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KNOWLEDGE COMPLEMENTARITY AND FUNGEABILITY: IMPLICATIONS FOR REGIONAL STRATEGY

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KNOWLEDGE COMPLEMENTARITY AND FUNGEABILITY: IMPLICATIONS FOR REGIONAL STRATEGY[1]

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ABSTRACT
Complexity and fungeability are two specific aspects of knowledge indivisibility. Complexity matters when the production of new knowledge requires the combination of diverse and yet complementary bits of knowledge. Fungeability is found when some units of knowledge can apply in a variety of different contexts, different products and different processes. Both knowledge complexity and knowledge fungeability are the cause of increasing returns in the generation of knowledge. The governance of the distribution of knowledge instead is affected by decreasing returns to the variety of elements of knowledge. Exchanges in the markets for knowledge are limited by transaction costs. Internalization of different bits of knowledge is constrained by coordination costs. Firms can take advantage of knowledge complexity and fungeability by means of networking in regional space.

KEY-WORDS: INDIVISIBILITY- COMPLEXITY- FUNGEABILITY - SUPERMODULARITY - ECONOMIES OF SCOPE- GOVERNANCE- TRANSACTION- AGGLOMERATION-COORDINATION

JEL CLASSICIFICATION CODE: D23 - O31 - O34 - R11

1. INTRODUCTION

The grafting of the recent advances of the economics of knowledge into the theory of the firm, regional economics and the geography of innovation seems a promising field of investigation and cross-fertilization. Relevant results can be obtained especially to understand the factors of the persisting economic heterogeneity across regional spaces and the role of regional space in the persistent heterogeneity across firms.

The paper provides in section 2 a synthetic account of recent developments in the economics of knowledge. Section 3 elaborates the new understanding of the non-divisibility of knowledge and identifies two interrelated and yet idiosyncratic aspects namely knowledge complexity and knowledge fungeability. Section 4 elaborates the analysis of the governance mechanisms that emerge to regulate the dynamics of increasing returns stemming from knowledge complexity and knowledge fungeability. In this section market exchanges, internalization and agglomeration are viewed as distinct and interdependent governance mechanisms which concur to define the amount of knowledge an economic system is able to generate and to use. The conclusions summarize the results and put them in a broader perspective.

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2.SHIFTS IN THE ECONOMICS OF KNOWLEDGE

Economics of knowledge plays a key role in all efforts to provide a dynamic analysis of the economic system. According to the economic understanding of the process by means of which knowledge is generated, distributed and used, different interpretations of the dynamic working of the economic system can be deducted. Major changes have characterized the evolution of the economics of knowledge. This process has had major implications for the dynamic analysis of the laws of change and growth of firm, industries and regions.

Three major shifts in the economics of knowledge have occurred in the last decades. In the first the foundations to understanding technological knowledge as a public good are laid down. The second is characterized by the new attention upon the notion of appropriability and the new understanding of knowledge as a proprietary good. The identification of the central role of external knowledge in the production of new knowledge marks the third step, where the discovery of the knowledge trade-off stresses the role of governance in all interactions and exchanges for knowledge.

The seminal contributions of Kenneth Arrow and Richard Nelson had long shaped the debate about the economic organization for the supply of knowledge. In their approach technological knowledge was seen as a public good for the high levels of indivisibility, non-excludability, non-tradability and hence non-appropriability. 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. The public provision of technological knowledge, and especially scientific knowledge has been long 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 Academy of Sciences received new endorsement and support (Arrow, 1962; Nelson, 1959).

More recently much empirical evidence and theoretical research have shown that appropriability is de-facto much higher than assumed. Knowledge is contextual and specific to the original conditions of accumulation and generation: as such natural appropriability conditions are far better than assumed. Imitation costs seem high as well as the costs of receptivity and re-engineering necessary to make use of non-proprietary knowledge. The costs of the non-invented-here-syndrome are appreciated. The assistance of original knowledge holders to perspective users is relevant, if not necessary. The notion of non-appropriability has been the object of systematic redefinition and new understanding (Levin, Klevorick, Nelson, Winter, 1987).

The new growth theory built upon the new appreciation of de-facto appropriability arguing that the economic effects 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 (Romer, 1990 and 1994; Aghion and Tirole, 1994).

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. Intellectual property rights can help not only to increasing the incentives to the production of scientific and technological knowledge, but also its tradability and hence the efficiency of the generation process (Geroski, 1995; Arora, Fosfuri and Gambardella, 2001).

The new theory provided theoretical support to a new 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. 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, 1993, 1994 and 1999; Audretsch and Stephan, 1996; Audretsch and Feldman, 1996; Geuna, 1999)

A third relevant step has been made when a closer analysis of the generation of new knowledge made it possible to understand the key role of technological externalities and the positive effects of technological spillovers. The new approach is based upon the discovery of external knowledge as an essential intermediary input in the production process of new knowledge. A major progress is made when the special character of knowledge as a good that is at the same time an output and an input is grasped and retained at the core of the analysis (Nelson, 1987; Griliches, 1992; David, 1993).

The core of the analysis is centred upon the exploration and identification of the conditions to which external knowledge, as an essential input in the production of new knowledge and new technologies, is distributed in the economic system. This line of enquiry contributes 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 of and distribution of new knowledge. Regional analysis again is deeply affected by the new understanding of knowledge as a way to understand the role of geographic space. At the same time regional economics contributes significantly the new approach highlighting effectively the role of geographic space in the distribution and circulation of knowledge (Feldman and Audretsch, 1999; Feldman and Massard, 2002; Antonelli, 2001 and 2003a).

The new attention and analysis on the notion of indivisibility provides a relevant contribution to understanding the mechanisms of governance at play in the distribution and circulation of knowledge.

3. KNOWLEDGE INDIVISIBILITY: COMPLEXITY AND FUNGEABILITY

Indivisibility has long been considered one the most problematic attributes of knowledge as an economic good. According to Kenneth Arrow, together with non-appropriability and non-rivalry in use, non-divisibility had contributed to the understanding of knowledge as a public good (Arrow, 1962).

