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Collective Knowledge Communication and Innovation: The Evidence of Technological Districts[1]

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ANTONELLI C. (2000) Collective knowledge communication and innovation: the evidence of technological districts, *Reg. Studies* 34, 535–547. Technological knowledge is a collective good in that its generation is the result of a process that combines pieces of information and knowledge that are owned by a variety of parties and cannot be traded as such. With low transaction and communication costs technological externalities can fully deploy their effects in terms of increasing returns and positive feedbacks. The conditions and features of communication processes explain the clustering of innovations in well defined regional spaces. Localization in technological districts featured by multichannel communications systems favours access to external knowledge, now viewed as an essential intermediary input in the generation of technological knowledge, and encourages the introduction of localized technological changes, leading to self-reinforcing mechanisms based upon localized increasing returns.

Communication Localized technological knowledge Technological districts

ANTONELLI C. (2000) La transmission de la connaissance collective et l'innovation: des preuves provenant des districts technologiques: *Reg. Studies* 34, 535–547. La connaisasance technologique est un bien collectif dans la mesure où elle résulte d'un processus qui allie des renseignements et des connaissances possédés en copropriété qui ne peuvent pas être échangés en tant que telle. Etant donné les coûts des transactions et de la communication peu élevés, les effets externes puissent se déployer entièrement en termes de leurs rendements accroissants et de leurs retombées positives. Les conditions et les caractéristiques des processus de communication expliquent le regroupement des innovations dans des espaces régionaux bien délimités. L'implantation dans des districts technologiques caractérisés par des systèmes de communication à plusieurs chaînes, favorise l'accès à la connaissance externe, considéré de nos jours comme un facteur intermédiaire indispensable à la connaissance technologique, et encourage l'introduction des transformations technologiques localisées, ce qui entraîne des mécanismes de renforcement autonomes basés sur des rendements accroissants localisés.

Communication Connaissance technologique localisée Districts technologiques

ANTONELLI C. (2000) Kollektive Wissensvermittlung und Innovation: Beweismaterial technologischer Gebiete, *Reg. Studies* 34, 535–547. Technologisches Wissen ist ein Gemeingut insofern als seine Schaffung das Ergebnis eines Prozesses darstellt, in dem Einzelinformations- und Wissensbrocken zusammengefügt werden, die von vielerlei Gruppen stammen und als solche gehandelt werden können. Dank niedriger Geschäfts-und Kommunikationskosten können externe technologische Faktoren ihre Wirkungen angesichts zunehmendem Profits und positiver Rückinformationen voll einsetzen. Die Bedingungen und Merkmale von Kommunikationsprozessen erklären die Häufung von Innovationen in genau umschriebenen regionalen Räumen. Örtliche Begrenzung in technologischen Distrikten, die in Mehrfachkanalsystemen für Kommunikation vorkommen, begünstigen den Zugang zu Außenwissen, das jetzt in der Generation tcchnologischen Wissens als wesentlicher Vermittlungsaufwand angesehen wird, und fördert die Einführung örtlich begrenzten technologischen Wandels, der zu einem sich selbst verstärkenden, örtlich begrenztem, auf zunehmendem Profit beruhenden Mechanismus führt.

Kommunikation Örtlich begrenztes technologisches Wissen Technologische Gebiete

INTRODUCTION

The clustering of fast rates of introduction of technological changes in well defined regional districts has been the object of a growing attention in recent economic analysis (JAFFE *et al.*, 1993; FELDMAN, 1994; PATEL, 1995; SWANN *et al.*, 1998).

Two traditions of analysis have contributed to the development of this field: the transaction costs and the externality schools, respectively. The externality approach stresses the role of increasing returns within circumscribed regional spaces to which firms have access because of the important role of proximity. Externalities stem from imperfect divisibilities among

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production factors; proximity provides enhanced opportunities for agents to internalize their benefits (BRUSCO, 1982; ANTONELLI, 1986; BECATTINI, 1987). The transaction costs approach, by contrast, values the role of proximity in terms of the enhanced confidence and trust that make it possible to reduce the costs involved in the definition of a proper price for goods that have been already manufactured (STORPER and HARRISON, 1991; HARRISON, 1992).

Although the two approaches are often mingled in most analyses, it seems important to stress that they refer to radically different analytical frameworks. The externality approach in fact has been elaborated to accommodate increasing returns. On the contrary, the transaction cost approach identifies such local systems as 'perfect markets' where no market failure takes place and *ex-post* co-ordination is perfectly achieved by markets. An effort seems necessary to provide a single integrated framework which actually combines the two approaches and yet is able to appreciate their distinctive features.

The main purpose of this paper is to provide such an integrated approach building upon the notions of collective knowledge, technological communication and technological districts as key factors in the definition of the rate of technological change.

The paper is structured as follows. The next section provides the basic analysis of the role of communication in technological change. The third section identifies the distinctive features of technological districts in technological communication and provides a framework for empirical analysis. The conclusions summarize the main findings.

THE ROLE OF COMMUNICATION IN THE DYNAMICS OF LOCALIZED TECHNOLOGICAL CHANGE

A framework to integrate the transaction cost approach to understanding the dynamics of innovation clusters with the externality framework can be elaborated impinging upon the notion of localized technological knowledge.

Recent developments in the economics of technological knowledge have stressed the demise of the linear model which related unidirectional scientific progresses to technological advances and the decline of the notion of technological knowledge as a bookshelf of blueprints easily available to everybody (KLINE and ROSENBERG, 1986). A new understanding has been implemented. In this new approach technological knowledge is distinct and yet biunivocally interactive with scientific knowledge (METCALFE, 1995). Second and most important, technological knowledge is now viewed as an indivisible and yet fragmented and dispersed stock of structured information. Because of its highly idiosyncratic applications and specific contexts of implementation, technological knowledge is embedded in a great variety of specific productive and market conditions and partially owned by a wide variety of agents each of whom is able to command a limited portion of it (COHEN and LEVINTHAL, 1989). Third, following and elaborating upon Simon's contribution (SIMON, 1985; LOASBY, 1998), innovative capabilities and broadly the ability to generate new technological knowledge are now seen as resting upon a specific learning capability which draws from diverse knowledge bases and is able to activate a systemic recombination process.

