and internal knowledge, as well as among the learning efforts of each agent and the modules of knowledge possessed by each agent, to be implemented;
D) finally, and most important, agents can learn and make intentional efforts to generate new knowledge including intentional strategies, based upon procedural rationality, to modify locally, because of switching costs, their position within the knowledge networks. Such efforts take place when the dynamics of localized technological change exerts its effects and agents need to change their current techniques.

In this context, the conditions, which characterize the access to external knowledge, play a key role in explaining the innovation capability of agents within a system. At each point in time the topology of agents in the space of knowledge, hence their relative distance and the structure of their relations and interactions are key features of the system. Accessibility of external knowledge and hence the scope to implement the potential complementarities of the knowledge possessed by each agent are influenced by the channels and flows of communication in place at each point in time. So far the typical frame for complex system dynamics is set. Occasional stimulations -such as the mismatch between plans and actual market conditions and the incentive to introduce localized technological change- push agents to generate new knowledge. In so doing the links in place provide access to external knowledge. According to an array of parameters, such as the existing topology, the distance among learning agents, the stock of communication channels in place, their connectivity, the receptivity of co-localized agents and hence the complementarities of their internal modules of knowledge and the structure of stochastic effects of such relations, some agents in some regions are more successful than others. Eventually the process can spread across regions and the full map is finally covered.

Complex system dynamics provides an analytical framework into which our analysis can be accommodated with some qualification. Kauffman (1993) provides a path breaking definition of complexity based upon the interaction of size and interdependence, which fits very well in this approach to the economics of knowledge. Kauffman elaborates a model of complexity based on two parameters, N, the number of components comprising a whole, and K, the degree of interdependence among these components. In this context, complexity is defined as the number of components of a certain piece of knowledge and the degree of interaction between them. In so doing, indeed complexity provides a general context into which the generation of knowledge can be viewed as a collective process undertaken by a myriad of interacting and complementary agents. So far knowledge generation shares the characteristics of an emergent property.

With respect to standard complex system dynamics[3], economic analysis cannot forget two major aspects that are intrinsic to economics and often bypassed by superficial applications of models drawn from physics. First, the scope for intentional action of agents matters. Agents are indeed affected by bounded rationality and myopic capabilities, nevertheless they can act, albeit locally because of the limits of switching costs and procedural rationality, and build connections, create communication channels, implement their connectivity, align their receptivity and especially direct their learning efforts towards fields of knowledge practiced by agents that are localized and yet rich in terms of potential integrations with external pools of knowledge. In so doing agents are expected to try and maximize the expected, although myopically, profitability of their intentional activities[4]. Second, and most important, market selection is at work. Within a given topology of agents and hence a given density in a map of distances among agents and related structure of communication channels and communication flows, some agents can happen to align their learning capabilities and direct their communication efforts better than others, or simply in a more effective way than others, even by chance, if not by mistake. Such agents will nevertheless experience faster rates of generation of new technological knowledge and hence faster rates of introduction of localized innovations. Market selection will appraise such events. In both cases the effects of profit maximization do change the course of events as anticipated by the sheer adaptive and stochastic dynamics of complex systems where blind agents are not able to anticipate the course of their actions and the market is never able to select the direction of their actions. It is clear that the metaphor of stochastic action within a symmetric lattice is not appropriate to account for the intentional activity of economic agents within an economic system: such a behavior can be appropriate to analyze the conduct of ants, but not of human agents that are credited to be creative and able of intentional, albeit myopic, action both with respect to the generation of knowledge and to their location in the space of knowledge (Antonelli, 2003)[5].

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[3] The results of this analysis are consistent with complex dynamic system approach. The latter builds upon five basic elements: I) individual and hence heterogeneous agents with specific characteristics are elements of a system and their action is characterized by systemic interdependence; II) the distribution of agents in a multidimensional space is essential to understanding the dynamic behavior of the system; III) each agent has access only to local information and local knowledge, i.e. no agent knows what every other agent knows; IV) agents are embedded within multidimensional topological spaces shaped by networks of relations, ranging a variety of interactions, transactions and communication channels that affect locally their behavior; V) agents are creative, i.e. agents can change the rules of their behavior. In standard complex dynamic system methodology the topology of the system into which firms are embedded plays a key role: it can change but only as the result of stochastic processes but the intentional action of agents is rarely accommodated (Rosser, 2004).

