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THE PRODUCTION OF COLLECTIVE KNOWLEDGE: SOME EVIDENCE FROM EUROPEAN METROPOLITAN AREAS

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THE PRODUCTION OF COLLECTIVE KNOWLEDGE: SOME EVIDENCE FROM EUROPEAN METROPOLITAN AREAS[1]

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ABSTRACT. Relying upon original empirical evidence gathered in 12 European metropolitan areas, this paper focuses on conditions characterizing the generation of localized technological knowledge. Complementarities relying upon favorable industrial and institutional conditions support collective learning, which in turn emerges as the determinant in the generation of new knowledge. Technological knowledge emerges as a collective good both from a structural and a dynamic viewpoint. Knowledge production is the result of a process that relies upon diverse and yet interdependent knowledge bases, which are systematically accessed, accumulated and recombined through different interpolating processes. Implications for regional and local innovation systems are thus raised appreciating connectivity between the variety of knowledge producers, and therefore communication opportunities and communication channels as central concerns for knowledge-enhancing technology policy.

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1. INTRODUCTION

The role of collective learning has been recently stressed as a crucial factor in the analysis of the regional conditions and determinants in the generation and accumulation of new portions of technological knowledge. Collective learning improves the production and diffusion of different and yet complementary kinds of knowledge, fostering their recombination into a common pool of knowledge, in turn enhancing the regional capacity of generating new knowledge and the eventual rate of innovation (Archibugi and Michie, 1997 and 1998; Clark, Gertler and Feldman, 2001; Storper, 1996; Swann, Prevezer and Stout, 1998).

The recognition of the role of external knowledge in the generation of new knowledge is most important in this context. Those firms that are able to interact with complementary knowledge owners can take advantage from the interdependence between their internal knowledge base and external ones (Griliches 1992; Stiglitz, 1994). Complementarities among internal characteristics of the firm and external industrial and institutional factors are crucial conditions in the production of technological knowledge. The generation of new knowledge in turn emerges as a collective process where firms are not merely involved in in-house R&D and internal tacit know-how accumulation, but rather where firms co-operate within user-producer relations, with academic and scientific institutions, and with services players (Bijker, Hughes and Pinch, 1989; Gibbons et al., 1994; Latour, 1987; Lundvall, 1985).

In this perspective, metropolitan areas emerge as major structures governing such collective learning and the recombination of complementary bits of internal and external, tacit and scientific knowledge (Enrietti and Bianchi, 2002; Keeble and Wilkinson, 1999; Lawton-Smith et al., 1998; Lever, 2002; Saxenian, 1994). More precisely, metropolitan areas account for valuable complementarities in terms of the mix of industrial, scientific and market conditions, and illustrate wide opportunities for learning and communication mechanisms that make the exploitation of such complementarities easier and more effective. The variety of economic conditions and their interdependence can find in relational proximity and the sharing of a common body of social norms and practices the favorable regional conditions that make the transmission of technological knowledge reliable and collective learning successful (Antonelli and Quéré, 2002; Howells, 2002).

Providing original empirical evidence for 12 European metropolitan areas, this paper focuses on the structural characteristics and dynamic conditions determining the generation of collective technological knowledge. Complementarities rely upon favorable industrial, scientific and market conditions, and support collective learning and the recombination of different and yet interdependent portions of internal and external, general and tacit knowledge. Metropolitan areas therefore emerge as favorable environments in which complementarities at the firm, industrial and institutional (i.e., scientific and market) levels can take place, making collective learning effective and the transmission of knowledge reliable.

Therefore, the goal of this paper is to provide empirical evidence for the collective character of technological knowledge as a result of the interdependence and interaction between internal conditions of the firm, and external factors (at the industrial and institutional level) that find in metropolitan areas a positive environment to be implemented.

The paper is organized as follows. Section 2 briefly recalls the elements upon which an empirical analysis of the generation of collective knowledge in metropolitan areas can be built upon. Section 3 presents the original empirical evidence of 12 European metropolitan areas, showing that the generation of technological knowledge is the collective result of the interaction between internal and external production of technological knowledge. Section 4 sums up the results and puts them in perspective.

2. GEOGRAPHY AND THE COLLECTIVE GENERATION OF TECHNOLOGICAL KNOWLEDGE

The spillover-based and the innovation system approaches appreciated the production of technological knowledge in terms of productive indivisibility and institutional complementarity, in turn representing two distinctive and yet interdependent empirically based underpinnings to the systemic character of the localized production of technological knowledge. The production of technological knowledge shows clear features of a collective process.

Knowledge production is strongly affected by both horizontal and vertical indivisibility and systematic cumulability among advances and increases made available in different industrial and institutional contexts. The former are both internal to the firm and external, i.e. related to user-producer relations, labor and industrial dynamics at large. The latter are external to the firm and can account for the role of universities, technology transfer centers and knowledge-intensive business services.

Technological knowledge can now be understood as a collective good (Latour, 1987; Stephan, 1996). Technological knowledge is now seen as coherent stock of fragmented pieces of information, embedded in a number of economic conditions, and partially owned by a variety of economic agents (Cohen and Levinthal, 1989; Malerba, 1992). Moreover, and more importantly, the production of technological knowledge entails that learning efforts are needed to accumulate and recombine such dispersed and complementary pieces of knowledge, in order to make it possible the access and use of such different and external knowledge bases in contexts that are different from those in which they have been elaborated and implemented (Loasby, 1999; Richardson, 1998; Simon, 1985).

Technological knowledge is thus the result of the collective accumulation and distribution of diverse and yet interdependent pieces of internal and external knowledge. Such collective dynamics takes place through the integration of 1) firm-based learning and accumulation of internal tacit knowledge, 2) intra-muros R&D activities, 3) access to external tacit know-how and competence, 4) accumulation of external codified knowledge. In such a systemic recombination, interactive behaviors and communication opportunities are the key determinants in fostering collective learning, the circulation of complementary bits of knowledge and in turn the generation of new knowledge. In this systemic process of knowledge production each element is necessary (Antonelli, 1999 and 2001).

In this context, 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 and fragmented in a number of artifacts, technologies and users. Access conditions are nevertheless harmed by communication costs, that are costs necessary to search, store and decode the relevant bits of knowledge owned by a certain different and complementary agent (Carter, 1989).

In such a framework where the access, accumulation and recombination of knowledge are by no means free and communication conditions are key factors explaining the dynamics of collective knowledge, location has been seen as conducive for lower costs in the communication and hence in the production of technological knowledge. The externalities approach (Becattini, 1987 and 1989; Brusco, 1982) and the transaction costs approach (Storper and Harrison, 1991; Harrison, 1992) respectively acknowledged local economic spaces in terms of recursive exchanges of complementary know-how and of trustworthy relations countervailing opportunistic behaviors. Nevertheless, agglomeration is not sufficient *per se* to give place to technological communication. The institutional context of economic systems in terms of communication channels and opportunities plays a major role in assessing the conditions of the production of technological knowledge (Antonelli, 2000).

The construction of a multilateral network of dissimilar but complementary communicative relations based on institutional variety favors the accumulation and recombination of different knowledge bases, and hence ensures the production of new technological knowledge (Patrucco, 2002 and 2003). The features of economic systems are in turn key factors explaining the dynamics of the production of technological knowledge in that economic systems are conceived as communication networks where knowledge and information are exchanged (Hayek, 1945; Lamberton, 1971, 1996 and 1997).