Specifically, in a framework elaborated by synthesizing the Marshallian and Neo-Schumpeterian traditions, the generation of new technological knowledge is now viewed as a localized process heavily dependent on the multiplicative relationship of: (1) internal learning processes which lead to the accumulation of tacit knowledge; (2) internal R&D activities which enable codified knowledge to be gathered; (3) access to the external tacit knowledge, experience and competence independently owned and implemented by each firm; and (4) the recombination of the stock of existing codified knowledge, external to each firm and yet internal to the economic system. In such a complex mix, each element is indispensable (ANTONELLI, 1999).

Technological knowledge as a collective good

This approach to the economics of technological change and the new emphasis on the key role of existing internal and external knowledge, viewed as an essential intermediary input, makes it possible to reconsider the notion of technological information as a public good.

The public character of technological information emerges in the context of allocation analysis. According to a long standing tradition, technological innovation should be considered a public good in that 'one man's consumption does not reduce some other man's contribution' (SAMUELSON, 1954, 1955). Following the seminal contribution of ARROW, 1962, technological information in fact exhibits the classical features of non-excludability and non-rivalry in use and as such is difficult to appropriate. The definition of technological information as a public good clearly refers to its conditions of distribution and use, rather than to the conditions of the generation process.

A different picture emerges when attention is focused on the conditions of production of technological knowledge. From this view point, technological knowledge exhibits clear features of a collective good. A collective good is found when its production process is shaped by radical indivisibility and hence complementarity of inputs.

The production of technological knowledge is strongly influenced by both horizontal and vertical indivisibility and systematic cumulability. The generation of new technological knowledge is in fact affected by vertical indivisibility or cumulability in that it is generated mainly using previous technological knowledge, i.e. standing on the shoulders of giants. The generation of new technological knowledge is also characterized by horizontal indivisibility in that each increase, even within a narrow field, can have important effects in terms of complementarity and additionality with other parallel and yet convergent advances made in seemingly unrelated fields and contexts[2] (STEPHAN, 1996).

Major economies of density shape the cost function of innovation activities. In fact the accumulated stock of competence and technological knowledge acquired by each agent exerts strong inter-temporal effects so that average costs decline with the repeated use of such superfixed production factors. By the same token most innovation costs, that is the costs of generating additional technological knowledge and extracting relevant technological innovations, can be portrayed as incremental costs which are added to existing long term fixed costs. In this context the costs of searching, locating and accessing the relevant external knowledge also play a major role.

The basic argument here is that in a world where nobody can claim full control of all existing knowledge, each agent possesses diverse and yet complementary pieces of information and knowledge which are not only useful *per se*, that is in the dedicated activity in the course of which they have been implemented and elaborated, but also for broader and different uses (RICHARDSON, 1998; ALBIN, 1998). In a parallel way, it is clear that each individual advance is not only useful for the specific dedicated purpose for which it has been elaborated but also for a variety of other possible uses. This latter argument is important in many ways: specifically each piece of information is useful at large both in a positive way, in that it enlarges the amount of knowledge available, and in a negative way, in that it helps identify dead ends and blind alleys, reducing the waste of resources by third parties.

As such the generation of technological knowledge is characterized by radical indivisibility and hence increasing returns which are both internal and external to each firm. However, technological knowledge is dispersed among many different agents and institutions, while the generation of new knowledge takes place at the same time at each agent's premises. The generation of each new bit of technological knowledge by each agent requires access to the (fragmented) pool of existing knowledge. Moreover the generation of new knowledge by each agent benefits from instantaneous access to the new bits of knowledge generated by each other agent. In other words our basic argument is that the perfect access of each agent to: (1) the knowledge stored in each other agent; and (2) the research and learning activities of each other agent would greatly enhance the productivity of resources invested in the generation of new knowledge.

The notion of localized knowledge is relevant in this context, and our analysis applies to the conditions for the generation of new localized knowledge. The access to fully codified and generic, scientific knowledge is in fact, to some extent, provided by universities and academic training which performs the basic role of maintaining the basic pool of scientific and codified knowledge and making it available to students.

Universities moreover also provide basic access to their research activities through the medium of publications. Access to technological knowledge by contrast, especially when its localized character is stressed, is made difficult by its tacit and idiosyncratic character. Yet technological knowledge and technological procedures elaborated by company A to solve a specific and highly idiosyncratic problem in a completely different and apparently unrelated context can be of great help to company B active in another industry and even in a different technological field.

In this context it is clear that the productivity of that piece of knowledge would be greatly enhanced if each agent were ready to put in a common pool each piece of knowledge which in fact is complementary to a variety of others. More generally, I would argue, the generation of knowledge provides the archetypal evidence of a network process where the productivity of the resources is larger the larger the number of agents that take part in it. In other words I am raising an issue of network externalities on the supply side in that the productivity of that specific asset is a function of the number of complementary pieces each other agent is ready to contribute to the (collective) undertaking.

Along these lines of analysis growing evidence emerges of the collective character of technological knowledge. Technological knowledge is collective when and if it is the result of a process that combines pieces of information and knowledge that are owned by a variety of parties and cannot be traded as such. From this view point the definition of a collective good and specifically technological knowledge refers to the production process of a new good, rather than to its allocation.

The tradition of analysis of technological information as a public good is embedded in allocation analysis while our approach to technological knowledge as a collective good builds upon the analysis of the generation process of new technological knowledge where existing technological knowledge is an input into the generation of new technological knowledge. Existing technological knowledge, however, is an indivisible and yet fragmented production factor whose command and ownership is dispersed in the economic system.

The difference with respect to the public good approach is sharp in that it should be clear that a new piece of knowledge, generated by means of existing, indivisible and yet dispersed and, as such collective, technological knowledge can be itself partly appropriated because of high levels of reproduction and imitation costs. In this case, a new piece of knowledge has been generated with the contribution of a variety of knowledge elements each of which was owned and controlled by a variety of agents, but once generated it can be partly appropriated by the agent who has been able to master the generation process. Hence we have the case that a piece of knowledge can be collective and quasi-public, as well as collective and public. In the former case a piece of technological knowledge is the result of the recombination of a variety of preliminary elements and bits of knowledge dispersed in the economic and technical system and once produced cannot be appropriated.

Within this framework the collective nature of technological knowledge highlights the importance of the conditions for accessing the technological knowledge already stored, but dispersed in a myriad of applications and developments. These conditions become a key factor in improving the rate of technological advance in any economic system (CARTER, 1989; ARORA and GAMBARDELLA, 1994).

Transaction costs and externalities in the generation of localized technological knowledge

Drawing upon this framework, the integration of the externality approach and the transaction cost approach becomes productive in explaining why and how some economic environments are more conducive to fast rates of introduction of technological change, for a given amount of dedicated resources, than others. Technological change in fact is primarily generated by technological knowledge which in turn is heavily influenced by each agent's conditions of access to the indivisible and yet fragmented pool of existing knowledge.