Our understanding of the non-divisibility of knowledge has made much progress more recently. The analysis of the specific dynamic characteristics of the production processes that characterize the generation and the usage of new knowledge has made it possible to appreciate the differences in the key role of the indivisibility of knowledge in its own generation, from the role of indivisibility in the usage of new knowledge. Knowledge indivisibility is defined in terms of complementarity of bits of knowledge. Upstream complementarity takes places among inputs and it is found in the generation of new knowledge while downstream complementarity affects the output when it applies to the usage of a given bit of new knowledge.

The distinction between upstream complementarity and downstream complementarity seems relevant on many counts and deserves careful assessment.

When attention is focused on the generation of new knowledge, the traditional notion of knowledge indivisibility is articulated here in the more specific notion of knowledge complexity. The chances to generate new knowledge are conditional on the identification and integration of the diverse bits of complementary knowledge that are inputs into the knowledge production process (Gibbons, Limoges, Nowotny, Schwarzman, Scott and Trow, 1994; Loasby, 1999; Nooteboom, 2000).

The understanding of the notion of 'modularity' contributes this field of investigation. The map of knowledge can be organized in terms of modules. Each module is associated by weak and strong ties of complementarity to others, according to the specific direction of the research process (Baldwin and Clark, 2000; Brusoni and Prencipe, 2001).

When complexity matters, recombination plays a key role in the generation of new knowledge. New knowledge is generated mainly by means of the recombination of both pre-existing and parallel units of knowledge. Such recombination is both synchronic and diachronic. Diachronic, vertical, recombination consists of the reorganization of elements of knowledge acquired in the past with new bits and insights recently elaborated. Here the Newtonian understanding of the production of science as 'standing on giants' shoulders identifies a key attribute of knowledge complexity such as cumulability, i.e. the cumulative complementarity between different vintages of knowledge. Synchronic complexity and the related horizontal recombination activities stress the complementarity between the parallel and contemporary acquisition of new bits of knowledge (Antonelli, 1999).

Technological knowledge varies with respect to the role of knowledge complexity. In some industries the technological knowledge necessary to introduce technological innovations and to run the current business effectively is characterized by high levels of complexity. The sources of the knowledge currently used are diverse and yet need to be all kept under control. The automobile industry is a clear example of an industry with high levels of technological complexity. The effective production of competitive cars requires the command of an impressive range of different technologies including mechanical engineering, electronics, chemistry, electrical engineering, plastics technology, informatics, telecommunications and robotics. The introduction of new technologies in the automobile industry requires the full understanding of the compatibilities and complementarities of each and between each of these technologies.

New information and communication technologies themselves are the result of the complementarity among a wide variety of scientific fields including electronics, telecommunications, space technology, physics, chemistry, plastics and rubber. The new information and communication technological system is the result of the sequential introduction of a variety of complementary and interdependent technological innovations.

General systemic technologies emerge when a variety of specific bits of knowledge are drawn together and organized and combined in a new system of understanding. New information and communication technologies provide to-day a clear example of a new technological system which emerges on the basis of the identification and valorization of both synchronic and diachronic complementarities among units of knowledge possessed by a myriad of actors and as such dispersed and fragmented. New technological systems emerge around new organizing principles, which make it possible to recombine different bits of knowledge and integrate them into a new single framework (Bresnahan and Traitenberg, 1995; Lypsey, Bekar and Carlaw, 1998).

This understanding leads to the notion of resource pooling. The chances to generate new knowledge are conditional on the capability to draw together bits of knowledge that are actually diverse and yet complementary.

When attention is concentrated upon the use of new technological knowledge, a second and quite distinct specification of the notion of indivisibility emerges: fungeability. Fungeability defines the downstream complementarity of any bit of knowledge. Some elements of technological knowledge may apply to a narrow and specific range of activities, either new products or new processes. Other bits of new knowledge can have important applications to a great array of new products and processes. Fungeability is defined and measured by the scope of application of a new bit of knowledge.

New information and communication technologies, like previous general purpose technologies, are characterized also by this second relevant aspect. New information and communication technologies in fact have also high levels of fungeability as they apply to a great variety of products and processes. No product and process can be manufactured without the substantial application of new information and communication technologies or without substantial effects of the application of new information and communication technologies (Antonelli, 1992).

Biotechnology provides clear evidence about the pervasive role of knowledge fungeability and yet low levels of knowledge complexity. Biotechnologies apply to a wide range of industries and activities including pharmaceuticals, food and beverages, pesticides and agricultural chemical products at large. Advances in biotechnology stem from a rather limited range of scientific fields and technological competencies.

A large part of the XX century has been characterized by the high levels of fungeability of mechanical engineering in internal combustion technologies. The same core of technological knowledge and competence has been sequentially applied to the production of a wide range of products including cars, trucks, buses, armoured vehicles, agricultural machinery, construction machinery, ships and planes.

Complexity feeds the generation of new technological knowledge. New fungible technological knowledge in turn feeds new recombinations and hence new steps forward. This dynamics has all the characteristics of a self-reinforcing process. Such a process in turn is wider and faster the larger is the fungeability of each bit of new knowledge.

Here two distinct and well-specified dimensions of the traditional notion of knowledge indivisibility have emerged: knowledge complexity and knowledge fungeability. Both specifications have a direct and clear-cut empirical dimension. Knowledge complexity can be identified and measured with respect to the variety of bits of knowledge that it is necessary to recombine in order to generate a new bit of knowledge. Knowledge fungeability is measured with respect to the number of units of knowledge and products it applies to. Both specifications have important and well distinct effects in terms of forms of increasing returns, mechanisms of governance and opportunities for regional strategy.