In the context of generation of technological knowledge, urban and metropolitan areas can account for the mix of variety and complementarity of productive and market conditions, endowment of scientific and technological infrastructures, and systemic and systematic communication mechanisms, and they seem to provide a far more positive context explaining the features of the collective dynamic of technological knowledge.

Complementarities among industrial, technological, institutional and geographical factors shape both synchronically and diachronically the production and distribution of different and yet interdependent portions of technological knowledge, in turn being the key driver for the emergence of a common pool of technological knowledge (Patrucco, 2004).

Four elements have been especially pointed out in the literature. Firstly, much economic analysis appreciated the role played by complementary productive features in enabling by-product interactions and the dissemination of technological knowledge, in turn complementing internal (to the firm) innovative efforts (such as, tacit learning and R&D). In this context, the following are crucial elements to support the generation and diffusion of technological knowledge: upstream and downstream user-producer relations, i.e. the sub-contracting, provision and purchase of specific and complementary intermediary inputs (Lundvall, 1985; Russo, 1985; Von Hippel, 1988); a multisectoral industrial structure where intersectoral externalities enhance diverse knowledge bases to be accessed and recombined (Jacobs, 1969); localized industrial dynamics provide opportunities for new knowledge to be tested and communicated, via market entry, local start-ups, and multinational corporations linkages (Cantwell and Iammarino, 2000; Baptista and Swann, 1999; Feldman, 2001; Feldman and Ronzio, 2001).

Secondly, the local concentration of technology centers and R&D laboratories and of academic infrastructures provides the suitable endowments to generate opportunities for co-localized firms to take advantage from the diversity of science- and technology-based knowledge. The local diffusion of scientific and technological complementary knowledge bases is more and more supported via the knowledge externalities which stem from the university and the R&D laboratories, e.g. by means of postgraduates and researchers mobility and linkages (Audretsch and Stephan, 1996; Feldman and Audretsch, 1999; Quéré, 1994).

Thirdly, agglomeration favors the building up of the conditions for localized market exchange and accumulation of codified knowledge: when considering R&D outcomes and patenting activities, agglomeration greatly ensures knowledge flows and externalities to be gathered, in turn strengthening local markets for the generation of formalized knowledge (Jaffe, Trajtenberg and Henderson, 1993; Jaffe and Trajtenberg, 1999; Patel, 1995).

Finally, urban and metropolitan areas provide an appropriate environment for the production of technological knowledge in that they are characterized by better infrastructures and conditions to access and recombine external knowledge. Technology-enabled communication channels, ex-ante co-ordination via business associations, learning processes and the presence of a local sector of knowledge intensive business services are major factors to ensure the access to and the recombination of the dispersed and yet complementary portions of knowledge (Castells, 1989; Freeman, 1991; Harrison, Kelley and Gant, 1996; Richardson, 1972).

When considering these four elements characterizing the localized production of technological knowledge, four dimensions of the systemic process of the production of technological knowledge can be identified together with the specific factors contributing to each process.

1) Product-oriented knowledge production processes are based on external specific and tacit knowledge, embedded in the productive context in which firms are located, created and shared only by means of productive interactions between complementary business firms, through vertical and lateral technological interdependencies, and local industrial dynamics.

2) Market-oriented knowledge production processes instead depend on internal codified knowledge, which is now disembodied and hence tradable in the marketplace through the results of formal R&D activities integrated by the firms, e.g. by means of patents.

3) Science-and-technology-oriented knowledge production processes are also resting upon the generation and diffusion of external codified knowledge by means of the production of scientific advances made available by research in the universities and collective laboratory.

4) Finally, communication-oriented knowledge production processes are contingent on the accumulation and recombination of internal and external tacit and codified knowledge, their peculiar role being recognized in the transmission of tacit knowledge and its translation into more codified knowledge.

In order to address the empirical evidence of metropolitan areas, the systemic conditions which emerged from the conceptual context so far articulated are useful to acknowledge the dynamic interdependencies characterizing the knowledge production, i.e. the complementarity between communication-; science&technology-; market- and product-oriented processes. When coupling them with the framework elaborated by Antonelli, Gaffard and Quéré (2003) appreciating the structural factors contributing to the production of technological knowledge, three main knowledge bases can be also identified:

1) Internal knowledge, which relates to technological knowledge produced internally by each firms. In that it relates to both tacit and codified knowledge, main sources are formal R&D activities as well as internal learning mechanisms. Digital communications, e.g. Intranet, are to be though of as key factors contributing to the codification of tacit knowledge;

2) External knowledge that belongs to sources which are external to the firm but consistent with productive systems where firms play. I.e. inter-sectoral interdependencies between local industrial specialization, dynamics of market entry, market re-organization and labor mobility, interactions within the supply chain which can be enhanced by both production relations and technology-enabled communication infrastructures;

3) External knowledge that pertains to external sources relating to the institutional environment of local innovation systems. Universities and research centers,

technology transfer centers, business associations and knowledge intensive business services (KIBS) (i.e. telecommunication services, business consultants, venture capitalists) are key knowledge-producing and -recombining institutions.

These elements can be useful in classifying knowledge systems on the base of the structural and dynamic conditions which contribute the overall production of knowledge. In our hypothesis the most distinctive character of collective technological knowledge is the interpolation between the different knowledge bases and processes.

3. COLLECTIVE TECHNOLOGICAL IN 12 EUROPEAN METROPOLITAN AREAS

3.1. Sources and data

Original empirical evidence has been gathered in 12 European metropolitan areas explaining both quantitatively and qualitatively the structural and dynamic features that contribute the collective generation of knowledge.

The methodological approach taken in order to address the empirical evidence aims at coupling quantitative and official economic indicators with more qualitative information gathered by means of both online questionnaires and face-to-face interviews. Quantitative and statistical data are screened and tested by means of qualitative and direct interviews, during which a 'sample' of local experts was asked to evaluate the contributions of each local knowledge-producing organization and factor using a scale of five degrees of knowledge production's intensity. This approach is likely to allow us to homogenize information and data stemming from different sources. The empirical data set deals with a period of five years, from 1995 to 2000.

Three kinds of sources of quantitative and qualitative information have been employed.

Firstly, official statistical sources has been considered in order to identify the following features characterizing the economic system in each metropolitan areas: economic indicators at large, providing the introductory description of the economic background of each area, mainly in terms of GDP per capita and unemployment rate; industrial indicators showing the distribution of sectors in each area in terms of numbers of firms and employees, according to the NACE classification, in order to identify the local industrial specialization; innovation indicators accounting for the overall innovative level of each area, mainly in terms of the ratio between R&D expenditures and GDP, and in terms of the number of patents application. In this context, the Eurostat online database and the Eurostat report on science, technology and innovation (Eurostat, 2001a) allow providing a preliminary comparison (on the base of standard and official key economic and innovation indicators) among metropolitan areas and among European, national and local economic and innovation features (see Table 1).

INSERT TABLE 1 ABOUT HERE

Secondly, in order to provide information at the meso-level, local official statistical and economic sources has been used. More precisely, local chambers of commerce and municipality's offices for economic and statistical studies have been contacted online for each metropolitan area, submitting a questionnaire. Each relevant office was asked to fill up both quantitative and qualitative information concerning the economic and institutional context that characterizes the metropolitan area, taking into consideration the period 1995-2000. Each relevant office for the 12 areas returned the filled questionnaire, in turn having 24 questionnaires. Information was referred to the following points: a) the structure of the local economic system; the industrial dynamics of the local economic system; c) the institutional and infrastructural endowment (see Appendix 5 for the phrasing and the structure of the questionnaire).