Static and dynamic access are, however, made difficult by many transaction costs. First, the public good character of existing technological knowledge and the related well known appropriability problems play a major role. Agents are reluctant to make access to their own bits of knowledge easy because it would further reduce their appropriability conditions, especially for competitors and prospective imitators. Second and relatedly, the owners of each bit of knowledge are rarely aware of the value of their own portion of knowledge for other users that are not strict competitors and as such prospective imitators. The stronger the appropriability conditions of existing technological knowledge owned by each agent, and the larger the possibility of trading it in the market place without any risk that access is restricted and rationed, the easier it is for both the vendor and the customer to meet in the market place and fix a price for it.

This analysis suggests a need to reconsider the traditional knowledge trade-off; with a strong intellectual property rights regime which does not care for the implicit risks of technology-rationing, the owners of technological knowledge, in the absence of a fully articulated market for technological knowledge, may limit access to their knowledge and ration all technological sales with clear costs in terms of duplication and foregone output due to unrealized increasing returns. On the contrary a property rights regime which does not provide any protection is likely to encourage industrial secrecy with evident costs in terms of communication and search costs for prospective users. An intellectual property rights regime designed to enforce both appropriability and derivative usage seems, in this context of analysis, necessary. Derivative property rights on the knowledge generated by means of proprietary knowledge on the one hand, or copyright-oriented intellectual property right regimes which reduce excludability but enforce the remuneration of owners, might become useful solutions. THUROW, 1999, has recently aired the growing concern about the need for a change in intellectual property rights regimes stressing the need to enforce better appropriability and yet at the same time reduce excludability, suggesting that different classes of patents could be created. Technological knowledge with a strong generic content and with a large scope for wide applicability to many different economic activities could be patented but with compulsory licensing obligations. Extensions of existing knowledge with a stronger idiosyncratic content could be patented with high levels of excludability (see also SCHERER, 1999).

Access to existing knowledge, however, is harmed by communication costs. Establishing the complementarity to one's own technological knowledge and one's own research agenda of each other bit of knowledge and each other on-going research and learning process is a time-consuming matter of discovery. Substantial search, decodification and assessment costs may induce each agent to reproduce internally the necessary knowledge. Technological knowledge in fact is industry-specific, region-specific and firm-specific; and because of this it is costly to use it elsewhere, in other industries, other regions and other firms (ANTONELLI, 1999).

The stronger the codified content and the lower are the decodification costs, the larger is the possibility for prospective customers to screen the market place and assess the relevant bits of knowledge which are actually complementary. Clearly when and where each bit of technological knowledge is kept hidden and obscure as a result of the strategic behaviours of owners worried about low replication costs and high imitation opportunities for third parties, and moreover where the search, assessment and decodification costs are high because of its large tacit and idiosyncratic content, access to external knowledge becomes extremely costly and is substantially barred (Hirschleifer, 1971).

The notion of collective goods is important in this case in that it strongly entails externalities. Externalities, as it is well known, emerge from imperfect divisibilities of production factors. The useful distinction introduced by Griliches, 1992, building upon Scitowsky, 1954, between rent technological externalities, i.e. pecuniary externalities for which external knowledge is actually purchased at low(er) prices with significant consumers' surplus, and knowledge technological externalities for which technological information is available in the atmosphere, seems very useful. In our communication approach, knowledge technological externalities matter as much as rent technological externalities.

The distinction between symmetric and asymmetric externalities is also relevant in this context. The symmetric externalities case clearly applies to two companies working in totally unrelated industries which can share symmetrically the benefits of some technological breakthroughs. The asymmetric externalities case applies to typical user–producer relations where either is able to take advantage of the knowledge generated externally. Firms are ready to join the collective undertaking only when the advantages stemming from cooperative behaviour are larger than costs in terms of leakages of proprietary knowledge. When returns in the production of collective knowledge are increasing, such a situation can easily arise.

The conditions for symmetric externalities in the communication of technological knowledge are very strong for all parties engaged in technological communication who 'share the same code' and hence symmetrically benefit from a radical reduction in the huge decodification and search costs necessary to locate the bits of existing and external knowledge which can be directly relevant to each firm's new technological knowledge generation process. Technological communication itself is a collective good where each agent and each party is interested in enhancing the communication conditions among all the members of the community. Technological communication, however, is an interactive process where both parties are actively and purposely involved. The levels of effective technological communication depend upon the resources devoted by each agent to establish technological connections with other firms and academic and scientific institutions in innovation systems and the amount of information that each firm is able to receive and actually assimilate from the innovation system in which it operates.

Technological communication and technological knowledge

The institutional context of economic systems in terms of communication conditions plays a major role in assessing their innovation capabilities. Access to external tacit and codified knowledge depends on the extent to which effective communication among innovators takes place through the innovation system. In this context the properties of economic systems, conceived as communication networks into which information flows, matter in explaining the capability to generate new technological knowledge (Hayek, 1945; Lamberton, 1971, 1996,1997).

The notion of technological communication makes it possible to appreciate the role of technological externalities and yet complements it with the notion of transaction costs in the absorption and communication of external technological knowledge. While the notion of technological externalities is consistent with the Arrovian notion of technological information, a public good with low levels of appropriability and excludability, it misses the key role of the specific costs that the decodification and understanding of available information entail. The traditional approach in fact assumes that technological externalities do spill freely into the environment, and no provision is made to take into account the relevant costs of search, decodification and assessment of existing technological knowledge dispersed in a myriad of agents and buried in tacit and idiosyncratic procedures. Technological communication differs from technological externalities. Too much emphasis has been put in the innovation systems' literature on technological externalities as if external technological knowledge could be acquired freely in the 'atmosphere' without dedicated efforts. In other words it is not sufficient that technological externalities are freely available in the air for effective technological communication to take place. Substantial communication costs are to be accounted for. The notion of technological communication seems far more appropriate to the new theorizing about the quasi-private nature of localized technological knowledge from the allocation viewpoint and its collective nature from the generation viewpoint.

Within communication networks, we see in fact that, at each point in time, the magnitude and the impact of the effective flow of information which is both emitted and received by each agent can be thought to be the outcome of the interaction between two classes of stochastic events: (1) the connectivity probability that the flows of effective communication and the exchange of information take place; and (2) the receptivity probability that the results of the research and learning efforts of each firm in the system are effectively assimilated. This methodology moreover makes it possible to reproduce analytically the dynamic laws of a process where the actual transfer of technological information can either take place or decay: stochastically in fact communication can fail (David and Foray, 1994; Krugman, 1996; Antonelli, 1999).