[4] See (Barabasi, 2002) for a convincing analysis of the emergence of scale-free networks as the result of the convergence in a hub of qualified relations of the micromobility of agents aware of the opportunities of local commons of collective knowledge.

[5] See Hayek (1945:520): "It seems to me that many of the current disputes with regard to both economic theory and economic policy have their common origin in a misconception about the nature of the economic problem of society. This misconception in turn is due to an erroneous transfer to social phenomena of the habits of thought we have developed in dealing with the phenomena of nature".

Path dependence seems in this context the single approach, which can help understanding the dynamics of the process. The approach to path dependence considers creative agents, that at each point in time, are both learning and capable of intentional action and yet under the constraints of the effects of irreversibility and local externalities. The topology of the space exists as much as the array of its characteristics such as the structure of communication channels in place, their connectivity and receptivity, the structure of relations and interactions which build upon the connections in place. Agents however, within such a context, are both able to generate new knowledge and also to change the topology at each point in time. Path dependence provides the framework to understand such a twin dynamics, the dynamics of the generation of new knowledge and the dynamics of structural change of the topology within which agents operate.

The issues of dynamic coordination are clearly central in this context and hence the related key notion of governance. Systems where agents are better able to achieve dynamic coordination are likely to experience faster rates of generation of new technological knowledge and hence faster rates of introduction of technological innovations. By means of dynamic coordination, missing links among key complementary modules of knowledge can be built, effective alignment of agents towards a common design able to enhance the potential complementarities among the learning agents can be practiced (Richardson, 1998; Amendola and Gaffard, 1988).

The role of the State in the provision of inputs for dynamic coordination can now be fully appreciated. The State can play a key role for the emergence of dynamic coordination among the variety of heterogeneous players involved in the generation of knowledge as a collective, complex and path dependent process. Specifically the State can specialize in the direct supply of knowledge, by means of University and Public research centers, only when it has high levels of fungeability, that is, knowledge with a wide scope of applications in a broad array of activities and high levels of incremental enrichment. Second the State can favor the activity of interface bodies that have the specific mission to increase the dissemination of scientific knowledge and its communication to potential users. This role is especially important when codified knowledge generated in scientific bodies can feed the generation of technological knowledge by means of recombination within firms. The announcement of important, long-term programs of scientific and technological research where a broad array of public agencies is involved is a third major line of activity. Here credible announcements can favor the alignment of the research activities of a myriad of firms and hence the emergence of complementarity and interoperability. Finally, the State can favor the reduction of the exclusivity associated with intellectual property rights especially when knowledge cumulability matters and hence the chances to generate new technological knowledge depend heavily upon the access condition to pre-existing knowledge. The public implementation of the access conditions to such knowledge, viewed as an essential facility, is key to achieving dynamic efficiency in the generation of new knowledge.

The implications of the notion of knowledge as a path dependent, complex and collective process pave the way to a brand new approach to public research policy, well distinct from the role of generalized supplier of knowledge as a public good and the role of enforcement of exclusive intellectual property rights associated with the notion of knowledge as a quasi-private good.

5. CONCLUSION

Major changes have occurred in the economic understanding of knowledge in the second part of the XX century. Knowledge has first been 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, through the 60s and 70s, to the build-up of the infrastructure for the public provision of knowledge. Consensus on the analysis of the public good character of knowledge has first been contrasted and eventually substituted by the new argument about the quasi-private nature of technological knowledge. The privatization of the knowledge commons and the new reliance on the markets for knowledge, as a private good, emerges as the second model of governance, since the early 8os and through the 90s. Intellectual property rights and the new organization of financial markets based on the direct access of new high-tech companies to the stock exchange become important tools for the governance of technological knowledge. The identification of the central role of external knowledge in the production of new knowledge marks the third step. The 're-discovery' of the knowledge trade-off, towards the end of the century, stressed the key role of its dissemination and highlighted the limitations of intellectual property rights. Eventually a view of knowledge as collective and path dependent complex process has emerged: it is based upon a deeper analysis of the interaction of the generation and distribution of knowledge, the appreciation of the role of the variety of learning and creative agents, the understanding of their complementarity and systemic interdependence, in a context where prices do not and cannot convey all the relevant information. This third approach has made possible to grasp the relevance of path dependence and dynamic coordination within complex system dynamics.