These kinds of information and data at the meso level were completed with Eurostat data on the number of patent applications to the EPO (European Patent Office) at regional level for 1999, which considers the top three leading regions of each Member State (Eurostat, 2001b).

Thirdly, in that issues such as the dynamics of local networks, communication and knowledge production are very complex, a more qualitative source has been used in order to complement the set of quantitative data. Direct interviews with a group of local experts were carried out in order to appreciate the endogenous dynamics of interaction within each metropolitan area. The role of the different actors in the process of knowledge production has been emphasized, seeking to acknowledge the complementarities between different knowledge bases and between different knowledge producers. Following the schema used for the online questionnaire, a set of 12 managing directors or senior managers of agencies for local development located in the 12 metropolitan areas was interviewed. They were asked to provide qualitative description of the complementarities and interactions between local knowledge-producing institutions, in order to understand the complex network dynamics characterizing local innovation systems. Moreover, they were asked to measure the intensity of the contribution of each institution to the overall stock of knowledge produced in the area, using a scale of five degrees of intensity (not relevant/applicable; low; medium; high; determinant). In doing so, a standardized though 'soft' set of measures for the values of each factor in each area was carried out.

When coupling the sources so far described, a qualitative and quantitative database containing information on 11 structural and dynamic characteristics of each of the 12 urban innovation systems has been elaborated. Such 11 structural and dynamic characteristics, described in quantitative and qualitative terms, are the following: internal (to the firm) R&D activities; internal tacit learning mechanisms; internal use of ICT; inter-sectoral interactions; entry dynamics; user-producer relations; ICT infrastructures; University and research linkages; technology centres; ex-ante co-ordination organisations and mechanisms; knowledge-intensive-business-services (see Appendix 1). Relying upon such a dataset and upon the integration of official statistics with online questionnaires and direct interviews, the decisive assessment of the contributions' intensity of the diverse factors in the 12 metropolitan areas has been carried out (see Appendix 2). In other words, if official statistics provided only a partial evaluation of the conditions and features of the collective production of knowledge, online questionnaires and direct interviews completed the empirical set appreciating more qualitative effects.

The following table summarizes the set of variables used to measure the collective dynamics of knowledge production and the relevant indicators taken as proxies.

INSERT TABLE 2 ABOUT HERE

3.2. Measuring collective technological knowledge

In that the main purpose of this paper is to provide empirical evidence for the collective character of technological knowledge comparing 12 European metropolitan areas, it is important to assess the different actual contributions of the diverse knowledge bases in the diverse region-specific economic spaces. To do so, both qualitative (e.g., the features of the local telecommunication infrastructures) and quantitative (e.g., the number of patents registered by firms located in a certain area) information has been homogenized. Five levels (0, 1, 2, 3, and 4) were employed, and they can be conceived as measures explaining the intensity (not applicable/relevant, low, medium, high, and determinant, respectively) with which a certain element enters in the production of the relevant knowledge base (see Appendix 2 for the distribution of factors' intensity in the different areas).

In order to provide a quantitative assessment of the production of technological knowledge in the 12 European metropolitan areas considered in this paper, the following set of equations is a preliminary attempt to formalize and estimate the contributions of the different elements to each relevant knowledge base and to the overall structural dimension of technological knowledge. In turn, they also represent a tentative effort to measure the stock of each knowledge base and the overall level of technological knowledge, taking into account the cumulability and complementarity effects in the production of knowledge (Stephan, 1996).

When considering the analysis of productive contexts characterized by strong complementarities between heterogeneous inputs and especially diverse and interdependent kinds of knowledge entering the generation of new knowledge, theoretical and empirical contributions built models in which the heterogeneous knowledge inputs enters the production function multiplicatively, that is to say with increasing returns (Caves, 2000; Kremer, 1993). Moreover, these analysis also appreciated the distinctive contributions of the diverse inputs in the production function, in that certain and key factors enter the production function multiplicatively, while certain others enter it with constant or even standard diminishing returns. In this paper, although a set of heterogeneous knowledge inputs is assumed, the knowledge production function is modeled as additive, that is to say the heterogeneous knowledge inputs enters the production function with constant returns. The preliminary character of this empirical assessment makes it more appropriate to assume a cautious hypothesis on the nature of the complementarities between the diverse knowledge inputs. In this regard, the very nature of the multiplicative production function is instead of emphasizing the increasing as well as decreasing impact of each factor and input in a certain production function. Moreover, the object of this paper is, first and foremost, to provide empirical evidence for the collective character of technological knowledge in terms of both the institutional context and the diverse processes characterizing the knowledge production. In this regard, the acknowledgement of the peculiar kinds of contributions of each knowledge-input (i.e. with increasing, constant or diminishing returns) should be considered as the object of further research works.

The following figure (Figure 1) shows the different knowledge bases and the relevant factors affecting each knowledge base that contribute to the systemic structure of technological knowledge. Moreover, it exemplifies the basic methodological tool employed in order to gather and categorize information and knowledge about the empirical analysis (see Appendix 4 for the overall empirical assessment). Finally, it exhibits the different factorial contributions of each specific feature adding to the process of knowledge production. The basic and preliminary assumption here is that each element is *per se* indispensable in the collective dynamic of knowledge production. Hence, each knowledge base (i.e., internal knowledge, external knowledge product dependent, external knowledge institutions dependent) has been considered to be as significant as the others (o, p, q = 0.3333) in determining the overall stock of technological knowledge. Subsequently, as far as each knowledge base is taken into account, the contribution of each specific element determining to the relevant knowledge base's dimension is to be weighed as influential as the others. E.g., when accounting for the overall dimension of the internal knowledge base, codification, internal learning mechanisms and digital communications show the same factorial contributions (a, b, c = 0.1111). In a similar manner, when taking into account the external and product-dependent knowledge base, and the external and institutions-dependent knowledge base, each element has been given the same factorial contribution (i.e., d, e, f, g, h, i, l and m = 0.0833). In that the (factorial contributions of the) knowledge base level addresses the (factorial contributions of the) relevant elements, the framework is formulated so as to keep equal the knowledge bases' contributions even when adding elements entering the process of knowledge production. To put it simply, the specific factorial contribution of each element to the overall dimension of technological knowledge is a reverse function of the number of elements in the pertinent knowledge base.

INSERT FIGURE 1 ABOUT HERE

Equation (1) estimates the collective character of the stock of internal knowledge at the firm level (IK), where internal codification activities, internal learning mechanisms and internal digital communication systems are taken into account, and where a, b, c are the factorial contributions of each relevant element (see Figure 2).

$$IK= (CODIFIED^{a})+(LEARN^{b})+(ICTfirm^{c}) \quad (1)$$

Equation (2) assesses the amount of knowledge that belongs to sources which are external to the firm but consistent with the industrial system where firms play (EKproduct). Inter-sectoral complementarities, entry dynamics, user-producer relations and the role of technology-enabled communication infrastructures are considered, and where d, e, f, g are the factorial contributions of each element.

EKindustrial=
(INTERSECTORd)+(ENTRYe)+(USEPROf)+(ICTinfrastructureg) (2)

Equation (3) appraises the stock of knowledge that pertains to external features relating to the institutional environment of the local knowledge system (EKinstitutions). The different contribution of universities and research centers, technology centers, associations and knowledge intensive business services is considered, and h, i, l, m are the factorial contributions of each element.

