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THE KNOWLEDGE TRADE-OFF: CIRCULATION, GROWTH AND THE ROLE OF KNOWLEDGE-INTENSIVE BUSINESS SERVICES IN URBAN INNOVATION SYSTEMS

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The knowledge trade-off: circulation, growth and the role of knowledge-intensive business services in urban innovation systems[1]

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Abstract. Technological knowledge can be analyzed as a collective good since it is the result of systemic dynamics that make possible the access, accumulation and diffusion of interdependent bits of localized technological knowledge among complementary actors. Interactive behaviors and shared learning are the determinants of such collective character highlighting the need for effective communication opportunities and channels. Technological communication relies upon favorable social and institutional conditions which can find in the regional, and especially urban innovation space the proper environment to take place. In cities the opportunities for and actual implementation of technological communication find in social proximity the suitable factor to take advantage from the existing structural variety. Social proximity can enhance the quality of personal and collective relations, in turn accounting for low free-riding, reciprocity and thus repeated interactions based on trust which underpin effective communication of knowledge. Under these circumstances knowledge circulation emerges as the crucial factor in the generation of new technological knowledge and eventually innovation. Technological knowledge and the eventual introduction of innovation are now understood as the results of a cumulative process of recombination of different, preexisting bits of knowledge embodied in a variety of actors which can be effective only when and if the appropriate circulative conditions have been implemented. Knowledge-intensive-business-services (KIBS) play a major role in fostering the rate of knowledge circulation and therefore the overall rate of knowledge production since they operate as intermediary actors in knowledge exchanges, sustaining the development of (quasi)markets for knowledge and therefore enhancing the tradability of knowledge. KIBS are drivers for the creation and circulation of general purpose knowledge (GPK, drown by analogy with general purpose technology) and allow the transformation of such GPK into both idiosyncratic and generic knowledge, and their accumulation over time, even if under specific conditions concerning the costs of appropriation and diffusion of specific and generic knowledge respectively. Finally and most important, the dynamics of collective technological knowledge *cum* KIBS clearly show that the traditional Arrovian trade-off between knowledge generation and knowledge circulation is still most relevant to the economics of innovation and yet can help to qualify some of its implications. When technological knowledge can be analyzed as a collective good

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because it is the result of the cumulative recombination of previously existing and dispersed bits of generic and specific knowledge, and such recombination is constrained because of technical and geographical factors, cities and KIBS provide appropriate conditions to support both individual incentives to innovate brought about by higher factor productivity and the social welfare associated with larger diffusion of knowledge.

1. Introduction

The analysis of technological knowledge as a collective good recently paid increasing attention to the structural variety of economic conditions that characterize specific geographical locations. Such structural variety is seen as a key driver in fostering the rate of production of technological knowledge and it can account for local firms' growth opportunities (Clark et al., 2000; Swann et al., 1998; Storper, 1997). However, the process of knowledge generation itself is an important precondition for the development of several features encompassing innovation, productivity growth and the creation of new markets.

Hence, the microeconomic determinants involved in this analysis cannot be taken for granted. To appreciate the two-way relation between the growth of knowledge, and the growth of the economy, it is necessary to further assess the conditions under which this process is realized.

In this context, the role of cities needs be emphasized. A large amount of empirical evidence showed that cities support collective technological knowledge because they provide the appropriate structural conditions defined in terms of the mix of industrial, scientific and institutional infrastructures. Local firms can take advantage from such structural variety by means of interactive behaviors and collective learning, thus sustaining the diffusion and recombination of complementary kinds of knowledge. If access to productive resources represented in the past an important strategic advantage for urban areas since it supported the creation of industrial activities and their subsequent expansion, access to existing channels of knowledge access and transmission seems as much relevant today.

The aim of this paper is to suggest that the effective exploitation of the structural conditions characterizing cities relies on lower transaction costs in the individual exchange of knowledge and more effective opportunities for collective learning. This paper aims to disentangle the micro-analytical foundations of the dynamics of technological knowledge as a collective process in the geographical space of cities. In these dynamics, services, and knowledge-intensive-business-services (KIBS) in particular, play a most important role.

The evolution of industrial systems is qualified by the creation of new, dispersed activities and by the integration of the relevant spillovers. In this context, the analysis of technological knowledge as a collective process provides a suitable framework to assess the role of business services in the process of generation of technological knowledge in urban areas.

One key point of the analysis is that in urban areas the distribution of the activities of firms, their interrelations and recombination underpin the realization of innovative processes. Services stimulate the circulation of intangible specific assets by means of localized learning processes, and ensure viability for the creation of new knowledge. They can create new opportunities for the firm to access external knowledge, such as academic and R&D-based knowledge, but also financial competencies. Technological knowledge is an intermediary input and innovation benefits in a cumulative way from the circulation, access and recombination of different, pre-existing bits of knowledge embodied in a variety of actors.

Moreover, the understanding of the role of services in the dynamics of innovation and technological knowledge can qualify some new implications of the traditional Arrovian trade-off between knowledge creation and knowledge diffusion. Knowledge intensive service firms have increasingly specialized in the management of the interfaces between external and internal knowledge operating as 'converters' of codified knowledge into localized competencies resulting in accumulation of special purpose knowledge. In this perspective, the traditional view of knowledge as a public good can be challenged by the recognition of localized factors in the underlying processes of generation and exchange. Services, thus, gradually emerge combining the advantages of technological proximity and socio-economic variety and the concurrent advances in the fields of information and communication technologies made possible the access to such a general-purpose knowledge base, giving these firms a global scope within a growing service dimension.