4. KNOWLEDGE FUNGEABILITY AND KNOWLEDGE COMPLEXITY AS A SOURCE OF INCREASING RETURNS

Indivisibility is the cause of increasing returns. Much progress has been made in economic analysis in understanding the different forms of increasing returns. Different types of increasing returns have different implications for both economic analysis and economic policy. Knowledge complexity and knowledge fungeability are the cause of different forms of increasing returns that have significant and yet different effects on the organization of economic activity. This distinction has relevant implications both for the theory of the firm and for regional economics.

As far as knowledge complexity is concerned, it is clear that the larger is the number of the bits of knowledge, which can be recombined, and the larger are the chances of generating new relevant knowledge. Here the effects are found on the input side. More specifically the effects run from the variety of inputs towards the levels of output. A special kind of increasing returns where the relationship between inputs and outputs is shaped by the variety of inputs that can be engaged in the process, matters here. Traditional forms of increasing returns associated with the quantitative scale of the production are substituted here by increasing returns associated to the variety of inputs.

When knowledge complexity matters, the larger is the variety of the carriers of different bits of knowledge that are able to interact and the larger is the result in terms of the amounts of new knowledge which can be generated. As a matter of fact, the efficiency of the production is affected by the variety of the specific activities that are brought together.

Many advances in this context can be provided by the new understanding of supermodularity. According to Milgrom and Roberts: "…supermodularity provides a way to formalize the intuitive idea of synergies and system effects- the idea that 'the whole is more than the sum of its parts'…. Supermodularity is mathematically equivalent to the statement that for every such x and y, the gains from increasing every component to y_1 and x_1, is more than the sum of the gains from the individual increases…"(Milgrom and Roberts (1995:184). Knowledge supermodularity applies to the generation of new knowledge when the positive effects of the increasing number of complementary kinds of knowledge on the efficiency of the generation process, are considered.

In the case of knowledge fungeability, the effects are found on the other side. Here for a given amount of new knowledge the economic effects are larger the larger is the number of activities to which the new knowledge can be applied. Low costs of replicability play a key role.

When knowledge fungeability matters, the greater is the variety of the activities which can share the same pool of knowledge and the larger are the possibilities to implement new technologies and hence the lower are the unit costs. In this case the notion of joint-use seems relevant and hence the dynamics of economies of scope. The knowledge pool in fact can be assimilated to a quasi-fixed production factor whose applications to the diverse specific contexts engender low variable and incremental[2] costs and almost no wear costs. The larger is the number of activities and the larger is the opportunity to spread the quasi-fixed costs. Economies of scope are found when, with a given fixed or quasi-fixed fungible input, costs decline when the variety of outputs increase, because of the opportunity to use it repeatedly. Economies of scope emerge typically when relevant excess capacity is caused by imperfect divisibility and high threshold of the investment and when there is little exclusivity and decay in usage. The same knowledge can be applied to an increasing number of different activities with no or little duplication and wear costs.

Both supermodularity in the production of knowledge stemming from knowledge complexities and economies of scope stemming from the joint-use of knowledge are forms of increasing returns where unit costs decline with the variety of activities being involved.

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[2] Drawing from telecommunication economics incremental costs are defined by the costs of adding dedicated and complementary units of knowledge to the existing stock for each specific application (Baumol and Sydak, 1994)

5. THE GOVERNANCE OF KNOWLEDGE COMPLEXITY AND KNOWLEDGE FUNGEABILITY

The identification of the increasing returns in the generation of knowledge, engendered by knowledge complexity and knowledge fungeability, brings back into full evidence the strategic role of the distribution of knowledge.

Technological knowledge is not only an output, but also an input, an essential intermediary production factor that is relevant both in the generation of new technological knowledge and in the generation of other goods. The dynamic efficiency of each firm and of the system at large depends upon the factors affecting the distribution of knowledge and the conditions of access to existing knowledge.

In the public good tradition of analysis the access to technological knowledge was considered very easy and only intellectual property rights could reduce its spontaneous circulation in the economic system. The distribution of knowledge was mainly based upon personal interactions, rather than on market transaction. The well known knowledge paradox limited actual market transactions: nobody would be ready to buy disembodied technological knowledge without a full disclosure, but as soon as the content is disclosed, opportunistic behaviour would take place and nobody would be ready to pay for it.

In the approach to knowledge as a proprietary good, much emphasis has been paid to the new markets for technological knowledge, based upon a regime of intellectual property rights designed to favour its tradability. In the knowledge-trade-off approach, the limitations of intellectual property rights to the circulation of technological knowledge and the risks of excess appropriation have been highlighted (David, 1993).

Along these lines, some progress can be made when technological knowledge is considered as a quasi-private good with significant imperfections in terms of limited appropriability, poor non-exclusivity, substantial indivisibility articulated in complexity and fungeability and hence partial tradability: significant transaction costs reduce, but do not impede the working of arms'length exchanges (Coase, 1937; Williamson, 1975, 1985, 1996).

Technological knowledge can circulate within economic systems by means of three alternative and yet complementary governance mechanisms: by means of actual knowledge transactions, especially if implemented by appropriate intellectual property rights regimes and specialized intermediaries, internalized within corporations by means of the coordination provided by hierarchical bureaucracy and finally, within networks based upon transactions implemented and integrated by means of qualified interaction systems. Let us analyse how these three governance mechanisms complement each other and how knowledge fungeability and knowledge complexity affect them.

The extension of the governance approach elaborated by Oliver Williamson to the analysis of knowledge generation and distribution seems a fertile area of investigation, especially when it applies to variety rather than to quantity.

5.1. KNOWLEDGE TRANSACTIONS

The markets for knowledge are characterized and limited by transaction costs. 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 costs. On the supply side the uncontrolled usage of the knowledge can take place with evident damages for the vendor. Knowledge transaction costs arise mainly because of the high risks of opportunistic behaviour of the customers (Geroski, 1995; Arora, Fosfuri, Gambardella, 2001).