The location of each agent within communication flows becomes extremely important in this context.

Communication flows are multi-channel in that they take place at different levels and involve many different aspects of economic interactions. Moreover communication flows are complex and structured. At any point in time we can observe at each layer well defined structures of communication flows where some agents are better located than others in that some agents have access to more communication links than others and some agents happen to have access to more effective links than others. Specifically we see that some agents can be more receptive than others for a given level of available technological externalities. And we also see that some agents have access to technological externalities at low communication costs, while others do not have such access. From the viewpoint of the specific role of each agent within the communication flow network, analysis provides important insights in that it makes it possible to understand the dimension of the relevant networks in place, their density and their structure, so that each agent can be classified in terms of the number and quality of the links in place.

According to the hypotheses outlined above, it is assumed that the production of technological knowledge by each firm can be formalized as the result of the interaction of internal research and learning activities, creative access to external technological knowledge and its actual implementation. The different levels of effective communication among innovators, as measured by the mixed probability of communication processes, are likely to affect significantly the productivity of the total amount of resources devoted by each firm to research and learning activities and hence reduce substantially innovation costs (NELSON, 1987).

In sum, high levels of innovation activities, as induced by good technological communication conditions are likely to increase the amount of external knowledge available, as well as the access to both rent and knowledge technological externalities. This in turn affects positively the efficiency of research activities and further stimulates the firms in their innovative efforts. All the characteristics of a self-reinforcing mechanism, based upon positive feed-backs, are now in place. Local communication probabilities at time t are likely to affect the behaviour of agents not only with respect to the levels of their innovation activities but also to the levels of deliberate action taken to build up connections and receptivity which can enhance the efficiency of the funds invested in research activities. Hence the local communication probability at time $t + 1$ is influenced but, because of its stochastic nature, not determined by the conduct of the firms and the outcome of their interactions at time t.

This process is especially evident within technological districts such as Turin in Piedmont, Modena and Bologna in central Italy, Toulouse in France, and Route 128 and Silicon Valley in the US[3] (ANTONELLI, 1986; RUSSO, 1985, 1996; DORFMAN, 1983).

TECHNOLOGICAL COMMUNICATION AND INNOVATION WITHIN TECHNOLOGICAL DISTRICTS: A REVIEW OF THE EVIDENCE AND AN AGENDA FOR EMPIRICAL RESEARCH

Location plays a major role in favouring technological communication, but agglomeration *per se* is not sufficient for technological communication to take place. Technological communication takes place at a variety of levels. Important scope for empirical analysis emerges when the different forms of interaction of firms in the different market places are analysed from the view point of their implications for communication. This analysis is especially relevant when it takes into account the variety of channels by means of which technological communication can take place within technological districts as well as the variety of positions within each channel of each agent.

A tentative review of the rich and still growing empirical literature makes it possible to list five different and relevant communication channels:

1. *Factor market conditions play a major role.* Labour markets provide important opportunities for technological communication. Interfirm mobility greatly enhances the dissemination of information. As a matter of fact external labour mobility is a basic factor in the recombination of existing information and in the regeneration of a common information pool within an economic system. Intrafirm labour mobility performs a similar role at the company level although within a narrower field of action. Hence we can expect that the greater interfirm labour mobility, the higher the rates of technological communication. Economic systems where seniority within companies plays a major role can suffer from a reduced level of technological communication. The result can be even worse in the case of an economic system with reduced interfirm and intrafirm labour mobility. It is clear in fact that, if too fast, labour mobility can reduce the scope for learning processes, and a rigid allocation of personnel to limited tasks within the same company can impede the dissemination and recombination of all technological information (BRUSCO, 1992; SALAIS and STORPER, 1992; CLARYSSE *et al.*, 1995; EDQUIST, 1997).

   Intermediary markets also play a major role in enhancing technological communication. The role of both upstream and downstream user–producer relations has been greatly appreciated by much economic analysis. It seems clear that an economic system with an articulated industrial structure with many intermediary markets where a variety of firms interact in the provision and purchase of specific intermediary inputs can support technological communication much better than economic systems where vertically integrated firms control the full *filière* (LUNDVALL, 1985; RUSSO, 1985; VON HIPPEL, 1988; LANGLOIS, 1992; SAXENIAN, 1994; ROBERTSON and LANGLOIS, 1995).

Financial markets play a major role not only for the well known venture-capital effects, but also as active factors of interorganizational mobility because of the possibilities for merger and acquisitions they offer and hence the scope to change the borders of firms in terms of external growth via integration and diversification as well as sell-off with increased specialization. From a technological communication viewpoint, financial markets, especially for new innovative firms, can become a major tool in implementing the 'mix and match' generation of new technological knowledge. Local accessibility to such financial markets in turn becomes a key factor in sustaining the rates of introduction of technological change (see SCHERER, 1999).

2. *The features of local industrial structures are also important.* Proximity and co-localization within a local system favour both the intrasectoral and intersectoral dissemination of technological knowledge both vertically and horizontally.[4] Intersectoral communication is especially relevant when general purpose technologies are at play: agents are much less reluctant to share their knowledge with firms active in other markets. Relevant barriers to communication arise, however, from the differences between codes and the idiosyncratic character of the information available. New technological knowledge generated in one industry however often has considerable potential for direct applications in other industries either in common functions or along the production *filière* or even beyond in user–producer interactions. As far as intersectoral dissemination is concerned, communication can be thought of as the outcome of the co-operative attitudes of agents who can share new technological knowledge with little fear of harming appropriability conditions due to differences in their markets and customers. The reverse is true for intrasectoral communication; the risks for opportunistic behaviour are higher, as are the homogeneity of languages and codes. Technological communication here can easily become a factor of imitation. While collective innovation is harmed by appropriability concerns, the diffusion of both product and process innovations is very fast.