The paper is organized as follows. Section 2 briefly introduces the economics of collective technological knowledge. The role of learning activities and communication processes is stressed in fostering the distribution of complementary kinds of knowledge, and their merging into a common pool. In this perspective, the circulation of existing knowledge is considered a crucial input in the production of new knowledge. Section 3 presents a conceptual framework in which co-localization favors social, rather than merely physical proximity, which bears in turn effective and reliable opportunities for technological communication. Cities favor the development of common norms of interaction and can therefore account for trustworthy, mutual individual and collective relations. These repeated interactions consolidate over time the circulation and transmission of knowledge at the industrial, scientific and institutional levels. Within this highly integrated network, KIBS are suggested to play a key role, as it shall be argued in Section 4. Section 5 puts the conceptual analysis articulated insofar into a more formal perspective that values social proximity, structural variety and KIBS as the determinants of the replicability of knowledge exchanges and in turn of the generation of new knowledge. Conclusions summarize the results.

2. Technological communication and the emergence of knowledge as a collective good

As Hayek (1945) suggested, knowledge is distributed and embodied in individuals as the outcome of a collective process. The degree of heterogeneity between interacting groups is the outer limit to knowledge exchange. The dynamics of technological knowledge as a process can be further implemented in the analysis of market interactions when specific communication conditions and the appropriate institutional framework encourage the proliferation of communication intensive activities.

The understanding of technological knowledge as a collective good can provide a useful tool to grasp the role of geographical space and communication in the dynamics of innovation. This understanding can benefit from the integration of three complementary approaches.

First, much empirical evidence gathered in regional and innovation economics has revealed that innovation activity is strongly localized in well-defined technical and geographical spaces (Audretsch and Feldman, 1996; Davies and Weinstein, 1999; Jacobs, 1962 and 1969; Jaffe and Trajtenberg, 1999; Jaffe et al., 1993; Paci and Usai, 2000; Patel, 1995). Technological knowledge is localized in the geographical and technical space. Its production is more and more concentrated in narrow regions, it benefits from agglomeration economies and it is the result of the complementary accumulation of specific know-how stemming from different and yet contiguous industries.

Second, the innovation systems approach has clarified the characteristics of technological knowledge in terms of technological and scientific complementarities that impinge upon common social opportunities to access and diffuse, i.e. to learn, new bits of interdependent kinds of knowledge (Carlsson, 1997; Edquist, 1997; Freeman, 1995; Lundvall, 1992; Nelson, 1993). This approach incorporated formal and informal institutions as relevant sources of knowledge production and innovation.

Third, the emphasis recently given to communication opportunities and recombinatorial learning as the microfoundations of cumulative innovation, underlines that the integration and recombination of existing complementary kinds of knowledge, most of which are external to the firm, is central in the creation of new further technological knowledge and technological change. Agglomeration economies favor the accumulation of knowledge over time, and cumulative effects in the generation and diffusion of knowledge (i.e., standing on the shoulders of giants) apply when and if geographical spaces have higher concentrations of varied supporting institutions and opportunities for communication (Antonelli, 2001; Feldman, 1994).

The circulation of knowledge is now a key determinant in the generation of new knowledge and innovation. Technological knowledge and the eventual introduction of innovation are now understood as the results of a cumulative process of recombination of different, preexisting bits of knowledge embodied in a variety of actors.

An array of problematic consequences arises from such collective character of technological knowledge. First, access conditions to existing external knowledge are key factors improving the effectiveness and rate of knowledge production, enabling the acquisition and accumulation of technological knowledge already stored but dispersed in a number of different but yet complementary artifacts, technologies and users. Although, since technological knowledge is industry- and region-specific and ultimately individual, it is very idiosyncratic and costly to use it elsewhere, i.e. in other regions, other industries and also other firms and individuals. Consequently, access conditions are harmed by communication costs, that is, the costs agents must face to search, store and decode the relevant bits of idiosyncratic knowledge owned by different and complementary actors (Antonelli, 1999; Carter, 1989).

In other words, the problem of communication arises as an economic problem since actors must face specific costs to have access to very idiosyncratic external knowledge.

In a framework where the access, accumulation and recombination of knowledge are by no means free and communication conditions are key factors explaining the effective opportunities to access, understand and use an array of external knowledge bases, the analysis of the conditions under which the transfer of knowledge can be effectively implemented can benefit from the development of an integrated framework that appreciates geographical locations as a carrier of technological communication. .

3. Geography, social proximity and the circulation of knowledge

The merging of three distinct and yet complementary research programs such as the Arrovian economics of knowledge, the transaction cost analysis and the economics of learning, is likely to yield major benefits in grasping the role of cities and in providing a context for the analysis of the dynamics of collective technological knowledge.

The Arrovian tradition of analysis upon knowledge as a public good because of high levels of indivisibility, non-rivalry in use and non-tradability can be enriched by the Coasian approach to the analysis of the costs of using the market and the Penrosian approach to the economics of learning can provide a new and original framework to understand the conducive role of cities in fostering the rate of accumulation and generation of technological knowledge.

Geographical proximity in cities has been often conceived in terms of physical proximity that reduces physical costs such as transport costs. Lower transportation costs are the results of the physical proximity in narrow, and especially urban regions and are the key determinants making for the spatial accumulation of technological knowledge (Krugman, 1991).

Nevertheless, the appreciation of the advantages of geographical proximity in terms of mere physical proximity that reduce the costs of transportation of goods neglects a variety of economic, and especially institutional and social factors that influence the dynamics of collective technological knowledge in particular, and the dynamics of regional economies at large (Martin, 1999). The understanding of these factors is most consistent with our collective approach to the emergence of technological knowledge, which underlines the interdependencies among social, institutional and industrial factors in the distribution and generation of technological knowledge. Especially, it is most pertinent to grasp the role of communication and interaction in building-up a collective pool of technological knowledge in narrow regions that are characterized by a far more positive institutional and social context, such as cities.

Agglomeration is not sufficient *per se* to give place to technological communication. The localized production and diffusion of technological knowledge is the result of the interdependencies between firms' based tacit learning and the formalized acquisition of external knowledge originated in both firms and institutions, which are fostered by the presence of multiple, formal and informal, interactive mechanisms (Maskell, 2001; Maskell and Malmberg, 1999).