The appreciation of the different forms and characteristics of knowledge makes it possible a closer analysis of the role of knowledge interactions and transactions as aspects of a broader governance problem which includes strategic behavior at the firm level, the evolution of specific institution and policy interventions. This debate has important consequences on the analysis, the design and the implementation and of the institutional architectures best suited to favor the generation and distribution of knowledge.

References

Aghion, P. and Howitt, P. (1998), *Endogenous growth theory*, Cambridge, The MIT Press.

Alchian, A. and Demsetz, H. (1973), The property rights paradigm, *Journal of Economic History* 33, 16-27.

Allen, R. C. (1983) Collective invention. *Journal of Economic Behaviour and Organization* 4, 1-24.

Amendola, M. and Gaffard, J. L (1988), *The innovative choice. An economic analysis of the dynamics of technology,* Basil Blackwell, Oxford.

Antonelli, C. (1999), *The microdynamics of technological change*, London, Routledge.

Antonelli, C. (2001*), The microeconomics of technological systems,* Oxford University Press, Oxford.

Antonelli, C. (2003), *The economics of innovation, new technologies and structural change*, London, Routledge.

Arora, A., Fosfuri, A. and Gambardella, A. (2001), *Markets for technology*, Cambridge, MIT Press.

Arrow, K. J. (1962), Economic welfare and the allocation of resources for invention, in Nelson, R. R. (ed.) *The rate and direction of inventive activity: Economic and social factors,* Princeton, Princeton University Press for N.B.E.R. pp.609-625.

Arrow, K. J. (1969), Classificatory notes on the production and transmission of technical knowledge*, American Economic Review* 59, 29-35.

Atkinson, A. B. and Stiglitz, J.E. (1969), A new view of technological change, *Economic Journal* 79, 573-578.

Audretsch, D. B. and Feldman, M. (1996), Spillovers and the geography of innovation and production, *American Economic Review* 86, 630-640.

Audretsch, D. B. and Stephan, P. E. (1996), Company-scientist locational links: The case of biotechnology, *American Economic Review* 86, 641-652.

Avimelech, G. and Teubal, M. (2004), Venture capital start-up co-evolution and the emergence and development of Israel's new high tech cluster*, Economics of Innovation and New Technology* 13, 33-60.

Barabasi, A.L. (2002), *Linked. How everything is connected to everything else and what it means for business, science and everyday life*, Plume, New York.

Boschma, R. A. (2005), Proximity and innovation: A critical assessment, *Regional Studies* 39, 61-74.

Buchanan, J.M. (1965), An economic theory of clubs, *Economica* 34, 1-14.

Cantwell, J. And Iammarino, S. (2003*, Multinational corporations and European regional systems of innovation*, London, Routledge.

Caves, R.E. and Porter, M.E. (1977), From entry barriers to mobility barriers: Conjectural decision and contrived deterrence to new competition, *Quarterly Journal of Economics* 91, 241-261

Chandler, A. D. (1990), *Scale and scope: The dynamics of industrial capitalism*, Cambridge, The Belknap Press.

Cohen, W.M. and Levinthal, D.A. (1990), Absorptive capacity: A new perspective on learning and innovation, *Administrative Science Quarterly* 35, 128-152.

Cooke, P. (2002), *Knowledge economies*, London, Routledge.

Cowan, R., David, P.A. and Foray, D. (2000), The explicit economics of knowledge codification and tacitness, *Industrial and Corporate Change* 9, 211-253.

David, P.A. (1975), *Technical choice innovation and economic growth,* Cambridge University Press, Cambridge.

David, P. A. (1993), Knowledge property and the system dynamics of technological change, in Summers, L. and Shah, S. (eds), *Proceedings of the World Bank Annual Conference on Development Economics.* Washington, The World Bank, pp. 215-248.

Etzkowitz, H. (2002), *MIT and the rise of entrepreneurial science*, London, Routledge.