EKinstitutions= (UNIh)+(TECHi)+(COORDl)+(KIBSm) (3)

Equation (4) works out the collective dimension of the total stock of technological knowledge (TK), where the contributions of internal sources (firm-based), external sources at the industrial level and external sources at the institutional level are appreciated.

TK= IK+EKindustrial + EKinstitutions (4)

Equations (1), (2), (3) and (4) estimate the systemic dimension of technological knowledge from a structural viewpoint. In other words, they account for the different knowledge bases, and subsequently for the specific elements determining each knowledge base, which add to the total stock of technological knowledge.

Nevertheless, section 2 has recognized the systemic and collective character of technological knowledge also from the viewpoint of the diverse processes contributing to the general production of knowledge. Four different orientations were identified in the process of knowledge production: science & technology-oriented knowledge production; market-oriented knowledge production; industry-oriented knowledge production; communication-oriented knowledge production.

In order to address whether the collective recombination of complementary factors takes place also considering the diverse process dimensions are involved in, and in order to assess the different contributions of such processes to the total stock of technological knowledge, a further set of equations shall be articulated.

Equations (5), (6), (7) and (8) estimate the production of technological knowledge taking into consideration the systemic complementarities of specific features and sources of knowledge in terms of different dynamics. Moreover, as the previous one [see equations (1), (2), (3) and (4)], also this set of equations gives evidence to the cumulability (with constant returns) of complementary pieces of knowledge which originate in different contexts and sources. In other words, the systematic access and recombination of complementary and cumulative pieces of knowledge that shapes the collective nature of technological knowledge is now seen from the viewpoint of the diverse processes interpolating in the production of technological knowledge.

Equation (5) estimates the contribution of the different factors affecting the communication dimension in the process of knowledge production. It appreciates the cumulability and interplay of the diverse pieces of knowledge that originate from learning mechanisms internal to the firm, from the ex-ante co-ordination of associations and third parties and from the ICT-enabled communication processes enhanced via the local infrastructures and the systems internal to the firm. b, c, g, l, are the relevant factorial contributions of each communication feature.

COMMTK=
(LEARNb)+(ICTfirmsc)+(ICTinfrastructureg)+(COORDl) (5)

Equation (6) accounts for the contribution of science-and-technology based processes to the production of technological knowledge. The cumulability and interdependence of knowledge stemming from both academic research and technology transfer are acknowledged; h and i are the relevant factorial contributions of each science-and-technology feature.

S&TTK=(UNIh)+(TECHi) (6)

Equation (7) shows the contribution that market-oriented processes play in the collective production of technological knowledge. It assesses the process of knowledge codification into marketable bits of information (e.g., by means of R&D activities and patenting), and the contribution of KIBS in the tradability of knowledge. a, m are the relevant factorial contributions.

MARKETTK=(CODIFIEDa) + (KIBSm) (7)

Finally, equation (8) works out the product-oriented dimension of knowledge production, apprehending the accumulation and recombination of complementary pieces of knowledge generated in complementary productive features (i.e., cross-sector externalities, entry dynamics, upstream and downstream provision and purchase of specific products), and where d, e, and f are the relevant factorial contribution of each element.

PRODUCTTK=(INTERSECTORd)+(ENTRYe)+(USEPROf) (8)

3.3. The empirical evidence of 12 European metropolitan areas

Elaborating on the framework introduced in the previous paragraph, this section aims at summarizing some European evidence and gives support to the relevant complementarities between different knowledge bases and different knowledge processes in the production of technological knowledge.

In that knowledge is more and more considered the key input fostering the collective dynamics of growth and innovation, the empirical investigation of whether there are different sources and processes explaining the production of technological knowledge in such 12 metropolitan areas can identify the different contributions of such diverse knowledge bases and processes, and could represent a first assessment to understand the collective character of technological knowledge.

Charts 1, 2, 3 and 4, are based on equations (1), (2), (3) and (4) summarize empirical evidence accounting for the contributions of the three different knowledge bases (i.e., internal firms-based knowledge, external industry-based knowledge, external institutions-based knowledge) and relevant specific elements to the production of the total stock of technological knowledge into 12 European metropolitan areas. Hence, carts 1, 2, 3 and 4 aim to assess the collective structure of technological knowledge, measuring the contributions and the complementarity between the diverse knowledge bases and knowledge elements.

INSERT CHARTS 1, 2, 3, 4 ABOUT HERE

From a structural viewpoint and considering the contribution of the different knowledge bases to the production of technological knowledge (Chart 1), main results are:

- There is not any clear-cut predominance of one kind of knowledge base, nor at the aggregate level, neither within the same metropolitan area;
- Nevertheless, five metropolitan areas are more oriented towards a mono-lateral kind of technological knowledge:
- In fact, firstly, the areas of Vienna, Barcelona and Strasbourg are more characterized by the importance of the product-dependent external knowledge, which contributes for 72.00%, 46.87% and 47.62% to the total stock of technological knowledge, respectively; secondly, firm-dependent internal knowledge is almost distinctive in the areas of Östergötland and Copenhagen, determining 45.08% and 41.24% of the total stock of technological knowledge.

When considering the structure of each knowledge base and the specific contributions of the relevant knowledge-producing institutions and features, the collective nature of technological knowledge also emerges, with few distinguishing elements.

In fact, when comparing internal knowledge base to external knowledge bases (both product- and institutions-dependent knowledge bases), the former is more likely to be affected by the explicit role of certain factors than the latter; in other words, external knowledge bases are more likely to affect the collective nature of technological knowledge than firm-based knowledge.

Moreover, when taking into consideration firm-dependent internal knowledge base (Chart 2), three main result emerge:

1. four areas (Bologna, Barcelona, Vienna and Bruges) show that the role of new communication technologies as knowledge producing factors is by no means relevant or at least not yet applicable;
2. internal tacit learning mechanisms generate the total stock of firm-based knowledge in the area of Vienna and 75% of the firm-based knowledge in the area of Bruges;
3. Milan's firms knowledge base is much more characterized by the activities of knowledge codification (e.g., R&D and patenting) rather than the other areas.

When considering product dependent external knowledge base (Chart 3), the collective nature of technological knowledge is more and more evident, both at the aggregate level and within the same area. As a matter of fact, the contribution of a certain factor to the total stock of the knowledge base is tending to be dominant (that is to say, the factor's contribution to the overall stock of the relevant knowledge base is ≥50%) only in 8.33% of the aggregate distribution of the knowledge base's factors (4 factors are likely to be dominant out of 48 totally available); in the areas of Barcelona and Helsinki, cross-sector knowledge externalities are the most distinguishing factor in the production of the knowledge base, generating 60% and 50% of the knowledge base stock, respectively; the new communication technologies infrastructures characterizing the local industrial endowment contribute to 50.00% of the total stock of product-dependent external knowledge in the case of Helsinki; finally, user-producer interactions determine 50% of the overall product dependent knowledge base in the area of Bologna.

Finally, as far as the institutions-dependent external knowledge base is taken into consideration (Chart 4), the systemic dimension of knowledge production is also appreciated. At the aggregate level, only 5 factors out of the 48 (10.41%) knowledge base's factors totally categorized are tending to be dominant in the production of knowledge. At the unit level, the institutions-dependent knowledge base is more and more affected by the role of the local sector of knowledge intensive business services in the Östergötland's area, and by academic research in the areas of Barcelona, Vienna and Copenhagen.

Chart 5 is based on equations (5-8) and gives evidence to the collective nature of knowledge production from the viewpoint of the diverse processes impinging on the diverse opportunities to access, accumulate and recombine into a coherent stock the fragmented and yet interdependent pieces of knowledge.