The purposive implementation of a network of dissimilar but complementary communicative relations based upon the variety of local economic systems and the local division of labor favors the accumulation, absorption and recombination of different knowledge bases, in turn ensuring the creation of a new common pool of technological knowledge. Higher rates of innovation and growth can be achieved because of those better opportunities for the distribution of technological knowledge (Patrucco, 2003a,b).

These conditions, where economic variety can be exploited by means of learning and communication, thus fostering the accessibility and circulation of technological knowledge, are especially evident in urban contexts such as technological districts, the *cité scientifique* of Toulouse in France, Washington, Silicon Valley and Route 128 in the US, the financial districts of New York and London, and in Italy the Turin automobile district, the packaging district of Bologna, and the Brianza technological district nearby Milan (Antonelli, 2000; Belussi, 2002; Clark, 2002; Dorfman, 1983; Enrietti and Bianchi, 2002; Feldman, 2001; Lever, 2002; Patrucco, 2003a; Saxenian, 1994; Storper, 1995)[2].

[2] Relying on this evidence, we are dealing with a practical, qualitative and, in a certain respect, loose definition of cities as large urban agglomerations characterised by economic (i.e., scientific, industrial and institutional) variety,

In cities, several concurrent issues typical of the analysis of economic activities such as the division of labor, the activity of research and development and the increase in qualifications and skills, are strictly connected with the process of growth of knowledge. Interactions amongst a variety of actors embodying heterogeneous knowledge allow for the transmission of different, yet complementary, kinds of knowledge and favor their recombination into a common base. Firms are not merely involved in either internal R&D efforts or in user-producer and inter-firms relations. For instance, local innovative (financial and business) services play a major role in enhancing the tradability of both embodied and disembodied knowledge. Moreover, the scientific and research community contributes significantly to the diffusion of codified and science-based pieces of knowledge.

In this perspective, cities and urban areas might be therefore the proper environment for the dynamics of collective technological knowledge to take place. They provide an appropriate institutional and communication endowment enabling the development of local dynamics of personal and collective communication through which complementary kinds of knowledge can be accessed and circulated at the industrial, market and scientific levels (Patrucco, 2003c).

Geographical proximity is here conceived as a carrier of social proximity, which allows the sharing of a common array of institutional infrastructures and social structure and norms (i.e., formal organizations, rules and practices, and informal customs, routines and norms), in turn enhancing the quality of relationships among co-localized actors and allowing a collective recombination and regeneration of individual knowledge (Amin and Thrift, 1992 and 1995).

Ronald Coase (1960) stressed that common rules and governing structures establish the base for human interaction, giving a certain degree of predictability, certainty and hence replicability to market exchange without imposing new and higher transaction costs, and in turn also discouraging conducts (e.g., free-riding and opportunism) that violate shared norms and behaviors.

Along the lines of the economics of learning paved by Edith Penrose (1959), technological knowledge emerges from the contextual set of social interactions, routines and norms determining the dynamics of shared learning, which in turn drives the growth of the firm. Geographical factors are not *per se* a determinant of the dynamics of collective technological knowledge but only because they account for the proper social and institutional conditions. Technological knowledge can be exchanged because its production and distribution rely on a territorial base of common social norms. These kinds of interactions are often informal and not fully mediated by price mechanisms, but largely based on the connections of the societal structure and on the personal communication of tacit knowledge (Lawson, 1999).

Therefore, geographical proximity is not conceived as a mark of transportation costs but as a measure of the quality of relationships among individuals. Knowledge is mostly embodied in human beings and the specific set of institutional forms and social interactions arises as the crucial arrangement for the governance of collective knowledge production and distribution (Metcalfe, 2001 and 2002).

The understanding of the underlining trade off between codified and tacit knowledge, as articulated in the seminal work of Michael Polanyi (1958 and 1966), can help in clarifying the

which does not include only capital regions and does not strictly relate to quantitative parameters such as population density or surface extension.

relation between social proximity and the communication of knowledge. The more idiosyncratic and hidden the content of external knowledge, the higher are the costs of searching, accessing, storing and decoding relevant complementary bits of knowledge. On the other hand, the larger the codified base of external knowledge, the lower the costs of searching, assessing and integrating a given amount of technological knowledge. In turn the more tacit the knowledge and the stronger the need for personal communication and social interactions, while formalized and standardized channels of communication are often less appropriate and reliable in context characterized by strong idiosyncrasy.

In this perspective, the lower is the distance, the higher is the amount of social and institutional factors that are shared among actors, the higher are the costs of free-riding in terms of bad reputation, exclusion from the network and retaliation, the higher is the replicability of interactions based on trust and mutual exchange of skills, competencies and know-how. In other words, geographical proximity could be also conceived in terms of the reciprocal reputation among knowledge owners. Reciprocal reputation facilitates the search of the more viable source (i.e., a worker, a firm or an institutions) of complementary skills and competencies, the transmission and exchange of the bits of knowledge among such sources in terms of lower codification and decodification efforts because of the sharing of the same ‘language’ and communication norms, and the reproducibility of such knowledge exchange over time.

When articulating the effects of social proximity in urban areas on the quality of repeated and knowledge-oriented interactions, the well-known Arrovian approach to the market failure in the production of knowledge can be put in a new light by the appreciation of the spatial elements in the transaction costs analysis. According to Kenneth Arrow, the non-appropriability of knowledge and its non-rivalry in use lead to market failures in the generation of knowledge due to the trade-off between the social benefits of a public diffusion of knowledge and the private appropriation of invention efforts. Free riding and opportunism could undermine the latter when the diffusion of knowledge is public (Arrow, 1962 and 1969). This explains vertical integration strategies in the firm and in-house creation of new knowledge (Williamson, 1975, 1985 and 1996).

Social proximity facilitates a collective, i.e., quasi-public or quasi-private, transmission of knowledge where the exchanges are credible, loyal and replicable because of the sharing of the same social norms, conventions and practices and because of higher costs in terms of social exclusion, bad reputation and retaliation. In other words, because of the effects of social proximity, the dynamics of technological knowledge in cities can account for both private and social returns. In terms of opportunities and actual mechanisms for the circulation of technological knowledge, important implications for the KIBS sector could be developed upon this general argument: lower transaction costs and thus valuable conditions for the tradability of knowledge are favored by a trustworthy environment. As a consequence a network of repeated and reciprocal knowledge exchanges becomes established upon relational proximity and trust.