Feldman, M. P. (1994), *The Geography of Innovation,* Dordrecht, Kluwer Academic Publishers.

Foray, D. (2004), *The economics of knowledge*, The MIT Press, Cambridge

Freeman, C. (1991), Networks of innovators: A synthesis of research issues, *Research Policy* 20, 499-514.

Geroski, P. (1995), Markets for technology, in Stoneman, P. (ed.), *Handbook of the economics of innovation and new technology,* Oxford, Basil Blackwell, pp. 90-131.

Geuna, A. (1999), *The economics of knowledge production*, Cheltenham, Elgar.

Geuna, A., Salter, A. and Steinmueller, W.E. (eds.) (2003), *Science and innovation. Rethinking the rationales for funding and governance*, Cheltenham, Edward Elgar.

Gompers, P. and Lerner, J. (1999), *The venture capital cycle*, Cambridge, The MIT Press.

Griliches, Z. (1992), The search for R&D spillovers, *Scandinavian Journal of Economics* 94, 29-47.

Guilhon, B. (2004), Markets for knowledge: problems, scope and economic implications, *Economics of Innovation and New Technology* 13, 165-182.

Harabi, N. (1995), Appropriability of technical innovations: An empirical analysis' *Research Policy* 24, 981-992.

Hayek, F. A. (1945), The use of knowledge in society, *American Economic Review* 35, 519-530.

Kauffman, S.A. (1993), *The origins of order. Self-organization and selection in evolution*, Oxford University Press, Oxford.

Kealey, T. (1996), *The Economic Laws of Scientific Research*, London Macmillan Press Ltd.

Kingston, W. (2001), Innovation needs patents reforms, *Research Policy* 30, 403-423.

Laestadius, S. (1998), Technology level, knowledge formation and industrial competence in paper manufacturing, in Eliasson, G. et al. (eds.) *Microfoundations of economic growth*, The University of Michigan Press, Ann Arbour, pp. 212-226.

Lundvall, B.A. (1985), *Product innovation and user-producer interaction*, Aalborg University Press.

Machlup, F. and Penrose, E. (1950), The patent controversy in the nineteenth century, *Journal of Economic History* 10, 1-20.

Mansfield, E., Schwartz, M., and Wagner, S. (1981), Imitation costs and patents: an empirical study, *Economic Journal* 91, 907-918.

Mazzoleni, R. and Nelson, R.R. (1998), The benefits and the costs of strong patent protection: A contribution to the current debate, *Research Policy* 27, 273-284.

Menard, C. (ed.) (2000), *Institutions contracts and organizations. Perspectives from new institutional economics*, Cheltenham, Elgar.

Murmann, P. (2003) *Knowledge and competitive advantage*, Cambridge, Cambridge University Press.

Nelson, R.R. (1959), The simple economics of basic scientific research, *Journal of Political Economy* 67, 297-306.

Nelson, R.R. (ed.) (1993), *National systems of innovation*, Oxford, Oxford University Press.

Nelson, R. R. and Winter S.G. (1982), *An evolutionary theory of economic change*, Cambridge, Harvard University Press,

Nonaka, I. and Takeuchi, H. (1995), *The knowledge-creating company*, Oxford, Oxford University Press.

Nooteboom, B. (2000), *Learning and innovation in organizations and economics*, Oxford, Oxford University Press.

Penrose, E.T. (1959), *The theory of the growth of the firm*, Oxford, Basil Blackwell.

Richardson, G. B. (1972), The organization of industry, *Economic Journal* 82, 883-896.

Richardson, G.B. (1998), *The economics of imperfect knowledge*, Edward Elgar, Cheltenham.

Romer, P.M. (1986), Increasing returns and long-run economic growth, *Journal of Political Economy* 94, 1002-37.

Rosser, Jr J.B. (2004) Complexity in economics, Cheltenham, Edward Elgar.

Scotchmer, S. (2004*), Innovation and incentives*, Cambridge, MIT Press.

Stiglitz, J.E. and Weiss, A. (1981), Credit rationing in markets with imperfect information, *American Economic Review* 71, 912-927.

Von Hippel, E. (1988), *The sources of innovation*, Oxford, Oxford University Press.