The enhanced division of inter-industrial labour seems extremely relevant for technological communication as far as knowledge intensive business services are concerned. Here in fact it is clear that vertical integration within manufacturing companies of an array of advanced services reduces the scope for dissemination and recombination of specific technological knowledge that, once generated for one single use, can be easily applied to a variety of different contexts. This approach makes it possible to appreciate the characteristics of regions in terms of sectoral composition and the related opportunities for technological outsourcing by firms. The distribution and quality of knowledge-intensive business service industries in fact have important effects on the economic system in terms of its innovative capacity. An increase in the exchange of tacit knowledge, made possible by the local supply of the services of consultants and advisers, improves connectivity between agents, leads to a sharing of learning experiences and a creation of learning opportunities, and thus advances receptivity. Similarly, improved business services, in terms of distribution, capillarity, competence and access, improve the interaction between tacit, localized knowledge and increasingly larger amounts of generic knowledge, and in so doing are conducive to the accelerated introduction of technological and organizational innovations and solutions specifically tailored to a firm's individual needs. An active local supply of knowledge-intensive business services can stimulate technological outsourcing and hence the demand for knowledge-intensive services by small and medium sized firms in particular (ANTONELLI, 1999).

The coexistence of large and small firms within technological districts appears a critical element for many reasons. Communication is enhanced by variety and diversity among agents. The greater the opportunity for the exchange of information between firms, the larger are the differences in the channels in terms of the typology of the knowledge accumulated, the scope for its implementation and the sets of competencies. Small firms can benefit from faster decision making and entrepreneurial reaction than large firms. The latter can access the advantages of economies of size in conducting research and development activities. Firms, according to size, differ with respect to the typology of knowledge they produce and the knowledge they use. Large firms have a clear advantage in the production of codified knowledge while small firms excel in the accumulation of tacit knowledge. In turn, however, large firms mainly depend upon external tacit knowledge and small firms on external codified knowledge. The interactive coexistence of large and small firms is vital in enhancing the accumulation and circulation of technological knowledge. The key role of large firms within technological districts marks an important difference with respect to the Neo-Marshallian approach to industrial districts which emphasizes the role of small firms together with their homogeneity in terms of size (ANTONELLI, 1986; BECATTINI, 1979, 1987).

Industrial dynamics and specifically the entry and exit rates of firms are one additional and important channel of technological communication. The entry of either newly established firms, or the cross-entry of incumbents in other industries and other regions, enhance technological communication because they provide opportunities for the dissemination of the techniques and information well established in one industry and region to others. This is typically the positive effect of the entry of multinational companies. Newly founded firms on the other hand typically represent the opportunity for new ideas to be tested and hence communicated in the market place. Rich and detailed empirical evidence is provided by SWANN *et al.*, 1998, who stress the differences among entrants and incumbents in their capability to absorb spillovers. Specifically they show that spillovers in radical innovations tend to induce entry rather than rapid growth amongst incumbents.

3. *The knowledge infrastructure of the local innovation system is the third channel.* The level of the local academic infrastructure and the degree of interactivity with the local business community play a major role. The university and academic community at large do diffuse scientific and technological externalities as much empirical evidence has shown. Access to such externalities appears easy, however, only when (and if) the academic and the business community have established clear ways of interaction and communication as is often the case in the US. In this context the flow of postgraduate students from universities to firms is high as is the funding of academic research activities by firms. This is not the case in Europe where as a matter of fact the empirical evidence concerning the positive effects of academic externalities is much less strong[5] (MANSFIELD, 1991; BANIA *et al.*, 1993; JAFFE *et al.*, 1993; AUDRETSCH and STEPHAN, 1996; FELDMAN and AUDRETSCH, 1999).

The localized interaction between education and training and production are all the more useful to enhance rates of technological communication within a system. The alternation of training spells throughout the productive life of individuals can greatly favour the circulation of information within an economic system. The traditional concentration of education in youth with limited access to retraining later in life clearly reduces the chances for technological communication to take place (EDQUIST, 1997; FREEMAN, 1991, 1997).

The regional concentration of the research laboratories of industrial firms adds on to the opportunities for smaller firms located nearby to take advantage of technological externalities at low communication costs and enhances the probabilities that firms can take advantage of interstitial technological opportunities that are considered internally as second best and yet can lead to profitable technological innovations for smaller firms. The regional concentration of research laboratories can also become the institutional device for symmetric communication externalities among large firms (HOWELLS, 1990; QUÉRÉ, 1994; PATEL, 1995)

New emerging markets for disembodied technological knowledge where firms sell and buy patents, know-how and trade technological licences seem to pave the way to the increasing specialization of regions and firms in the generation of dedicated technological knowledge. The active search for licences of patents and know-how can help firms access the external knowledge available on international and domestic markets. Such external technological knowledge can be recombined and contribute to the internal elaboration of tacit and codified knowledge with evident advantages in terms of efficiency of the intramuros R&D activities (ARORA and GAMBARDELLA, 1990; ARORA, 1995, 1997).

4. *The quality of local communication infrastructure is the fourth factor.* The emphasis on the role of technological communication makes it possible to appreciate how the characteristics of the present wave of innovation in communications technology, itself a product of the clustering of localized and complementary technological changes, are likely to interact with the rate of introduction of localized technological changes to enhance the general levels of innovation capability of firms. The quality of local communications networks can play an important role in favouring the division of innovative labour when high speed data communication can take place and high-definition images can be easily transferred among research units. As growing evidence confirms, digital communication can complement rather than substitute for person-to-person communication. Technological districts with high-quality communication infrastructure can benefit from the spiralling interactions between digital and *vis-à-vis* communication (ANTONELLI, 1999).

Second and most important, substantial empirical evidence shows that urban and especially metropolitan areas provide a far more positive environment for communication and hence more opportunities to foster the rate of technological change (CASTELLS, 1989). Proximity and spatial density also enhance technological communication informally because of the higher chances of repeated interactions among heterogeneous and yet complementary agents. Co-localized firms within metropolitan areas have higher chances of sharing a common language and hence of saving on the costs of codification and decodification of information about technology as well as business conditions (ALLEN, 1983; FREEMAN, 1991; UTTERBACK, 1994; HARRISON *et al.*, 1996).

This is the third important difference between Marshallian industrial districts and technological districts (see BECATTINI, 1979, 1987, 1989;

Bellandi, 1989; Brusco, 1992; Bellandi and Russo, 1994; Russo, 1985, 1996). The traditional Marshallian district in fact, especially in the Italian literature, is mainly characterized as a regional space with low levels of population density and low levels of intraregional concentration of plants and firms. Metropolitan areas seem able to provide the mix of variety and complementarity of economic activities, endowment of scientific infrastructure and high quality of communication systems which favour technological communication.