KIBS play an important part in these localized dynamics since they sustain the circulation of knowledge and because they can benefit from structural variety and accessibility conditions in cities. Localized knowledge is usually appropriable in an urban environment although its circulation is often limited. Under specific condition, the creation of services enlarges the extent of the market creating a market mechanism that feeds its circulation and favors the division of labor. Services allow overcoming the traditional trade-off argument related to the circulation of new knowledge in that they represent a market mechanism that operates on the basis of market forces. More importantly, they create the basic rules of coordination that are necessary for the establishment of a market. As we shall see the importance of services rests in their contribution to the emergence of new opportunities for profitable exchanges of knowledge, in turn accounting for both private incentives to innovate and the social welfare associated with the diffusion of knowledge.

4. KIBS and local governance mechanisms in the dynamics of technological knowledge

The determinants and conditions of the process of growth of knowledge in cities can be analyzed along three interrelated arguments: the effects of knowledge recombination in the production of business services; the structural conditions of urban areas fostering such a process and, within these, the existence of specific governance mechanisms that sustain the circulation of knowledge.

In this process, KIBS play a most important role, especially when the exchange of productive inputs between the KIBS and the surrounding environment, qualified by the governance mechanisms, is taken into account.

Very often, this analysis is based on the transaction costs argument developed by Oliver Williamson. The risk of free-riding and opportunistic behavior in the market exchange entails transaction costs in the production of technological knowledge. When these are higher than in the case of internally-organized production of new knowledge, the firm will adopt a vertical integration strategy as proper governance mechanism for the organization of knowledge production and distribution rather than the market mechanism.

The analysis of transaction costs has provided a benchmark for understanding the boundaries of the price mechanism with respect to the convenience to produce a good or a service rather than buying it. Nonetheless, this "umbrella" argument needs be framed in a specific analytical context. The issue addressed by the transaction costs approach was referred to sequential productive processes of physical goods, a framework that is not always suitable with respect to services. Within that analysis, it is assumed for simplicity that intermediary inputs are managed either in a highly integrated structure with neatly distinguished bureaucratic levels or in market structures where the intensity of transactions is favored by low cost levels[3].

The analysis we propose in this paper is mostly aimed at the description of activities that employ intermediary inputs embodying high knowledge intensity and that, due to their peculiar nature, urge for a requalification of the underlying concepts about the organization of their production. The typical analysis based on transaction costs omits the recognition of the fundamental role that organizational choices and competence development have in the productive process (Antonelli, 1999a).

Governance mechanisms, in particular, play a distinctive role in the determination of the output as well as of the interplay between economic agents involved. Transactions occurring at a low level of commitment such as subcontracting, alliances or share swapping are more than frequent and the relative governance mechanisms constitute the backbone of industrial organizations where quasi-markets serve the fundamental function of exchange of dedicated inputs. In this perspective, the extent to which interactions can define the role of KIBS in urban areas depends on the specific relation with clients as well as with the environment. Users of

[3] An assessment of the transaction costs approach with respect to industry organization can also be found in Granovetter (1985), Dow (1987), Klepper (1997).

services play an important role in governing the development of capabilities together with preferences will yield differential efficiency gains in terms of knowledge, experience and skills (Gadrey and Gallouj, 1998; Langlois and Cosgel, 1998). Besides the acquisition of knowledge, the recombinatory effects originated from the contact between providers and users are relevant to our argument. According to Strambach (2001) these occur in a double direction: the request to the provider from the client will activate a learning process aimed at solving the problem. Subsequently, the effects of this transfer of knowledge will affect the client's performance.

Failing to appreciate the role of intermediary coordination levels such as local networks and temporary agreements entails discarding off the fundamental principle of coordination[4] (Richardson, 1972; Loasby 1991). Given this framework, it is natural to address the analysis towards the specific context of urban areas where KIBS have a growing scope in creating and reinforcing the growth of knowledge based on complementarity.

The argument that we are trying to develop is hence based on the idea that together with the actual costs of carrying out an activity, business services must also bear the cost of assessing the conditions of access and use the existing stock of collective knowledge (Antonelli, 2001). Internal reproduction of knowledge if on one hand may yield positive benefits for the single agent, on a broader level decreases the efficiency brought about by the increase in the pool of common local knowledge. This is particularly true in circumscribed contexts such as urban areas where agents share localized resources and the institutional framework and the contribution of each component is precious to the growth of external knowledge and to the benefits entailed by such a process.

Local externalities are characterized by the portions of knowledge shared by agents engaged in complementary activities. Each business service contributes to increase the collective stock of knowledge, hence the potential externality effects, so that the number of agents operating affect positively the growth of knowledge but with decreasing returns. Three kinds of costs can be identified in this process. First, the cost of assessment is generated whilst analyzing the prospective returns of producing in-house or to outsource. Second, in order to employ technological knowledge as an intermediary input it is necessary to bear the cost of absorption and access to external knowledge. Finally, the actual costs of communication are generated after the business service has engaged in the activity. An increase in any of these costs components, albeit temporally displaced, will lower the probability of observing as frequent intramodular exchanges. In other words, the lower these costs, the higher the probability of complementary knowledge exchanges interfaced by KIBS.

These considerations point the attention to the strongly localized character of the dynamics of collective technological knowledge. Knowledge resources are configured in a dispersed and often bundled manner so that their implementation may involve overlapping characters. Resources available to economic agents are distributed in a non-systematic way the more interrelated and complex is the structure of the environment in which they operate. The transformation of idiosyncratic knowledge into collective capital is more likely to happen in specific environments like urban areas, where systematic interactions consent the replication of daily activities (routines) whereas informal communication allows for the creation of variety

[4] Antonelli (1999a) investigated the substitution process between governance function and cost equation. When an array of governance mechanisms is considered with respect to several possible combinations of costs and coordination levels of dedicated resources transactions, governance and production dynamics account for a variegated range of possible outcomes, wider than the one predicted by the transaction costs approach.

and novelty. Proximity is a condition which cannot be derogated since it allows the process of exchange and provides the necessary shared modalities for the execution of those activities that determine the level of integration of the system.