INSERT CHART 5 ABOUT HERE

When examining whether technological knowledge is a collective good even from the viewpoint of the diverse processes adding to the systemic production of technological knowledge, the following are crucial results:

- At the aggregate level, only in 5 out of the 48 knowledge-oriented processes characterizing the 12 metropolitan areas, there is one single process that quite clearly emerge as the prevalent one, that is to say it generates at least 40% of the total stock of technological knowledge; in Barcelona 46.87% of the total stock of knowledge is generated through product-oriented processes, while in Nice and Helsinki 42.40% and 40.91% respectively are generated by means of communication-oriented processes. Finally, in Vienna, 40% and 48% of the total stock of knowledge is generated through communication-oriented and product-oriented knowledge processes. In these cases it is possible to say that the production of technological knowledge is tending towards a mono-dimensional process;

- In all the other cases, there is not any clear-cut predominance of one kind of process, nor at the aggregate level, neither within the same metropolitan area;
- Nevertheless, when considering the relative weights of the different process dimensions within each metropolitan area, the key role exerted by communication-oriented and product-oriented processes is clearly pointed out, in that in 41.66% and 50% of the cases respectively, these two kinds of process tend to generate a greater amount of the total stock of knowledge rather than each of the other three process dimensions.

The analysis so far conducted has addressed the systemic complementarities occurring in the production of technological knowledge both in terms of the structure of technological knowledge as described by the complementarities between different knowledge bases, and in terms of the dynamic of knowledge production as described by the interpolation between diverse knowledge-oriented processes.

Nevertheless, our approach allows also addressing a preliminary comparison between areas which are characterized by different absolute levels of knowledge production. In this concern, three main bunches including different sizes of knowledge production are identified:

- A first level including top performing areas (Nice, Stockholm and Copenhagen) in which the total amount of technological knowledge tends to rise up to 3.4712 (Nice), 2.9158 (Stockholm) and 2.6937 (Copenhagen);
- A second level covering the group of Italian areas, which present similar structural and process features, and in which the total stock of technological knowledge ranks from 2.0827 (Bologna) to 2.4437 (Turin);
- A third level comprehending northern European metropolitan areas in which the range of technological knowledge is reaching from 1.7772 (Bruges) to 1.9717 (Östergötland);
- A fourth level in which the total size of technological knowledge varies between 0.6942 (Vienna) and 0.8886 (Barcelona).

4. CONCLUSIONS

This paper provided empirical evidence for the systemic character of the production of technological knowledge in 12 European metropolitan areas.

The collective nature of technological knowledge was emphasized in terms of both structural and dynamic complementarities and complementarities. From the structural viewpoint, technological knowledge relies upon three main knowledge bases: firm-based internal knowledge base, product-dependent external knowledge base, and institutions-dependent external knowledge base. Moreover, each knowledge base is characterized by the systemic contribution of specific knowledge elements, which add to the production of the relevant knowledge base and are systematically accumulated and recombined in the production of the total stock of technological knowledge. The categorization of the empirical evidence about 12 European metropolitan areas showed that in most of the cases technological knowledge is the result of the cumulability and interplay between each of these different portions of knowledge.

From the dynamic perspective, the analysis of the production of technological knowledge appreciated four different process dimensions: science & technology-oriented knowledge production; market-oriented knowledge production; product-oriented knowledge production; communication-oriented knowledge production. When employing such taxonomy to the empirical context of 12 metropolitan areas, evidence is provided for the fact that the systematic access and recombination of complementary and cumulative pieces of knowledge that shape the collective nature of technological knowledge is also significant from the viewpoint of the diverse processes taking part in the knowledge production. In other words, also from the viewpoint of the diverse knowledge-producing processes, technological knowledge emerged as a collective good in that the total stock of technological knowledge is the result of the systematic cumulability and interplay of complementary knowledge-oriented processes. Especially, communication-oriented processes and product-oriented processes account for a great part of the production of technological knowledge.

In turn, technological knowledge emerged as a collective good in that its production is the result of a process that combines pieces of generic, scientific knowledge and specific, idiosyncratic knowledge, which are owned by a variety of economic agents, and which are accessed, accumulated and recombined through interpolating dynamics. Such a complementarity among the diverse knowledge bases emphasizes the importance of interactions among different knowledge owners. The proper knowledge-enhancing environment is made up by a communication network of producers and client firms building user-producer relationships in a multi-technological industrial structure and contributing each other to the internal, tacit and codified, knowledge base of productive partners. In this context, University and R&D institutions establish linkages with business firms undertaking basic research efforts and providing the external codified knowledge base upon which implementing firms' internal knowledge; telecommunications, consultants and the financial sector provide knowledge-based services for business, in turn favoring the knowledge transfer and recombination, acting as interfaces between the scientific and codified knowledge provided by institutional and business external sources, and internal tacit know-how and R&D efforts.

From a conceptual and policy-oriented point of view, the European evidence provided in the paper present supportive corroborative grounds for the fact that two notions are emerging as crucial in explaining the features and dynamics of regional knowledge and innovation systems, in turn defining the systemic character of regional innovation system itself: variety and connectivity (Metcalfe, 1995).

The creation of such conditions, i.e. connectivity among diverse and complementary agents, should be a central concern of knowledge-enhancing and growth-oriented technology policies. Especially, two kinds of implications for technology policy are stemming from our evidence. Firstly, as far as our evidence has shown that the production of technological knowledge depends on the whole pattern of institutional and productive actors, the creation and diffusion of complementary knowledge-producing institutions should be a major goal of regional technology and innovation policy.

Secondly, the collective character of technological knowledge highlights the importance of an institutional set stressing the strength and the coherence of (sub) regional innovation systems, particularly in terms of systemic interdependencies, in turn emphasizing the key role played by a variety of complementary interactions in the dynamics of knowledge production. This makes clear the appreciation of policies oriented to foster the connections among the diverse knowledge-producing institutions, and it is particularly relevant in terms of communication policies. In this regard, evidence about the positive effect of regional-defined and concentrated investments in ICT (Hicks and Nivin, 2000) calls for focalized policies oriented towards the implementation of digital communications networks. Nevertheless, the localized pattern of face-to-face communication and interaction mechanisms is still a key issue when explaining the production of new technological knowledge (Howells, 1996).

Within this context of analysis, the empirical evidence provided in this paper is consistent with a view of regional and sub-regional innovation systems that stresses the internal set of interactions among firms, and between them and institutions operating in the region. One where the institutional structure of the region in terms of communication opportunities and communication channels is the crucial factor favoring local learning and knowledge sharing, in turn determining the internal dynamics of new knowledge production (Cooke, 2001; Cooke et al., 1997; Howells, 1999).