Opportunity costs also matter both on the demand and the supply side. On the supply side 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. These risks are especially high and long-lasting when complexity takes the form of cumulability and exerts its effects in time. On the demand side the customer can acquire only a limited command of the technological knowledge which remains under the effective control of the vendor.

The costs of writing proper contracts for the transactions of technological knowledge are relevant and a large variety of contingencies must be taken into account. The judiciary system and generally the enforcement conditions of the contracts for disembodied technological knowledge are also most relevant.

High knowledge transaction costs reduce the viability of the market as the mechanism to ensure the proper circulation of knowledge in the economic system. Unit transaction costs in knowledge are affected by the variety of bits of knowledge and the number of players involved. A case for decreasing returns in knowledge transactions emerge with respect to variety rather than to quantity.

In this context patents play a key role from an informational viewpoint and can contribute to reduce the levels of knowledge transaction costs. An effective intellectual property rights regime is likely to reduce the risks of opportunistic behaviour, by tightening the command of innovators on technological knowledge and hence the opportunity to control the benefits stemming from its applications. Hence an effective property right regime can favour the use of knowledge markets to sell technological knowledge. Especially when the levels of appropriability are low and hence the risks of excessive leakage and uncontrolled appropriation are high, patents make it easier the interaction between supply and demand and facilitate the assistance of the vendors to buyers and perspective users (Granstrand, 1999; Dumont and Holmes, 2002).

The informational role of patents is relevant also to reduce knowledge transaction costs on the demand side. An effective intellectual property right regime reduces the risks that firms rely on secrecy and discrimination to prevent the uncontrolled dissemination of new knowledge. Secrecy can be considered a major source of search costs and hence a cause of duplications and missing benefits of knowledge complexity. In an intellectual property right regime, where the rights of exclusivity are properly tuned[3], patents can perform the key role of signalling devices of the quality of the knowledge held by the assignees. Finally, intellectual property rights can also help the creation and management of interfirms alliances (David, 1993; 1994; Granstrand, 1999; Oxley, 1999; Dumont and Holmes, 2002).

The transmission of knowledge in the market place may be favoured by knowledge intensive business service firms which act as intermediaries. Specialized intermediaries act as go-between firms respectively searching for complementary bits of knowledge and/or possible fields of application of the technology already generated in order to test its actual fungeability. Knowledge intensive business services can help the parties to establish the actual direct relationship when they

[3] Limitations to the exclusivity of the property rights provided by patents, by means of compulsory licensing or straightforward application of the liability rule, might increase the viability of intellectual property right to increase both the distribution of knowledge and the incentives to its production (Antonelli, 2003b).

act as assistant to the exchanges and help the transactions to be performed. In this case knowledge intensive business firm specialize in reducing the amount of search costs and provide basic assistance in assessing the reputation and reliability of the parties. They can also act as full intermediaries: they buy the licences and they sell them to third parties. Finally, knowledge intensive business services can play a major role as knowledge converters: they accumulate generic knowledge and specialize in the delivery of specific and contextual applications (Spulber, 1999; Antonelli, 1999).

When the support provided by the intellectual property rights regime and the supply of knowledge-intensive-business-services is not sufficient to reduce knowledge transaction costs, the case for market failure emerges. The costs of knowledge market failures are high in terms of the missing opportunities to take advantage from the increasing returns associated with knowledge complexity and knowledge fungeability. When returns are not constant and either increasing and decreasing returns are at play, tradability is a necessary but not sufficient condition to achieve dynamic efficiency.

5.2. LEARNING CORPORATIONS

Coordination costs limit the number of complementary activities that can be internalized by each firm and hence the amount of knowledge that can be generated and implemented internally. Unit coordination costs also are sensitive to the variety of activities that need to be internalized. The larger is the rate of increase, with respect to the number of activities, of unit coordination costs and the larger is the number of complementary activities that cannot be retained within the borders of the firm. Because of internal coordination costs, important opportunities are missed. Large corporations are unable to implement all the opportunities they contribute to create.

This analysis complements the resource-based theory of the firm in many ways. First of all it is clear that the firm is far more that a production function. The firm is a bundle of activities that are complementary with respect to the knowledge and the competence their collection makes it possible to gather (Penrose, 1959; Foss, 1997; Foss and Mahnke, 2000; Nooteboom, 2000).

The distinction between knowledge complexity and knowledge fungeability provides new insights about the assessment of the actual core competencies of the firm. The coherence of the collection of activities retained within the boundaries of the firm can now be appreciated from two distinct viewpoints. A collection of activities can be coherent with respect to their complementarity in the generation of new knowledge. A diverse collection of activities may be coherent however with respect to the logic of knowledge fungeability. The inclusion of some activities next to others within the borders of the firm is now influenced by their common use of the knowledge resource pool provided by the company.

The inclusion of an activity within the borders of a firm can now be understood with respect to both the different aspects of their knowledge base. The relatedness of the activities included in a diversified firm can be assessed both with respect to the production of new knowledge, and hence in terms of knowledge complexity and the relatedness in terms of knowledge use, and hence with respect to knowledge fungeability. Knowledge appropriability regimes play a role here. With low appropriability firms have a strong incentive to include additional activities within their borders especially when knowledge fungeability is high.

Hierarchical coordination is a resource consuming activity. The incentives to increase the number of activities coordinated internally consists in the positive effects of both knowledge complexity and knowledge fungeability on the general levels of output unit costs. The firm can grow until such effects are not balanced by the costs of hierarchical coordination[4]. Coordination costs limit the size of activities that can be coordinated within the corporation.

The failure of bureaucratic organizations to provide the internal coordination that is necessary to internalize all the variety of bits of knowledge that are at the origin of knowledge complexity and knowledge fungeability and hence both supermodularity and economies of scope, is the second major cause of dynamic inefficiency. Firms, and hence the system, grow at much a lower rate than they could as they generate less knowledge and make a less efficient use of it.