Although the nature of service provision is increasingly linked to the immaterial nature of its content, a factor which would facilitate the formation of networks despite distance, the intrinsically tacit interaction that favors the growth of activities around the common knowledge base still maintains a strong geographical character. Consolidated areas, like cities, are thus likely to experience increasing returns favored by informal, tacit interactions.

The development of local systems depends upon the balance between pure informal interaction and systematic institutional coexistence (Antonelli, 1999b). The way a system learns is also reflected in the way it institutionally responds to the changing dynamics of the market. However, learning itself depends on the available knowledge base and on the variegated set of internal distributed competencies. The process of internal learning is shaped by complementarities and coevolves with the reconfiguration of the environment (Mathews, 2003). Hence, specialization represents the result of a learning mechanism, more precisely the construction of a cognitive architecture towards the analysis of specific problems. A larger knowledge base also favors the definition of an extended learning activity which is often accrued by means of services. The process of cooperation stems from the intersection of shared activities but does not diminish the incentive for technological inventions. In this context services are qualified interfaces that convert technological information into localized knowledge (Antonelli, 1999b).

These arguments qualify geographical co-localization as a crucial factor. Co-localization could be seen as an alternative governance mode in the dynamics of technological knowledge because it provides the proper environment in terms of trust relations, transparency in economic behaviors and hence lower incentive towards opportunistic behaviors and information leakage. In this perspective, co-localization and the collective generation of technological knowledge emerge as a third governance mechanism between the market's and the firm's modes of organizing the production and diffusion of technological knowledge.

The implementation of local (quasi)markets for knowledge as viable devices in the generation and distribution of technological knowledge can be centered upon these arguments, finding in cities a far more suitable environment. Actual (quasi)markets for knowledge stem from the increasing specialization and division of labor in the production of knowledge and the development of institutional devices that allow trustworthy knowledge exchange and repeated user-producer interactions. Formal and informal institutional devices such as patents and informal agreements favor technological communication in that they provide a common definition of the codes, norms and procedures by means of which interactive agents can articulate their relevant demand and supply of problem solving capabilities, in turn making market transactions efficient and replicable in the future. At the same time, long-term interactions positively affect the implementation of institutional devices in that they favor the build-up of an environment of trust and confidence based on common experiences. The overall cost of trading knowledge may be reduced of the cost of eventual opportunistic behavior and excessive information leakage (Guilhon, 2001; Arora et al., 2002; Patrucco, 2002).

The development of a local sector of knowledge intensive business services is the strategic factor in this context. KIBS emerge as specialized interfaces between the suppliers of often-generic knowledge, such as universities and R&D laboratories of large firms, and specific users with idiosyncratic needs, such as small and medium firms relying on external knowledge. Whenever the proliferation of several significant pieces of knowledge is limited because of the existence of protection mechanisms, inefficiencies from the duplication of the costs and of the effort to reproduce them are likely to be observed. Such inefficiencies, however, could be avoided by the expansion of services providing an incentive to employ newly acquired knowledge in a classic market mechanism.

Services contribute to the creation of a knowledge infrastructure and to the definition of the relation between context and process of knowledge creation by means of a process that displays positive feedback. Having accrued the status of pervasive cross-sectoral activities, services enrich the knowledge infrastructure where a wide array of governance mechanisms favor a systematic interaction based on the existence of proximity. In the manufacturing activity the variation of capital entails the introduction of technical innovation and the subsequent division of labor and productivity gains. In the service sector these can be generally accrued either through specialization and/or by means of further variety in the way services are delivered. More generally given their high labor embodiment and intense knowledge-base, services experience growth accordingly with the dynamics of knowledge accumulation which can be referred to as the capital of service-oriented activities.

5. The knowledge trade-off, cities and KIBS: a formal analysis

A key characteristic of KIBS is that they are created and tailored around the activities they impinge upon, thus allowing to generate self-reinforcement for their expansion. In this process, these services embody the knowledge that they will distribute by means of a market mechanism. The contribution of KIBS to several industrial sectors is to sustain the growth of common knowledge by supporting the diachronic transmission and integration of dispersed portions of specific knowledge. In doing so, business services impact industrial activities through the creation of general purpose knowledge (GPK) in a threefold way. Initially, they carry a scope for specialization by allowing the employment of GPK in several downstream sectors. Hence, KIBS provide a generic function to specialized, indivisible portions of knowledge. Secondly, KIBS support the development of further dedicated activities by reinforcing the span of possible uses and, thus, the variety of the possible applications. Finally, they determine innovational complementarities across the system impacting on the productivity of downstream sectors through the wide extent of use that it is possible to make of that knowledge[5]. The immediate consequence of this is that the base of collective knowledge will result enlarged, both in quantitative and qualitative terms, by the exchange of KIBS.

KIBS yield changes to the pool of common knowledge by sustaining its intensity and by fostering its variety. Accordingly, the growth of knowledge can be depicted in a bi-dimensional way, cumulative and circulative. By cumulative we mean through a process that is constrained by the current set of competencies and, thus, is gradual and incremental since it builds on accumulated competencies in the firm's technical domain or routines (Nelson and Winter, 1982). The dimension of circulation qualifies the different phases of technical advance as a recombination of pre-existing cognitive elements generating new patterns of change. In a Schumpeterian fashion (Schumpeter, 1934), the growth of technological knowledge and the related development of innovation is a combinatorial process relying upon the new integration and combinations of previously existing bits of knowledge, technologies, artifacts. Such recombination is affected by both the structural conditions of the system in which it takes place

[5] We draw a similarity with General Purpose Technologies and their characteristics as argued by Breshanan & Trajtenberg (1995) and Helpman (1998).

and the historical sequence of previous combinations of ideas. Structural conditions and the previous combinations of ideas sustain and, at the same time, constrain human creativity in a recombinant and cumulative (i.e., standing on the shoulders of giants), self-sustained and path-dependent production of new knowledge and innovation (Weitzman, 1996 and 1998; Olsson & Frey, 2002).