5. *Localization and technological strategies are the final element*. Location plays a major role in favouring *ex-ante* co-ordination among innovating agents. As Richardson, 1972, clearly anticipated, *ex-ante* co-ordination plays a key role in the 'transfer, exchange or pooling of technology' (p. 892). According to Richardson:

> . . . the essence of co-operative arrangements . . . would seem to be the fact that the parties accept some degree of obligation – and therefore give some degree of assurance – with respect to their future conduct. But there is certainly room for infinite variation in the scope of such assurances and in the degree of formality with which they are expressed (p. 886).

Better information about the research agenda and mutual understanding of the competencies of agents are available within technological districts. This favours the division of innovative labour, enhancing specialization in complementary but dissimilar innovation activities and reducing duplications. Opportunistic behaviour is also constrained within technological districts by the long term interactions associated with co-localization; co-localization, as a matter of fact, can be thought of as a symmetric hostage. Transactions in disembodied technology and licensing agreements may be easier for firms co-localized within technological districts; continuity in the relationship favours the supply of technical assistance. As a consequence, better implicit co-ordination of investment decisions is achieved within technological districts where it is easier to gather information about the market conduct and the technological strategies of each agent.

Professional associations and industrial clubs provide important opportunities for technological communication and should be considered key factors in the definition of the organization of an industry. Ever since the path breaking analysis of Richardson, 1972, professional associations, including collective research institutions, are seen as basic institutions that facilitate the diffusion of relevant knowledge within limited regional spaces and that are conducive to a variety of forms of tacit exchange of information and know-how. Locally technological co-operation is often the result of implicit strategic actions taken by co-localized firms to increase connectivity and receptivity levels and hence technological communication (Dorfman, 1983; Watkins, 1991; Saxenian, 1994; Clarysse *et al.*, 1995; Hagerdoorn, 1995).

To a large extent intentional co-localization within technological districts and active participation in local communication systems can be thought of as a distinctive form of technological co-operation which can complement and even substitute for more formal technological partnership within footloose technological clubs (see Fransman, 1995, 1999, for detailed analyses of different forms of co-operative organization in innovation activities). The quality of receptivity and connectivity among agents can be influenced by deliberate strategies such as location close to other innovators. Location within technological districts moreover is also relevant for other factors than communication as it can help *ex-ante* co-operation more generally, favouring the co-ordination of different agents both with respect to technological strategies and investment decisions (Richardson, 1960).

In sum, location plays a major role in enhancing technological communication because of its positive effects on both connectivity and receptivity, provided a variety of communication channels are in place. Each of these local communication channels differs widely in terms of its effects, because of the role of density and interactivity. Moreover agents may have a differentiated role within each communication system. Agents can be marginal or central, and can be well connected or poorly connected. Agents can be poorly connected to strong actors and well connected to weak nodes. Here graph theory provides important methodological help to qualify both communication networks and the role of each agent within each of them.

The interaction of the different channels along which communication occurs and the quality of each communication system, as well as the appreciation of the role of each agent within each communication system, provide the final picture which can approximate the actual capability of firms to participate in the general communication process and the chances it has of taking advantage of the existing and yet fragmented pieces of technological knowledge available in the system. The innovative behaviour of firms is deeply affected by the local 'milieu' in that it provides the communication context and hence the intersection of classical agglomeration effects with specific firm effects and the features and characteristics of the distribution of existing technological knowledge, now viewed as an essential intermediary product. The complexity and multichannel dimension of local communication systems provides an important agenda for empirical research. Communication channels in fact complement each other especially within technological districts where proximity and agglomeration provide a complex web of interaction mechanisms.

In turn regional clusters can be ordered in terms of the variety and complementarity of communication channels in place: technological districts can now be defined as regions where technological externalities and low communication costs are especially conducive to raising the rate of introduction of technological changes and increasing the positive effects of agglomeration in terms of pecuniary and technical externalities.

CONCLUSIONS

Agglomeration is not a sufficient condition for a clustering of technological innovation and a diffusion of technological externalities. A number of important communication channels are necessary, and only their combination provides a conducive environment for encouraging the rate of accumulation of collective knowledge and the eventual introduction of technological innovations.

A communication based approach seems useful in many ways. First, it provides a theory to understand the dynamics of agglomeration within technological districts. The interplay between the collective character of technological knowledge and the characteristics of local communication processes is such that, in technological districts, i.e. regions with high levels of communication probability, the conditions for the circulation and actual assimilation of technological information and the introduction of technological innovations reinforce each other with a self-reinforcing mechanism based upon the dynamics of positive feedbacks.

Second, the dynamics of localized technological change and communication processes can explain the interplay between the externalities and the transaction costs approaches. Low transaction costs, namely communication costs, in fact make possible a full realization of the effects of technological externalities in terms of increasing returns and a virtuous self-reinforcing of agglomeration and economic growth. With high communication costs, technological externalities exert only a limited positive effect and firms, with given profitability conditions, are much less inclined to fund research and development activities and introduce technological innovations. By contrast, with effective multichannel communication systems in place, technological externalities can effectively 'spill' into the air and recipients can take full advantage of the collective nature of technological knowledge, reducing its intrinsic dispersion and taking advantage of its complementarity and indivisibility.

Third, it seems clear that technological districts differ significantly from industrial districts. The latter are characterized mainly in terms of high levels of Marshallian externalities among small firms localized in regions with small populations and small cities. By contrast the former are characterized by the coexistence of large and small firms, a large multisectoral range of economic activities including both manufacturing and service industries, a strong metropolitan character and an important scientific and communication infrastructure.

Finally, the implications for industrial and innovation policies are far-reaching. When the collective components of technological knowledge are identified together with the important role of external knowledge as an essential intermediary input, the characteristics of local innovation systems and specifically of technological districts, i.e. regional clusters of learning firms, working in complementary technologies, in terms of the quality and effectiveness of all of the communication networks within which technological information is shared and transmitted from one firm to another, become relevant and warrant greater attention. An appreciation of the factors governing technological communication and the effective internalization of local technological externalities among firms which are involved in complementary innovation activities become a possible strategy for public intervention in that such activities will lead to an increase in the productivity of the resources invested in innovation activities.

A second and more important issue concerning regional innovation policy should however be raised. High regional concentrations of innovation capabilities within technological districts play a major role in fostering the national rate of technological change. This 'spontaneous' concentration of factors takes place, within a country, in a limited number of regions. Its 'artificial' reproduction seems a complicated task. This leads one to wonder whether the classical debate about the Schumpeterian trade-off between static and dynamic efficiency might apply at a regional level as well. A large amount of empirical evidence, gathered in industrial economics, suggests that while low levels of concentration are a condition for the achievement of static efficiency, oligopolistic rivalry among a limited number of large firms is more conducive to dynamic efficiency in terms of faster rates of introduction of innovations. In this context it seems likely that the concentration of scientific and academic infrastructures and public subsidies in a few technological districts might be considered an appropriate choice in order to sustain the aggregate rate of technological change.