5.3. NETWORKING IN REGIONAL SPACE

Networking makes it possible to valorize knowledge complementarities and hence to access and generate additional knowledge. The interactions among activities that are not exchanged in the market place and are not retained within a firm but are complementary either with respect to the production of new knowledge or its usage can take place by means of networking. Knowledge networking however is not a 'free lunch' but requires dedicated activities and receptivity-enhancing networking behaviours. Networking consists in the systematic and organized sharing of codes of conduct among independent firms, which agree tacitly or explicitly upon knowledge interactions qualified in terms of trust, reciprocity and repetition.

The transmission of technological knowledge among independent and yet networking organizations in fact can take place by means of an array of interactions non-fully-mediated by the price mechanisms but implemented by organizational procedures that complement or substitute fully for market transactions. This includes the mobility of personnel and the informal barter of know-how both in user-producers relationships and even among competitors relying on tacit codes of reciprocity and repetition in mutual interactions.

Location provides a strong basis for networking. Geographical distance plays a major role in this context. Location has high levels of irreversibility: location roots firms in a given space and hence becomes a hostage in the interactions. Location in a given space exposes firm to repeated interactions and hence long time horizons in decision making about interactions with co-localized agents. Firms that are co-located are less prone to opportunistic behavior because they are exposed to retaliation and exclusion from other interactions in the future.

Co-location makes interorganizational coordination in knowledge interactions easier because of the higher levels of commonality in codes, protocols and cultural standards and hence more effective and less expensive communication systems (Patrucco, 2003).

High levels of reputation for local trust and an effective tradition of mutuality in knowledge interactions qualify the attraction of regions for firms seeking to benefit from the advantages stemming from both knowledge complexity and knowledge fungeability.

Location is a substitute and a complement to reputation and contractual agreements. As such location itself can be considered a networking activity. This is true especially when the choice of the site for the location of a production unit is decided with respect to the advantages provided by knowledge fungeability and complexity in terms of externalities. Location is clearly a receptivity-

[4] The notion of interstitial economies introduced by Edith Penrose (1959) makes it possible to identify the opportunities for internal growth that firms cannot take advantage because of fast rising coordination costs. If smaller firms cannot use such opportunities, the system at large can miss important opportunities for growth. The same argument applies when networking costs are too high, at the regional level.

enhancing factor that firms are more and more able to use strategically (Cohen and Levinthal, 1994).

Networking tends to be limited within circumscribed regional spaces also because of the role of distance in the mobility of qualified personnel. Such mobility in turn is a major vehicle of transmission of knowledge and interaction. In turn, co-localized firms are less hostile to labour mobility because of the reciprocity provided by agglomeration (Martin, 2000).

Networking also is expensive and it is the result of dedicated activities, which include the search, and identification of the activities that are external to each firm and yet exhibit some forms of knowledge complexity and knowledge fungeability. Each firm will pursue networking activities as far as their costs will match the benefits in terms of the economies of joint production and joint use of knowledge.

6.IMPLICATIONS FOR REGIONAL STRATEGY AND POLICY ANALYSIS

The implications of this analysis for public policy and the strategy of public actors at the regional level are important. In any given economic system, the levels of knowledge transaction costs define the amount of increasing returns that can be valorized by means of market transactions. Coordination costs internal to each firm define the amount of increasing returns stemming from knowledge complexity and knowledge fungeability that can be internalized within the firms. The levels of networking costs define the amount of increasing returns that can be valorized at the regional level.

For given levels of knowledge indivisibility and hence given levels of knowledge complexity and knowledge fungeability, each regional system will be able to take advantage of varying levels of increasing returns. Such a variance in the levels of increasing returns each region can take advantage of, depends upon the actual levels of the costs of knowledge networking.

The strong interdependence between organizational and technological knowledge emerges here with evidence. It is clear that the larger is the organizational knowledge, both in managing transactions, complex bureaucratic organizations and in networking and the larger are the benefits stemming from knowledge complexity and knowledge fungeability respectively. Within companies the higher are the levels of responsibility, reliability and loyalty of employees and hence the lower the extent to which hierarchical control is necessary and the larger the opportunities to internalize the benefits of knowledge indivisibilities. It is also clear that the lower the risks of opportunistic behaviour, the larger are the levels of trust in a system and the higher the levels of general efficiency within a regional system.

These results are most interesting from many different viewpoints. From an analytical viewpoint we see that economies of scope and knowledge supermodularity are two diverse forms of appropriation of the benefits, which stem from the intrinsic indivisibility of knowledge. It becomes apparent that decreasing returns in the governance of knowledge distribution and increasing returns in its generation are at odds. This effect is stronger when the role of knowledge as an intermediary input for the production of further knowledge is considered. The larger are knowledge transaction costs, bureaucratic coordination costs and networking costs, the lower are the advantages of increasing returns. This leads to a relevant point: increasing returns are finite and take place at a diminishing rate themselves.

This approach can be useful in providing basic guidelines for the regional policy maker in the attempt to direct the industrial and technological composition of a region. The coherence of the firms in regions can be enhanced and strengthened with a clear understanding of knowledge complexity and fungeability.

The new understanding of the role of knowledge complexity and knowledge fungeability in the assessment of the systemic coherence of a microsystem, such as the firm, in fact can be applied successfully to regional systems (Teece, 1986 and 1998; Williamson, and Winter, 1993). A resource-based theory of the region can also be elaborated on this basis. The dynamic region can be defined and hence identified as a collection of related activities that are complementary with respect to their contribution to the generation and usage of technological knowledge and competence. The actual levels of relatedness of the activities co-localized is a major factor in assessing the performance of a region (Martin, 1999).

From an organizational viewpoint it is clear that all reductions in networking costs, for given levels of knowledge complexity and fungeability, make regions more attractive. Regions where the identification of the firms engaged in complementary research activities is easier so as to reduce search costs, and where the knowledge interactions are less expensive in terms of risks of opportunistic behaviour and non-reciprocity, are likely to attract firms. The local viability of knowledge interactions within structured networks plays a key role in this context.