In order to model the basic features of knowledge accumulation by means of service production, we will represent the process of knowledge growth in a metric space and then describe its dynamics by means of a simple set of functional relations. This representation may be at odds with the concept of knowledge itself whose abstract nature has been since long object of an ample debate. Far from wanting to engage in any conceptual dispute, such a representation allows the analytical appraisal of the specific dimension of knowledge growth in the context here investigated. Moreover, to represent this process on a metric space entails a clear reappraisal of issues such as technological distance and complementarity between productive inputs and technological frontier of knowledge.

Similarly to Olsson and Frey (2002) we will assume a metric knowledge space in which it is possible to measure K_t , a subset of all the ideas I ordered and grouped in a specific way to constitute the basis for the use of a technology: $K_t \subset I \subset R^2_+$, where R^2_+ is the set of natural numbers. Henceforth, K_t will include all the existing recombinations of cumulated technological knowledge, including both new and old[6]. As it will be made clear in the remainder, such a space is limited by a frontier whose shifts occur "from within" for the factors causing transformation and change via the development of service oriented activities which are embodied in the arguments of the functional relation underlying the process of knowledge growth. This way of representing knowledge allows reinforcing the idea that a significant source of economic development rests in the ability to innovate by outgrowing the existing knowledge base[7].

The boundaries of the knowledge set are characterized with respect to the two dimensions considered, cumulative and recombinant. The set K_t is generally assumed infinite akin all the possible combinations of the portions of existing knowledge (Weitzman, 1998; Olsson & Frey, 2002). However, in this specific context, its process of growth needs comply with the dual dimensions considered here, the cumulative and the recombinant. Accordingly, the set of technological knowledge will be bounded, closed (hence, compact) and connected.

Boundedness yields that the combinatorial possibilities within the dimensions is assumed to have a finite maximum limit, although these are increasing as the set K_t grows because of expansion of service activities. To assume K_t closed will entail that the surface made by the limit points of its complement K_t^C will belong to the technological knowledge set[8]. Moreover, a connected set will ensure that there are no "holes" in the portions of existing technological

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[6] This definition yields that $I = K_t \cup K_t^C$. That is, the set which is the complement of K_t includes all the possible recombinations of existing technological knowledge that have not been discovered.

[7] Moreover, the technological knowledge set is assumed separated form the physical artefacts whose employment in different activities represent the application of a specific portion of knowledge. This yields that once the artefact is dismissed, the technological knowledge behind it still remains available in the set of cognitive inputs.

[8] Accordingly, the boundary points will be $Bd(K_t) = K_t \cap l_p(K_t^C)$ with l_p the set of limit points.

knowledge considered and that, at least in principle, there are no limitations to the combinatorial possibilities due to their position within this space.

The notion of collective knowledge as a cumulative asset relies on the idea that this heterogeneous combination is a unique whole partitioned in idiosyncratic bits and that its growth, the ultimate source of innovation, is the result of a recombinatory process (Kuhn, 1962; Weitzman, 1998). Because of both horizontal and vertical indivisibilities, new knowledge is stochastically determined by old knowledge. The role of KIBS is to support the dynamic efficiency of search processes consisting in the diachronic adjustments between actual and potential activities through the creation of complementarities and the accumulation of competences. The fostering of intangible capital assets such as knowledge and competences determine the pattern of growth of a system which is characterized by path–dependence in that local external conditions and irreversibility of production factors are at work (Stephan, 1996; David, 1998; Antonelli, 2001). In a Schumpeterian fashion, business services ignite this process by exploiting new opportunities that will sustain the growth of knowledge.

The size of the technological knowledge set K_t is defined by a function $f(K_t) \in R^2_+$ on the dynamics of the two complementary activities C=Circulation and CK= Accumulation that gives rise to a stock of cumulated knowledge, the degree of complementarity depending on the governance mechanism G.

$$K^{\mathbf{G}}_{\mathbf{t}} = f(C^{a}_{\mathbf{t}}, CK^{b}_{\mathbf{t}}) \qquad (1)$$

$$a+b=1;$$

$$dK/dC>0;\ d^2K/dC<0;\ dCK/dC>0;$$

Equation 1 indicates an implicit functional form for the frontier of actual technological knowledge in a system under the governance mechanism G. A shift of such a frontier will yield $K^{\mathbf{G}}_{\mathbf{t}} < K^{\mathbf{G}}_{\mathbf{t+1}}$. However, the point of this analysis is to assess the composition of such a shift rather than in its evaluation in absolute terms. One of the key points of the analysis, in fact, is that the way technological knowledge grows determines the long run performance of the connected activities.

Knowledge growth is the result of a composite process in which cumulativity entails building blocks of both generic and idiosyncratic, dispersed knowledge whereas circulation and recombination represent the mechanisms behind the variety of possible applications. As long as these relevant bits of knowledge have multiple alternative uses, their effects can be externalized the higher the complementarity of the available activities. This process is a self-reinforcing one in that each specific implementation of previously accumulated knowledge will provide feedback towards the enlargement of the common base.