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LIST OF FIGURES AND TABLES

Table 1. Growth and innovation in 12 European metropolitan areas

	GDP per capita*			Unemployment rate**			R&D expenditures/GDP***			Patents****		
	Local	**National**	**EU-15**	**Local**	**National**	**EU-15**	**Local**	**National**	**EU-15**	**Local**	**National**	**EU-15**
Bologna	25,462	16,278	18,102	3.3	10.6	8.0	:	1.04	1.85	281	143	261
Turin	19,788	16,278	18,102	9.0	10.6	8.0	:	1.04	1.85	235	143	261
Milan	25,629	16,278	18,102	6.9	10.6	8.0	1.22	1.04	1.85	272	143	261
Barcelona	11,900	11,890	18,102	8.7	13.7	8.0	:	0.53	1.85	93	43	261
Vienna	20,979	22,269	18,102	4.9	3.7	8.0	:	1.82	1.85	:	256	261
Nice	17,318	20,644	18,102	11.6	8.6	8.0	:	2.19	1.85	:	258	261
Strasbourg	20,733	20,644	18,102	6.0	8.6	8.0	:	2.19	1.85	296	258	261
Bruges	22,184	20,625	18,102	9.4	6.8	8.0	:	1.83	1.85	:	274	261
Östergötland	22,651	22,561	18,102	6.0	5.3	8.0	:	3.71	1.85	:	478	261
Stockholm	25,067	22,561	18,102	3.6	5.3	8.0	:	3.71	1.85	854	478	261
Helsinki	19,218	:	18,102	14.5	9.2	8.0	3.74	3.09	1.85	723	455	261
Copenhagen	24,592	26,494	18,102	7.0	4.7	8.0	1.94	1.99	1.85	251	251	261

*GDP in current EURO; EU-15, national and local level: 1997; exceptions Milan, Bruges, 1998; Strasbourg, Östergötland, Stockholm, Turin, 1999; Nice, 2000.

**EU-15 and national level: 2000; local level: 1999; exceptions Barcelona, Nice, 2000; Copenhagen, Helsinki, Vienna, 1997

***EU-15, national and local level: 1999; exceptions France: 1998

**** Patents applications to the EPO (European Patent Office) per million people in the labor force; EU-15, national and local level: 1999

Source: Eurostat, 2001a

Table 2. Variables and indicators of the generation of knowledge in the 12 metropolitan areas

Variable	Source	Indicator	Criteria for the assessment of knowledge intensity
Internal R&D	Eurostat, 2001b	Number of patent applications to the EPO (European Patent Office)	Four classes of intensity according to the degree of patenting 1) 1096-716 (intensity=4) 2) 553-323 (intensity=3) 3) 249-173 (intensity=1) 4) <173 (intensity=0)
Internal learning	Information concerning the organizational structure of the firms (tested with question 1.c of the questionnaire) Qualitative description from face-to-face interviews	The number of complementary learning activities (e.g., formal training and learning on the task) implemented by the firms in order to generate complementary kinds of knowledge (e.g., codified and tacit knowledge, respectively)	Formal training: intensity=1 Learning on the task: intensity=1 Formal training + learning on the task: intensity 2 No explicit training system: intensity=0
Internal digital communication systems	Information concerning the organizational structure of the firms (question 1.c of the questionnaire) Qualitative description from face-to-face interviews	The complexity and innovativeness of the digital communication systems adopted	Extranet networks: intensity=4 Intranet network: intensity=2 Internet as an advertising tool: intensity=1 No adoption of digital communication systems: intensity=0
Inter-sectoral interactions	Official statistics on the structure of the local economic system Information from the online questionnaire (questions 1.a and 1.d) Qualitative description from face-to-face interviews	The number and weight of industrial sectors in the area (Official statistics + Online questionnaire) The presence of technological and industrial complementarities among local sectors (Face-to-face interviews) The presence and weight of local clusters (Online questionnaire)	Multi-industrial context+complementary technology and production+local cluster: intensity=4 Multi-industrial context+complementary technology and production: intensity=3 Multi-industrial context: intensity=2, 1 (according to the number of industries) Mono-industrial context: intensity=0
Entry dynamics	Information from the online questionnaire (section 2) Qualitative description from face-to-face interviews	The number and complementarity of industrial dynamics	Four types of entry: intensity=4 Three types of entry: intensity=3 Two types of entry: intensity=2 One type of entry: intensity=1 No entry: intensity=0
User-producer relations	Information from the online questionnaire (questions 1.b and 1.d) Qualitative description from face-to-face interviews	The number and complementarity of interaction between clients and suppliers	Four types of interaction: intensity=4 Three types of interaction: intensity=3 Two types of interaction: intensity=2 One type of interaction: intensity=1 No interaction: intensity=1

ICT infrastructures	Information from the online questionnaire (question 3.b) Qualitative description from face-to-face interviews	The number and quality of telecommunication networks implemented in the area	ATM networks+Broadband networks+Mobile networks: intensity=4 ATM networks+Broadband networks: intensity=3 Broadband networks: intensity=2 Computer aided production: intensity=1 No effective adoption of networks: intensity=0
University and research centers	Information from the online questionnaire (question 3.a) Qualitative description from face-to-face interviews	The number and quality of academic and collective research centers in the area	At least three institutions of excellence: intensity=4 Two institutions of excellence: intensity=3 Two mid-range institutions: intensity=2 One institution: intensity=1 No relevant institutions: intensity=0
Technology transfer centers	Information from the online questionnaire (question 3.a) Qualitative description from face-to-face interviews	The number and quality of technology transfer centers in the area	At least three institutions of excellence: intensity=4 Two institutions of excellence: intensity=3 Two mid-range institutions: intensity=2 One institution: intensity=1 No relevant institutions: intensity=1
Co-ordination structures and mechanisms	Information from the online questionnaire (question 3.c) Qualitative description from face-to-face interviews	The number and quality of public and public-private institutions in the area	At least three institutions of excellence: intensity=4 Two institutions of excellence: intensity=3 Two mid-range institutions: intensity=2 One institution: intensity=1 No relevant institutions: intensity=2
KIBS	Information from the online questionnaire (question 3.d) Qualitative description from face-to-face interviews	The number and quality of the local banking system, venture capitalists, consultants and ICT business services in the area	At least three institutions of excellence: intensity=4 Two institutions of excellence: intensity=3 Two mid-range institutions: intensity=2 One institution: intensity=1 No relevant institutions: intensity=3

Figure 1. The systemic character of the production of technological knowledge and relevant factorial contributions to the process of knowledge production

TECHNOLOGICAL KNOWLEDGE		
INTERNAL KNOWLEDGE BASE (o=0.3333)	EXTERNAL KNOWLEDGE BASE - product dependent (p=0.3333)	EXTERNAL KNOWLEDGE BASE - institutions dependent (q=0.3333)
Elements • Codification (a=0.1111) • Internal learning mechanisms (b=0.1111) • Digital communications (c=0.1111)	*Elements* • Inter-sectoral interactions (d=0.0833) • Industry dynamics (e=0.0833) • User-producer relations (f=0.0833) • ICT infrastructures (g=0.0833)	*Elements* • University and research (h=0.0833) • Technology centres (i=0.0833) • Business associations (l=0.0833) • KIBS (m=0.0833)

Chart 1. The contribution of different knowledge bases to the production of technological knowledge