From an industrial and technological viewpoint however the strategies for the selection of the different sites vary according to the specific aspect considered. Industries differ widely with respect to the complexity and fungeability of their knowledge base. The automobile industry nowadays is a clear example of an industry with high levels of knowledge complexity but lower levels of knowledge fungeability. At the other extreme we find biotechnology characterized by low levels of complexity but very high levels of fungeability of the knowledge base.

For firms active in knowledge fields characterized by high levels of knowledge complexity, location in a region where firms are complementarity in their research activities and low networking costs, is most attractive. When knowledge complexity matters, firms will be searching for regions where the bits of the missing knowledge are accessible at low networking costs. Regions that reach levels of excellence in a given set of technologies will attract the location of research laboratories and industrial plants of firms searching for a direct access to that specific technological domain. Here the location is viewed as a way of quasi-internalizing the bits of knowledge that enter the specific recipe of the required technological complexity. Global companies are likely to be the most relevant actors in this context with the location of specialized units. Firms are likely to locate in such regions in order to internalize the benefits of local externalities. Location is a form of internalization in that it provides access to knowledge supermodularity (Howells, 1999).

When knowledge complexity matters, it is clear that the variety of competencies available in a given region is a major factor of attraction. The wider and broader is the knowledge base locally available, and the larger the interest for firms seeking access to complementary bits of knowledge. Metropolitan areas are likely to find here a source of competitive advantage. From the viewpoint of the strategies of local actors it seems clear that specialization in a narrow range of scientific fields is not appropriate. For the same reason it seems clear that the creation of science parks is likely to be more successful only in a large urban environment characterized by a wide variety of firms and a general public scientific infrastructure, and a large academic community.

When knowledge complexity matters, the attraction of exogenous firms provides important opportunities for economic growth. The entry of new firms in turn may activate a self-propelling dynamics. Each new firm can contribute to the resource pool adding its own competence and technological knowledge to make the local knowledge base not only larger but also wider. Newcomers are likely to be large firms able to search globally and to operate a multiplant organization.

A different process seems to take place when knowledge fungeability matters. Here the technological externalities spilling in the atmosphere concern the possibility of applying to a variety of industrial activities the basic technological know-how, which has emerged locally. The creation of new small firms seems most likely to characterize the process in this case. A region becomes an incubator in that it provides to start-ups the opportunity to take advantage of the non-rival use of a common resource provided by a technological knowledge with a wide range of applications. Historically, the growth of most technological districts characterized by a common technological base seems characterized by high rates of natality and entry of new small firms and their eventual growth fed by a distinctive local competitive advantage: the access to a local pool of technological knowledge. Spin-off is an important factor in the endogenous dynamics of regional growth specialized in industries with high levels of knowledge fungeability (Carlsson, 2002).

Knowledge fungeability paves the way to polarized growth as analyzed by Perroux[5]. Incumbents commanding the new technological knowledge with high levels of fungeability have major opportunities to grow fast and reach the maximum size compatible with hierarchical coordination costs, beyond which are unable to exploit all the opportunities for growth stemming from knowledge economies of scope. Their limits provide interstitial opportunities to smaller newcomers (Perroux, 1964; Antonelli, 1986).

Large firms that command a technological knowledge with high levels of fungeability can contribute regional dynamics when searching for regions where there is a large potential scope of application of their technological knowledge. Location is a way to enter into local networks and become a reliable and effective vendor yet retaining the proprietary control of its own technological basis. The levels of local trust and networking costs will be relevant factors in selecting the location. Location here is a way to valorizing downstream market opportunities and to take advantage of knowledge fungeability.

From a dynamic and systemic viewpoint the interaction between the two distinct forms of knowledge indivisibility identified seems most important. The sustained growth of region as well as of a corporation can be explained in terms of a sequence between increasing returns stemming from knowledge supermodularity and increasing returns stemming from knowledge economies of scope. The identification of the specific collection of activities, which is likely to make knowledge complementarities possible, is the first step. Low coordination costs for corporations and low networking costs for regions provide here the appropriate conditions for the process to start. Once the mix has been identified and put in place, new knowledge can be generated and some competitive advantage can be built upon. The identification of the fungeability of the knowledge generated makes it possible to feed the process. The competitive advantage now can spread to other product markets and to other industries at large with major benefits in terms of economies of scope.

7. CONCLUSION

The economics of knowledge has made much progress in the articulation of our understanding of the relevant characteristics of knowledge as an economic good. The Arrovian tradition of analysis

[5] It is worth stressing the clear complementarity in the analysis of Edith Penrose and Francois Perroux.

based upon the notion of knowledge as a public good for the well-known attributes of non-divisibility, non-rivality in use and non-appropriability has been the object of a systematic and still enduring reassessment and redefinition.

The new growth theory has elaborated the assumption that technological knowledge is appropriable to such an extent that individual firms have the necessary incentives to fund research and development expenditures. The markets would be able to provide the necessary coordination among firms for systematic knowledge-led growth to take place.

According to an alternative approach, based upon the Schumpeterian and Marshallian traditions of analysis, the Arrovian analysis of market failures associated not only to the generation but also to the distribution of knowledge is still very much valid, especially from the viewpoint of dynamic efficiency (Arrow, 1969). The investigation into the notions of knowledge indivisibility and knowledge governance seems most promising at this stage.

Complexity and fungeability are two specific aspects of knowledge indivisibility. The production of new knowledge requires the combination of and hence the access to diverse and yet complementary bits of knowledge. In turn some units of knowledge can have high levels of fungeability. Their application is relevant in different contexts, different products and different processes.

The new understanding of knowledge indivisibility in terms of knowledge complexity and knowledge fungeability makes it possible to identify two specific forms of increasing returns, namely supermodularity associated with knowledge complexity and economies of scope associated with knowledge fungeability.

Knowledge transaction costs limit the market exchanges and are the cause of major dynamic inefficiency. A clear case for dynamic efficiency takes place if prices cannot perform their role as single vectors of all relevant information and markets fail to provide the necessary dynamic coordination among firms and activities so as to achieve the optimum rates of growth in the generation and distribution of knowledge in the economic system.