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NOTES

1. A preliminary version of this paper was presented at the IRIS Workshop of Artimino in September 1998.
2. Formally we can write a production function for the generation of new 'localized' technological knowledge (LTK) by each firm where the internal efforts of research and learning (R&L) enter multiplicativily with the stock of existing knowledge (SK) to which the firm has access. In turn the efficiency of the stock of knowledge is a function of the number of agents (N) involved in technological communication in each firm. Hence we can write: $LTKi = f(R\&L^a, SK^b)$, where $b = f(N)$.
3. The stochastic nature of communication processes however makes such self-reinforcing feedback mechanisms random. Mixed communication probabilities are especially sensitive to all perturbations in both connectivity and receptivity probabilities. In such conditions, local innovation systems may eventually experience a sharp reduction in general communication efficiency and reverse negative feedbacks may take place with major discontinuities in long term growth patterns.
4. A large literature refers to intersectoral externalities as 'Jacobs externalities' and contrast them with MAR (Marshall-Arrow-Romer) intrasectoral externalities which characterize industrial districts (See Becattini, 1979, 1987, 1989; Brusco, 1992).
5. In the econometric jargon one could claim that much of the econometric evidence of the positive role of academic research on local economic growth suffers from a systematic misspecification of the role of technological communication.

REFERENCES

Albin P. S. (1998) *Barriers and Bounds to Rationality.* Princeton University Press, Princeton, NJ.

Allen R. C. (1983) Collective invention, *J. Econ. Behav. & Organiz.* 4, 1–24.

Antonelli C. (1986) *L'Attività Innovativa in un Distretto Tecnologico.* Edizioni della Fondazione Agnelli, Turin.

Antonelli C. (1999) *The Microdynamics of Technological Change.* Routledge, London.

Antonelli C. (2000) Restructuring and innovation in long term regional change, in Clark G. L., Feldman M. and Gertler M. S. (Eds) *The Oxford Handbook of Economic Geography.* Oxford University Press, Oxford.

Arora A. (1995) Licensing tacit knowledge: intellectual property rights and the market for know-how, *Econ. Innov. & New Technol.* 4, 41–60.

Arora A. (1997) Patents licensing and market structure in the chemical industry, *Res. Policy* 26, 391–403.

Arora A. and Gambardella A. (1990) Internal knowledge and external linkages: theoretical issues and an application to biotechnology, *J. Ind. Econ.* 37, 361–79.

Arora A. and Gambardella A. (1994) The changing technology of technological change, general and abstract knowledge and the division of innovative labour, *Res. Policy* 23, 523–32.

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 University Press, Princeton, NJ.

Atkinson A. B. and Stiglitz J. E. (1980) *Lectures on Public Economics.* McGraw-Hill, Maidenhead.

Audretsch D. B. and Feldman M. (1996) Spillovers and the geography of innovation and production, *Am. Econ. Rev.* 86, 630–42.

Audretsch D. B. and Stephan P. E. (1996) Company-scientist locational links: the case of biotechnology, *Am. Econ. Rev.* 86, 641–52.

Bania N., Eberts R. W. *et al.* (1993) Universities and the startup of new companies: can we generalize from Route 128 and Silicon valley, *Rev. Econ. & Statist.* 75, 761–66.

Becattini G. (1979) Dal 'settore' industriale al 'distretto' industriale; alcune considerazioni sull'unità di indagine dell'economia industriale, *Rivista di Economia e Politica Industriale* 2, 7–21.

Becattini G. (Ed) (1987) *Mercato e Forze Locali: Il Distretto Industriale.* Il Mulino, Bologna.

Becattini G. (Ed) (1989) *Modelli Locali di Sviluppo.* Il Mulino, Bologna.

Bellandi M. (1989) Capacità innovativa diffusa e sistemi locali di imprese, in Becattini G. (Ed) *Modelli Locali di Sviluppo.* Il Mulino, Bologna.

Bellandi M. and Russo M. (Ed) (1994*) Distretti Industriali e Cambiamento Economico Locale.* Rosenberg & Sellier, Turin.

Brusco S. (1982) The Emilian model: productive decentralization and social integration, *Camb. J. Econ.* 6, 167–80.

Carter A. (1989) Know-how trading as economic exchange, *Res. Policy* 18, 155–63.

Castells M. (1989) *The Informational City: Information Technology, Economic Restructuring and the Urban–Regional Process.* Blackwell, Oxford.

Clarysse B., Debackere K. and Van Dierdonck R. (1995) Research networks and organizational mobility in an emerging technological field: the case of biotechnology, *Econ. Innov. & New Technol.* 4, 77–96.

Cohen W. M. and Levinthal D. A. (1989) Innovation and learning: the two faces of R&D, *Econ. J.* 99, 569–96.

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, Proceedings of the World Bank Annual Conference on Development Economics.* World Bank, Washington, DC.

David P. A. and Foray D. (1994), The economics of EDI standards diffusion, in Pogorel G. (Ed) *Global Telecommunications Strategies and Technological Changes.* North Holland, Amsterdam.

Dorfman N. (1983) Route 128: the development of a regional high-technology economy, *Res. Policy* 12, 299–316.

Edquist C. (Ed) (1997) *Systems of Innovation: Technologies, Institutions and Organizations.* Frances Pinter, London.

ENGELBRECHT H. J. (1998), A communication perspective on the international information and knowledge system, *Inform. Econ. & Policy* 10, 359–67.

FELDMAN M. P. (1993) An examination of the geography of innovation, *Ind. & Corporate Change* 2, 447–67.

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

FELDMAN M. P. (1999), The new economics of innovation spillovers and agglomeration: a review of empirical studies, *Econ. Innov. & New Technol.* 8, 5–26.

FELDMAN M. and AUDRETSCH D. B. (1999) Innovation in cities: science-based diversity, specialization and localized competition, *Europ. Econ. Rev.* 43, 409–30.

FRANSMAN M. (1995) *Japan's Computer and Communications Industry.* Oxford University Press, Oxford.

FRANSMAN M. (1999) *Visions of Innovation.* Oxford University Press, Oxford.

FREEMAN C. (1991) Networks of innovators: a synthesis of research issues, *Res. Policy* 20, 499–514.