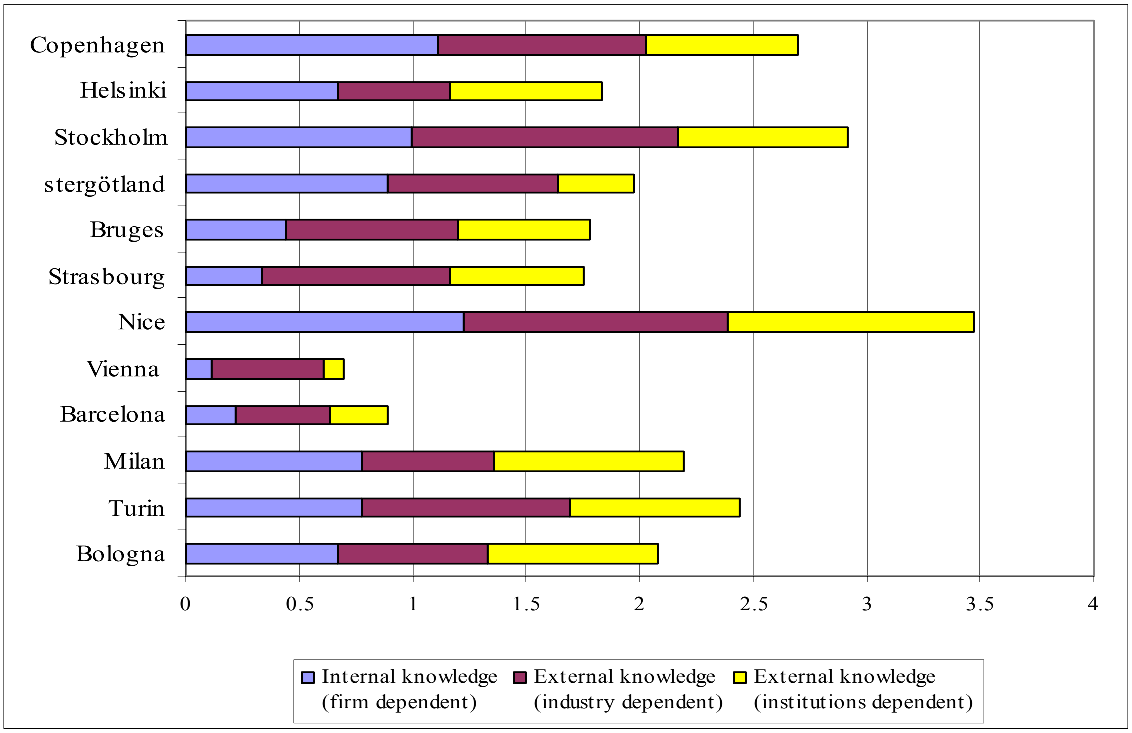


Chart 2. The contribution of specific elements to the production of internal knowledge (firm-dependent)

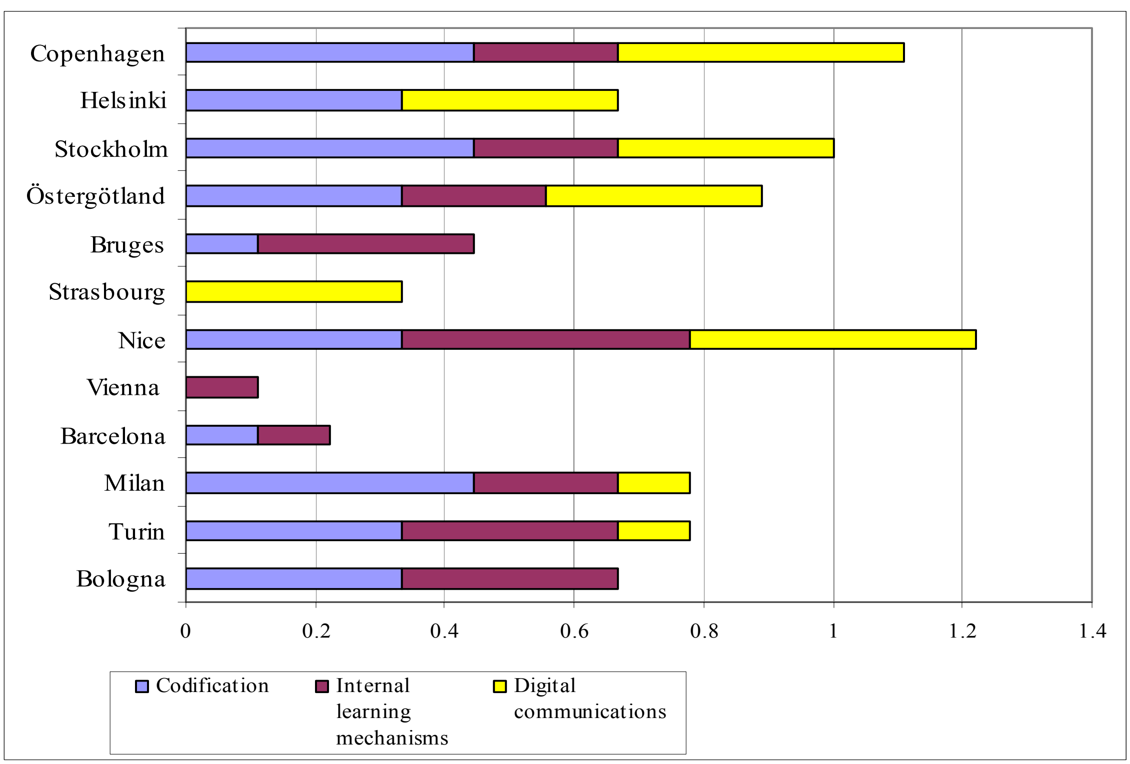


Chart 3. The contribution of specific factors to the production of external knowledge (product-dependent)

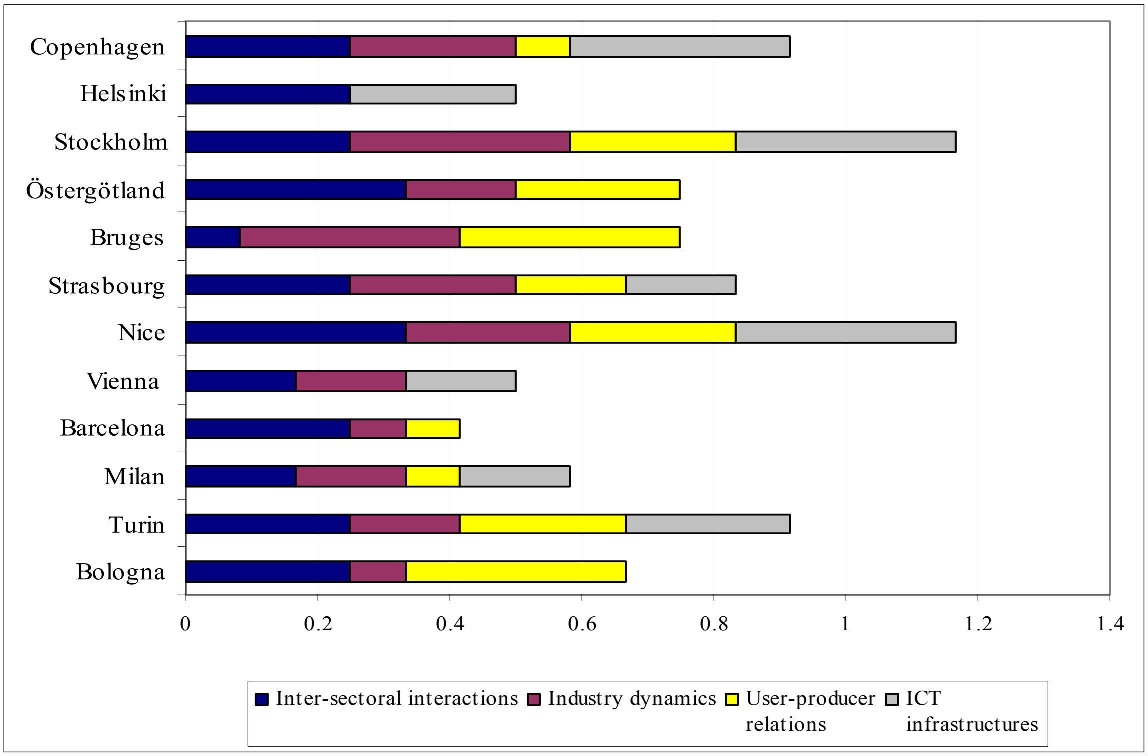


Chart 4. The contribution of specific factors to the production of external knowledge (institutions-dependent)