In this perspective, both the existing stock and the circulating flow are relevant in the process of accumulation of technological knowledge, albeit in a different way. Cumulated knowledge as in equation (2) expresses the notion of a common knowledge base largely accessible to anyone for it has already been circulated, where $C_{\mathbf{N},\ \mathbf{t-1}}$ represents in fact the knowledge circulated among actors at time t-1. This notion seems coherent with the argument previously outlined with respect to general-purpose knowledge.

$$CK_{\mathbf{t}} = g(C_{\mathbf{N},\mathbf{t-1}}, Stock_{\mathbf{T}}) \qquad (2)$$

Circulation as described by equation (3) under a specific governance mechanism is the result of an integrated accumulative process encompassing TR=Technical Replicability and SP=Social Proximity. Its essential function is to account for the range of related phenomena described in section 3 (such as the replicability of knowledge exchanges, recombination, systemic effects and the role of informal norms) which are clearer when we explicit the conditions that qualify circulation with respect to the two relevant dimensions, technical and social/institutional.

$$\text{Circulation}^{G}{}_{t} = h\,(TR_{t}\ ,\ SP_{t}) \qquad (3)$$

Equation (4) shows how technical replicability will depend on two main factors: the level of costs and a coefficient accounting for the interrelations of the system. In particular, this expression will be a proxy for the degree of technical proximity which can be attained by an increase in the production of services and represent an intermediate input for the production of new technological knowledge.

$$TR^{G}{}_{t} = i\,[\,IP\,(\,1 / TC_{t\,-1})\ KIBS_{t}\,] \qquad (4)$$

Where TC: Transaction Costs = (Diffusion Costs + Appropriation Costs);
IP= the connectivity, i.e. the number and the quality of the interrelations in the systems

Transaction costs are specified here as the result from the interplay between diffusion and appropriation costs. Diffusion costs are the costs associated to the circulation of knowledge and, drawing on the Arrovian argument of knowledge as a public good, are defined in terms of the costs of free-riding and opportunism, and thus in terms of decreasing incentive to private innovative efforts. Appropriation costs are instead associated to the idiosyncratic dimension of knowledge. The more specific the knowledge, the higher the costs of appropriating external bits of new knowledge, in terms of searching the appropriate bits, accessing them and integrating them in the stock of knowledge already owned by the firm. To make such appropriation and thus the accumulation of knowledge profitable, external knowledge must be searched, accessed and absorbed in an technical space that is proximate to that characterizing the firm in previous periods. Although we have assumed a coherent set of portions of technological knowledge, positioning on this metric space matters in terms of the impact it will have in determining the magnitude of the costs, hence, the effects on the accumulation of knowledge. The recombination of portions of existing knowledge that are localized in close neighborhoods is likely to occur in an urban area because of geographical, social and technical proximity. This concept recalls the outlined argument of co-localization and the advantage of carrying out bundles of complementary activities.

IP in equation (4) is a coefficient expressing the degree of connectivity between activities carried out with respect to the existing stock of technological knowledge. In this case we expect that complementarity and the speed of communication, that is the relative degree of overlap between the established, neighboring set of activities and the frequency of exchange that the latter yields, positively affects this coefficient. Besides, the quality of communication infrastructure will play a crucial role in determining the technological complementarities generated by the density of communication within the network[9]. Finally, KIBS is a proxy for

[9] In a geodesic network, that is where all agents are directly connected to each other, IP = N (N-1)/2 and the costs of communication increase the higher is the number of agents (Huber, 1986; Antonelli, 2001).

the level of service provision evaluated through the number of dedicated activities (eg professional activities) employed by the business service.

From an analysis of this equation we would conclude that the degree of external transferability is not an absolute characteristic of the product but, rather, a relative index which depends on the market conditions and on the receptivity of the environment with respect to the qualities of the product. Besides, this will depend on the number of agents with which business service firms are able to engage exchange of knowledge.

Equation (5) accounts for the social and institutional dimension of the circulation of knowledge.

$$(SP)_{i,t}{}^{G} = j\ [(\text{Variety}/TC_{t-1})\ SOC_{t-1}] \qquad (5)$$

Variety is the structural variety of the economic system conceived in terms of the number of complementary organizations characterizing the local economic environment in relation to the technical cost of communication. The index SOC expresses the activities dedicated to reinforce the sharing of social and informal norms and reciprocal information, while the cost argument (expressed by TC) applies in the same way as in equation (4).

Equation (5) is a proxy for the degree of social proximity. This expression accounts for the structural features of a system, the economic and institutional settings that characterize the receiving environment when the impulse of innovation is given by the generation of new activities. In fact, this expression describes how the propagation of such an impulse occurs and it is directly linked to the number of dedicated activities (i.e., agencies) towards the efficient expansion of service activities and inversely related to the cost of this. Proximity and shared localized institutional features provide the opportunity to assess higher returns that can be accrued by new activities by stimulating the spread of knowledge.

Finally, equation (6) represents the frontier of gross revenue generated through adjustment activities. The latter are aimed at either exploiting high factor productivity of portion of technological knowledge by appropriating further idiosyncratic knowledge and thus specialization, or at exploiting high accessibility and diffusion by accessing and integrating portions of generic knowledge within specialized activities.

$$(R\ Adj)_{i,t}{}^{G} = r\ (\text{Diffusion Costs}) + s\ (\text{Appropriation Costs}) \qquad (6)$$

A geometrical exposition of the dynamics described above helps to make clearer some of the implications of our analysis. It can qualify the classical Arrovian knowledge trade-off, putting into a new perspective the role of KIBS in the dynamics of knowledge, innovation and growth.

The double dimension of knowledge accumulation in terms of a trade off between accumulation and recombination is depicted in figure one. The former accounts for all those activities that are based on the mere implementation of the knowledge base while the latter is the basis for innovative activities and the source for new uses of existing knowledge. Accordingly in the diagram we will depict the cumulative and the transformative dimension on the two axes. We will then represent the frontier of knowledge accumulation of equation (1) by means of a nested frontier to indicate a trade off between the two dimensions and the locus of adjustments through costs by equation (6), depicted as an isorevenue curve.

INSERT FIGURE 1A AND 1B ABOUT HERE

If the production of services has an impact on the frontier of available knowledge, the two diagrams represent the case in which one of the two effects dominates. In the first case – figure 1a – the predominance of cumulativeness will determine an improvement for those agents whose activity is mostly based on the exploitation of the existing knowledge, that is, a range of low innovative activities. The diagram in figure 1b represents the opposite case in which the circulation of knowledge is more intense accruing benefits to those firms that are more innovative.