FREEMAN C. (1997) The national system of innovation in historical perspective, in ARCHIBUGI D. and MICHIE J. (Eds) *Technology, Globalisation and Economic Performance.* Cambridge University Press, Cambridge.

GRILICHES Z. (1992) The search for R&D spillover, *Scand. J. Econ.* 94(Supplement), 29–47.

HAGERDOORN J. (1995) Strategic technological partnership during the 1980s: trends, networks and corporate patterns in non-core technologies, *Res. Policy* 24, 207–31.

HARRISON B. (1992) Industrial districts: old wine in new bottles, *Reg. Studies* 26, 469–83.

HARRISON B., KELLEY M. R. and GANT J. (1996) Innovative behavior and local milieu: exploring the intersection of agglomeration firm effects and technological change, *Econ. Geogr.* 72, 233–50.

HAYEK F. A. (1945) The use of knowledge in society, *Am. Econ. Rev.* 35, 519–30.

HIRSCHLEIFER J. (1971) The private and social value of information and the reward to inventive activity, *Am. Econ. Rev.* 61, 561–74.

HOWELLS J. (1990), The location and organization of research and development: new horizons, *Res. Policy* 19, 133–46.

JAFFE A. B., TRAJTENBERG M. and HENDERSON R. (1993) Geographic localization and knowledge spillovers as evidenced by patent citations, *Quart. J. Econ.* 108, 577–98.

KELLEY M. R. and HELPER S. (1999) Firm size and capabilities: regional agglomeration and the adoption of new technology, *Econ. Innov. & New Technol.* 8, 79–104.

KLINE S. J. and ROSENBERG N. (1986) An overview of innovation, in LANDAU R. and ROSENBERG N. (Eds) *The Positive Sum Strategy.* National Academy Press, Washington, DC.

KRUGMAN P. (1996) *The Self-organizing Economy.* Blackwell, Oxford.

LAMBERTON D. (Ed) (1971) *Economics of Information and Knowledge.* Penguin, Harmondsworth.

LAMBERTON D. (Ed) (1996) *The Economics of Information and Communication.* Edward Elgar, Cheltenham.

LAMBERTON D. (Ed) (1997) *The New Research Frontiers of Communications Policy.* Elsevier, Amsterdam.

LANGLOIS R. N. (1992) External economies and economic progress: the case of the microcomputer industry, *Bus. Hist. Rev.* 66, 1–50.

LOASBY B. J. (1998) The organization of capabilities, *J. Econ. Behav. & Organiz.* 35, 139–60.

LUNDVALL B. A. (1985) *Product Innovation and User–Producer Interaction.* Aalborg University Press, Aalborg.

MANSFIELD E. (1991) Academic research and industrial innovation, *Res. Policy* 20, 1–12.

METCALFE S. (1995) The economic foundation of technology policy: equilibrium and evolutionary perspectives, in STONEMAN P. (Ed) *Handbook of the Economics of Innovation and Technological Change.* Basil Blackwell, Oxford.

NELSON R. R. (1987) The role of knowledge in R&D efficiency, *Quart. J. Econ.* 97, 453–70.

NELSON R. R. (Ed) (1993) *National Systems of Innovation.* Oxford University Press, Oxford.

PATEL P. (1995) Localised production of technology for global markets, *Camb. J. Econ.* 19, 141–53.

QUÉRÉ M. (1994) Basic research inside the firm: lessons from an in-depth case study, *Res. Policy* 23, 413–24.

RICHARDSON G. B. (1960) *Information and Investment.* Oxford University Press, Oxford.

RICHARDSON G. B. (1972) The organization of industry, *Econ. J.* 82, 883–96.

RICHARDSON G. B. (1998) *The Economics of Imperfect Knowledge.* Edward Elgar, Cheltenham.

ROBERTSON P. and LANGLOIS R. N. (1995) Innovation networks and vertical integration, *Res. Policy* 24, 543–62.

RUSSO M. (1985) Technical change and the industrial district: the role of interfirm relations in the growth and transformation of the ceramic tile production in Italy, *Res. Policy* 14, 329–43.

RUSSO M. (1996) *Cambiamento Tecnico e Relazioni tra Imprese.* Rosenberg & Sellier, Turin.

SALAIS R. and STORPER M. (1992) The four worlds of contemporary industry, *Camb. J. Econ.* 16, 169–93.

SAMUELSON P. A. (1954) The pure theory of public expenditure, *Rev. Econ. & Statist.* 36, 387–89.

SAMUELSON P. A. (1955) Diagrammatic exposition of a pure theory of public expenditure, *Rev. Econ. & Statist.* 37, 350–56.

SAXENIAN A. (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Harvard University Press, Cambridge, MA.

SCHERER F. M. (1999) *New Perspectives on Economic Growth and Technological Innovation.* Brookings Institution Press, Washington, DC.

SCITOWSKY T. (1954) Two concepts of external economies, *J. Pol. Econ.* 62, 143–51.

SIMON H. (1985) What do we know about the creative process?, in KUHN R. L. (Ed) *Frontiers in Creative and Innovative Management.* Ballinger, Cambridge, MA.

STEPHAN P. E. (1996) The economics of science, *J. Econ. Lit.* 34, 1,199–235.

Storper M. (1995) The resurgence of regional economics, ten years later: the region as a nexus of untraded interdependencies, *Europ. Urban & Reg. Studies* 2, 191–221.

Storper M. and Harrison B. (1991) Flexibility hierarchy and regional development: the changing structure of industrial production systems and their forms of governance in the 1990s, *Res. Policy* 20, 407–22.

Swann P., Prevezer M. and Stout D. (Eds) (1998) *The Dynamics of Industrial Clustering.* Oxford University Press, Oxford.

Thurow L. C. (1999) *Building Wealth.* HarperCollins, New York.

Utterback J. M. (1994) *Mastering the Dynamics of Innovation.* Harvard Business School Press, Boston, MA.

Von Hippel E. (1988) *The Sources of Innovation.* Oxford University Press, Oxford.

Watkins T. A. (1991) A technological communications costs model of R&D consortia as public policy, *Res. Policy* 20, 87–107.

Williamson O. E. (1975) *Markets and Hierarchies: Analysis and Antitrust Implications.* Free Press, New York.

Williamson O. E. (1985) *The Economic Institutions of Capitalism.* Free Press, New York.

Williamson O. E. (1993) The logic of economic organization, in Williamson O. E. and Winter S. G. (Eds) *The Nature of the Firm*. Oxford University Press, Oxford.