When increasing returns are at play, tradability is a necessary but not sufficient condition to achieve dynamic efficiency. In a context of evident market failure, alternative governance mechanisms are necessary to provide the coordination among individual decision-making in the generation and distribution of technological knowledge that markets cannot perform efficiently (Mathews, 2002).

The internalized governance of such knowledge interactions however is complex. Internalization of different bits of knowledge can yield relevant advantages in terms of supermodularity and economies of scope, but is constrained by coordination costs. Firms can take advantage of both knowledge complexity and fungeability by means of networking activities. Selective agglomeration can yield relevant benefit in the form of knowledge externalities. Agglomeration in regional space as well is constrained by search and networking costs. Internal coordination and external networking costs define the boundaries of the firms and the regional systems respectively where knowledge indivisibility applies.

The limits of organizations, networking and market failures reduce the positive effects of increasing returns stemming from knowledge indivisibility. The decreasing returns at play in the governance of the distribution of knowledge counterbalance the increasing returns in the generation and use of knowledge. The case for increasing returns at a diminishing rate applies to the combined dynamics of the generation and distribution of knowledge. This is the cause of a clear dynamic inefficiency:

the interplay between knowledge supermodularity and economies of scope is in fact constrained by governance costs.

The sequential interplay between knowledge fungeability and knowledge complexity can be a major source of self-sustained processes of economic growth both at the firm and the regional level. The analytical framework of the self-sustained dynamics of scale and scope articulated by Alfred Chandler to explain the growth of the US corporation finds a broader application in the context of the economics of knowledge. The growth of corporations and regions in fact can be understood as the consequence of the sequential and repeated interactions between the increasing returns stemming from knowledge complexity and the increasing returns stemming from knowledge fungeability both for firms and regions. The limits of organizations and markets in the governance of the distribution of knowledge have major consequences in terms of missing opportunities for growth (Arrow, 1974; Chandler, 1990; Chandler, Hagstrom and Solvell, 1998).

In this context economic policy, especially at the regional level, can play an important role. Next to the firm, the region can be viewed as an economic organization, which provides the necessary integration and context for knowledge interactions to take place and hence for increasing returns to be valorized and made possible.

The framework elaborated so far shows that markets, corporations and regions are well distinct organizational systems, designed around different procedures and governance mechanisms. Yet markets, institutions, regions and corporations complement each other to providing the necessary extended coordination for interactions to take place when the full array of exchanges cannot be reduced and managed by the price mechanism as the single coordination device.

The key issue is the divergence between increasing returns in the generation of knowledge and decreasing returns in its governance. The generation of knowledge is in fact characterized by increasing returns to variety, associated to knowledge complexity and hence supermodularity and knowledge fungeability and hence economies of scope. The governance of knowledge distribution instead is characterized by decreasing returns to variety that are especially strong in knowledge transactions and knowledge coordination. Networking is a key complementary mechanism for the governance of interstitial opportunities.

The design of governance systems, based upon the complementarity between transactions in the markets for knowledge, intellectual property rights regimes aimed at favouring the distribution of knowledge, hierarchical coordination within learning corporations and knowledge networking at the regional level becomes a necessary condition for knowledge circulation to be enhanced and hence to take better advantage of the benefits of increasing returns in its generation.

REFERENCES

Aghion, P., Tirole, J. (1994), The management of innovation, *Quarterly Journal of Economics* CIX, 1185-1209.

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

Antonelli, C. (1986), *L'attività innovativa in un distretto tecnologico*, Torino, Edizioni della Fondazione Agnelli.

Antonelli, C. (ed.) (1992), *The economics of information networks*, Amsterdam, Elsevier.

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

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

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

Antonelli, C. (2003b), The governance of localized technological knowledge and the evolution of intellectual property rights, in Colombatto, E. (eds.), *The Elgar companion to property rights*, Cheltenham, Elgar.

Antonelli, C. and Quèrè, M. (2002), The governance of interactive learning within innovation systems, *Urban Studies* 39, 1051-1063.

Arora, A. and A. Gambardella (1994), The changing technology of technical change: General and abstract knowledge and the division of innovative labour, *Research Policy* 23, 523-532.

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.

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

Arrow, K.J. (1974), *The limits of organization*, New York, W.W. Norton.

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.

Baldwin, C. Y. and Clark, K. (2000), *Design rules: The power of modularity*, Cambridge, Mass., MIT Press.

Baumol, W.J. and Sydak, J.G. (1994), *Toward competition in local telephony*, Cambridge, The MIT Press.

Bresnahan, T. F. and Traitenberg, M. (1995), General purpose technologies: 'Engines of growth'? *Journal of Econometrics* 65, 83-108.

Brusoni, S. and Prencipe, A. (2001), Unpacking the black box of modularity: Technologies products and organizations, *Industrial and Corporate Change* 10, 179-205.

Carlsson, B. (ed.)(2002), *Technological systems in the bio industries. An international study*, Boston, Kluwer Academic Publishers.

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

Chandler, A.D., Hagstrom, P. and Solvell, O. (eds.) (1998), *The dynamic firm: The role of technology strategy organization and regions*, Oxford, Oxford University Press.

Coase, R. H. (1937), The nature of the firm, *Economica* 4, 386-405.

Cohen, W.M. and Levinthal, D.A. (1989, Innovation and learning: the two faces of R&D, Economic Journal 99, 569-596.

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

Dasgupta, P. and David, P. (1987), Information disclosure and the economics of science and technology, in Feiwel G. (ed.), *Arrow and the ascent of modern economic theory*, London, Macmillan.

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.

David, P. A. (1994), Positive feed-backs and research productivity in science: Reopening another black box, in Granstrand, O. (ed.), *Economics and technology,* Amsterdam, Elsevier.