Figure 2 provides a graphical analysis of the overall process of knowledge growth by representing the typical argument of the knowledge trade-off. On the vertical axis we measure the growth of the total factor productivity that is attributable to technological knowledge; this can be thought of as the economic return obtained from carrying out activities that create knowledge and innovation. In other words, it can be defined in terms of the payback for investments in uncertain activities. On the horizontal axis we measure accessibility of knowledge, that is, the degree of codification of knowledge, or in other words the extent to which a given knowledge base can be reconnected to the Arrovian notion of knowledge as a public good, ensuring high levels of diffusion and the related social welfare. The combination of the two measures will provide the ratio between knowledge that yields higher factor productivity and the amount of knowledge that is accessible and that bears higher social returns.

INSERT FIGURE 2 ABOUT HERE

The amount of technological knowledge that is available in a system will depend on the composition effects that are at work with respect to the diachronic adjustments occurring between the employment of general knowledge onto specialized activities and their relative contribution to further GPK and even generic knowledge. Accordingly, it is possible to identify three areas in this diagram:

NP*: the area depicted by the NP_1 and NP_2 knowledge frontiers, at time t+1 and time t+2 respectively. It can be considered as a general knowledge base, whose content is largely accessible and whose impact on TFP growth is, thus, very low. This portion of knowledge could be thought as the basic notions of, say, mathematics or any other widely shared science content. The employment of this portion of knowledge usually entails the ability to convert general knowledge into a myriad of downstream specialized activities, hence can yield higher diffusion costs in terms of free-riding and opportunism.

MA*: the area of common, “marketable” knowledge, the direct result of the collective dynamics of technological knowledge *cum* KIBS, and depicted by the MA_1 and MA_2 knowledge frontiers. This portion of knowledge is the widest and contains all the specialized notions that need to have a basic degree of accessibility so that their employment can become frequent but also maintain a sufficient level of factor productivity level, so to encourage its recombination and exchange. An example of this could be the use of PC highly diffused software, whose degree of implementation is proportional to the ability of users. Higher skilled users will be able to exploit their potentials although low skills would not preclude their use, albeit limited.

NA*: this area, depicted by the NA_1 and NA_2 knowledge frontiers, represents the knowledge base that is not widely accessible for the specific nature of its content, thus it bears positive returns and high local efficiency. The exploitation and employment of such portions of knowledge requires very high and idiosyncratic skills, hence, yielding high specialization costs. Advanced, specialized software or programming languages are a good example of this portion of knowledge since their use is usually available to those who have gained a set of deep technical capabilities. According to the definition given previously, $K_t = NP_t \cap NA_t \cap MA_t$.

The frontier depicted by the nested frontier [equation (1)] represents the trade off between these two dimensions of knowledge, where R1 is the old isorevenue and R2 is the new isorevenue with the new knowledge frontiers resulting from the shifting upwards because of KIBS together with the local dynamics of collective technological knowledge.

The actual changes in technological knowledge accrued by the interaction between KIBS and locational effects are depicted by the three intersections occurring between that knowledge frontier and the revenue of adjustment. These changes can be qualified in three components. First and more generally, a shift upwards in the area of common knowledge is occurring because of the reduction in the overall costs together with the increase in the opportunities of new combinations of pre-existing bits of knowledge due to the higher levels of knowledge circulation. Second, the accessibility area is also larger in that KIBS within urban economies can routinize the circulation of previously very idiosyncratic knowledge, reducing the costs of appropriation of external and specific knowledge. Third, services act as an interface between generic knowledge produced in science- and R&D-based environments (such as University and public laboratories) and the application of such generic knowledge into the localized space of firms' production processes. KIBS can exploit the scientific infrastructure of urban areas, and reducing the costs of diffusion of public knowledge due to the risk of free riding and opportunisms, they sustain the diffusion of generic knowledge. KIBS in turn allow for the transformation of public knowledge into a profitable one, in turn enlarging the room for the private incentive to generate knowledge and innovate.

The dynamics of collective technological *cum* KIBS clearly show that the traditional Arrovian trade-off between knowledge generation and knowledge circulation is still most relevant to the understanding of the conditions, determinants and effects of innovation. At the same time, it helps to qualify new implications deriving from the increasing appreciation of the localized nature of innovation space and the role of KIBS within such space. When technological knowledge can be analyzed a collective good because it is the result of the cumulative recombination of previously existing bits of knowledge, and such recombination is bounded because of technical and geographical factors, cities and KIBS provide appropriate conditions to support both individual incentives to innovate and the social welfare associated with the diffusion of knowledge.

6 – Conclusion

Technological knowledge shows a dual nature since it resembles a generic, scientific dimension and a specific, idiosyncratic dimension. Technological communication, driven by KIBS and locational factors, emerges as a crucial element in recombining such two dimensions within a cumulative process in which the circulation and diffusion of preexisting bits of knowledge is most important to build up effectively new ideas and innovation. In this perspective the diffusion of knowledge is a key input in the creation of new knowledge and innovation.

Moreover and most important, technological communication clearly shows that the Arrovian trade off between the profitability and the diffusion of knowledge is still most important for the analysis of the dynamics of innovation. Technological communication is a key determinant in fostering the rate of economic growth as sustained by innovation diffusion. This paper shows that urban dynamics of technological knowledge together with the role play by knowledge intensive business services both increase the extent of a common knowledge base and maintain economic viability (i.e., profitability) as a crucial feature for the development of new knowledge.

The dynamics of collective technological knowledge *cum* KIBS allow qualifying with new implications the classical Arrovian knowledge trade-off. Such implications are most important in the analysis of the mechanisms governing knowledge and innovation. Figure 3 finally summarizes and compares the different mechanisms of governance with regard to the effects on the knowledge frontier.

INSERT FIGURE 3 ABOUT HERE

Cities emerges as favorable environments for the development of local innovation systems based on (quasi)markets for knowledge, and knowledge-intensive-business-services and the dynamics of collective technological knowledge an alternative governance mechanisms in between the Arrovian public provision of knowledge and the Williamson's vertical integration.

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