Dumont, B. and Holmes, P. (2002), The scope of intellectual property rights and their interface with competition law and policy: Divergent paths to the same goal, *Economics of Innovation and New Technology* 11, 149-162.

Feldman, M. P. (1993), An examination of the geography of innovation, *Industrial and Corporate Change* 2, 447-467.

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

Feldman, M. P. (1999), The new economics of innovation spillovers and agglomeration: A review of empirical studies, *Economics of Innovation and New Technology* 8, 5-26.

Feldman, M. and Audretsch, D.B. (1999), Innovation in cities: Science-based diversity specialization and localized competition, *European Economic Review* 43, 409-430.

Feldman, M.P. and Massard, N. (eds.) (2002*), Institutions and systems in the geography of innovation*, Kluwer Academic Publishers, Boston.

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

Foss, N. (1997), *Resources firms and strategies. A reader in the resource-based perspective*, Oxford, Oxford University Press.

Foss, N. and Mahnke, V. (eds.) (2000), *Competence governance and entrepreneurship. Advances in economic strategy research*, Oxford, Oxford University Press.

Furubotn, E.G. (2001), The new institutional economics and the theory of the firm, *Journal of Economic Behavior and Organization* 45, 133-153.

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

Gibbons, M., Limoges, C., Nowotny, H., Schwarzman, S., Scott, P. and Trow, M. (1994), *The new production of knowledge: The dynamics of research in contemporary societies*, London: SAGE Publications.

Granstrand, O. (1999), *The economics and management of intellectual property*, Amsterdam, Elsevier.

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

Guilhon, B. (ed.) (2001), *Technology and markets for knowledge. Knowledge creation, diffusion and exchange within a growing economy,* Boston, Kluwer Academics.

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

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

Howells, J. (1999), Research and technological outsourcing, *Technology Analysis & Strategic Management* 11, 17-29.

Langlois, R.N. and Robertson, P. L. (1995), *Firms markets and economic change. A dynamic theory of business institutions*, London, Routledge.

Langlois, R.N. and Foss, N.J. (1999), Capabilities and governance: The rebirth of production in the theory of economic organization, *Kyklos* 52, 201-218.

Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G. (1987), Appropriating the returns from industrial research and development, *Brookings Paper on Economic Activity* 3, 242-279.

Lypsey, R., Bekar, C. and Carlaw, K. (1998), General purpose technologies: What requires explanation, in Helpman, E. (ed.) *General purpose technologies and economic growth*, Cambridge, MIT Press.

Loasby, B.J. (1999), *Knowledge institutions and evolution in economics,* London, Routledge.

Milgrom, P. and Roberts, J. (1995), Complementarities and fit. Strategy structure and organizational change in manufacturing, *Journal of Accounting and Economics* 19, 179-208.

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

Oxley, J.E. (1999), Institutional environment and the mechanisms of governance: The impact of intellectual property protection on the structure of inter-firm alliances, *Journal of Economic Behavior and Organization* 38, 283-309.

Martin, R. L. (1999), The new geographical turn in economics: Some critical reflections, *Cambridge Journal of Economics* 23, 65-91.

Martin, R. L. (2000), Local labor markets: Their nature performance and regulation, in Clark, G. L, Feldman, M. and Gertler, M.S. (eds.), *The Oxford Handbook of Economic Geography*, Oxford, Oxford University Press, 2000.

Mathews, J.A. (2002), A resource based view of Schumpeterian economic dynamics, *Journal of Evolutionary Economics* 12, 29-54.

Metclafe, J.A. (2002), Knowledge of growth and the growth of knowledge, *Journal of Evolutionary Economics* 12, 3-16.

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

Nelson, R.R. (1982), The role of knowledge in R&D efficiency, *Quarterly Journal of Economics* 97, 453-470.

Patrucco, P.P. (2003), Institutional variety, networking and knowledge exchange: communication and innovation in the case of the Brianza technological district, *Regional Studies* forthcoming.

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

Perroux, F. (1964), *L'economie du XX siecle*, Paris, Presses Universitaires de France.

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

Robertson, P. and Langlois, R. N. (1995), Innovation networks and vertical integration, *Research Policy* 24, 543-62.

Rohlfs, J. H. (2001), *Bandwagon Effects in High Technology Industries*; Cambridge, Mass., MIT Press.

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

Romer, P.M. (1990), Endogeneous technological change, *Journal of Political Economy* 98, S71-102.

Romer, P.M. (1994), The origins of endogeneous growth, *Journal of Economic Perspectives* 8, 3-22.

Simon, H. A. (1985), What we know about the creative process, in Kuhn, R. L. (ed.), *Frontiers in Creative and Innovative Management*, pp. 3-20, Cambridge, MA, Ballinger

Spulber, D. (1999), *Market microstructures: Intermediaries and the theory of the firm*, Cambridge, Cambridge University Press.

Teece, D.J. (1986), Profiting from technological innovation: Implications for integration collaboration licensing and public policy, *Research Policy* 15, 285-305.

Teece, D.J. (1998), Capturing value from knowledge assets: The new economy, markets for know-how and intangible assets, *California Management Review* 40, 55-79.

Teece, D.J. (2000), *Managing intellectual capital*, Oxford, Oxford University Press.

Teubal, M., Yinnon, T., and Zuscovitch, E. (1991), Networks and market creation, *Research Policy* 20, 381-392.

Wang, Q. and Von Tunzelmann, G. N. (2000) Complexity and the functions of the firm: breadth and depth, *Research Policy* 29, 805-818.

Williamson, O.E. (1975), *Markets and hierarchies: Analysis and antitrust implications*, New York, Free Press.

Williamson, O. E. (1985), *The economic institutions of capitalism: Firms, markets, relational contracting*, New York, Free Press.

Williamson, O. E.(1996), *The mechanisms of governance*, New York, Oxford University Press.

Williamson, O. E. and Winter, S.G. (eds.) (1993), *The nature of the firm*, Oxford, Oxford University Press.