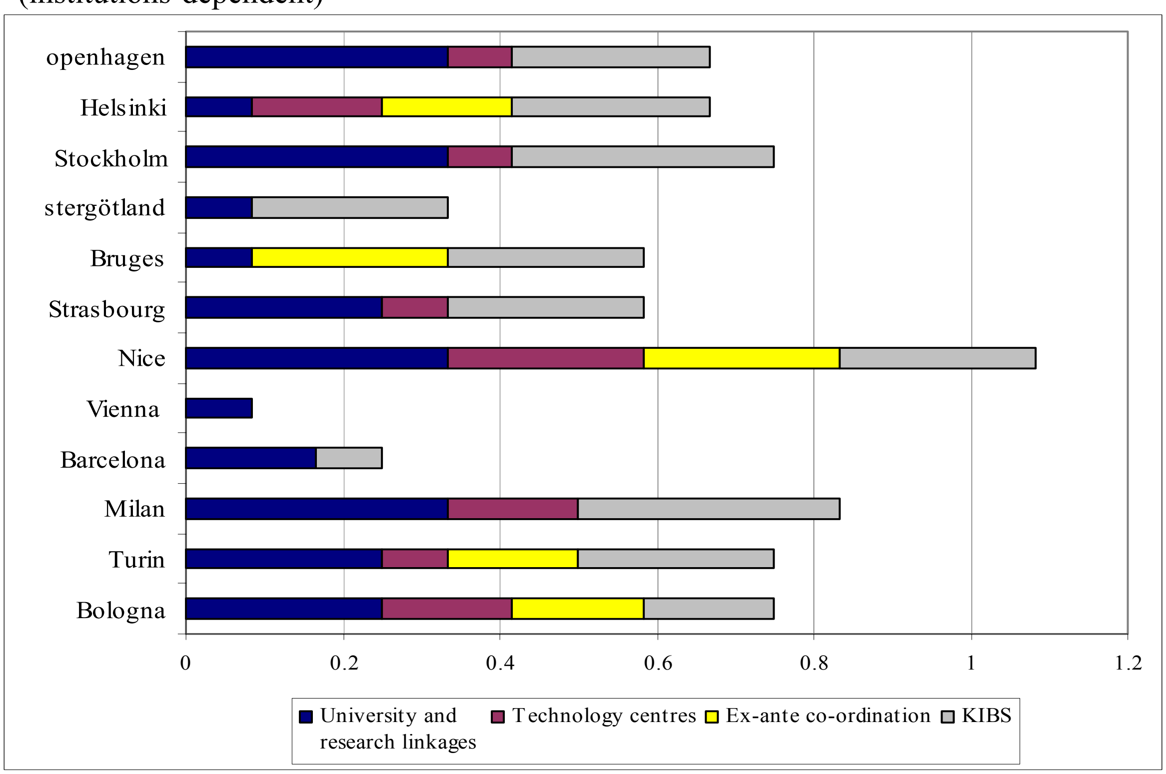
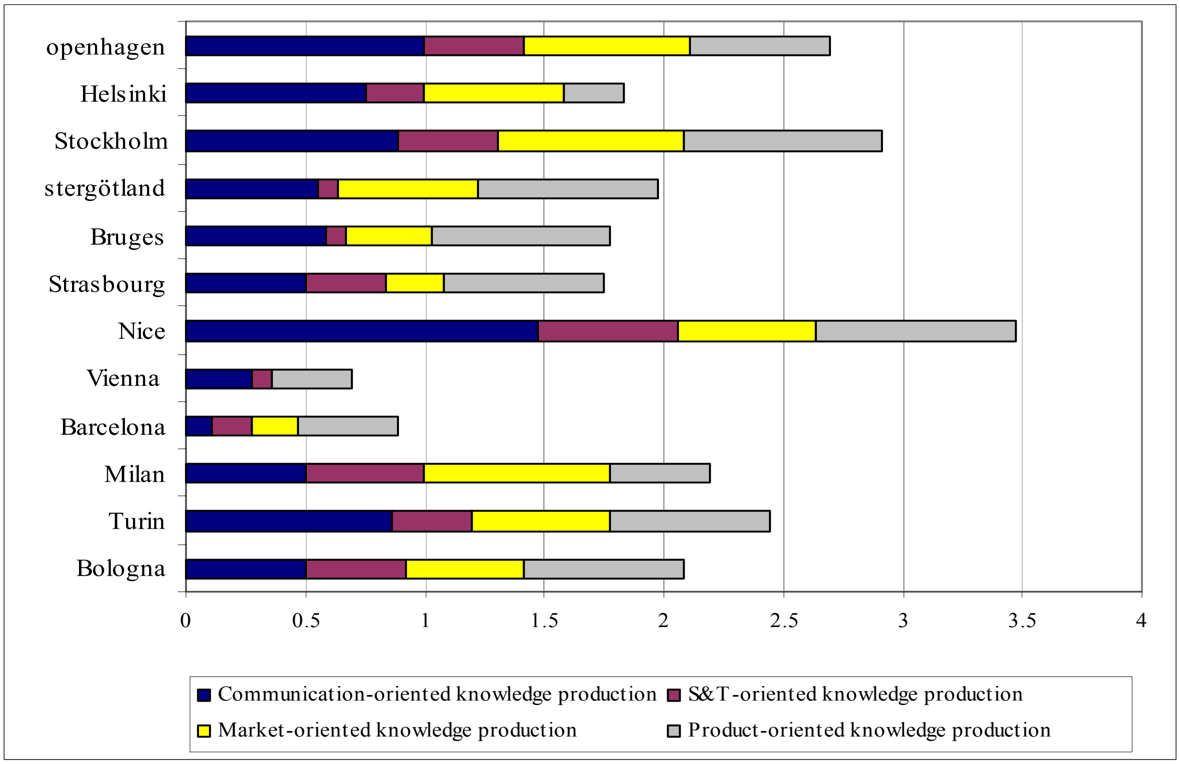


Chart 5. The contribution of different processes to the production of technological knowledge



APPENDIX 1. The knowledge-producing institutions and features in 12 European metropolitan areas

Knowedge institutions & features	**Internal knowledge (Firm-dependent)**			**External Knowledge (Product-dependent)**				**External Knowledge (Institution-dependent)**			
Regions	*Codification**	*Internal learning mechanisms*	*Digital communications***	*Inter-sectoral interactions*	*Industry dynamics*	*User-producer relationships*	*ICT infrastructures*	*University and research*	*Technology centers*	*Ex-ante co-ordination mechanisms*	*Knowledge intensive business services*
Bologna	• 508	• Tacit via production linkages • Learning by doing •	• Not applicable/relevant	Clusters: • Packaging automatic machinery • Motorcycle • Health and care	• Full labour market • Market entry mainly via M&A	• Highly specialised sub-contracting • Co-makership • LSEs-SMEs relations	• Productive automation (CAD/CAM)	• University of Bologna • Johns Hopkins University (EU Center)	• ASTER • CERMET • CNR • ENEA	• Bologna trade fair system •	• Financial sector • Consultants •
Turin	• 438	• Learning by doing • Formalised training	• Low	Clusters: • Mechanical engineering • Automotive • ICTs	• Market entry via foreign direct investments and multinational corporations	• Highly specialised sub-contracting • LSEs-SMEs relations	• Broadband network • ATM (Asynchronous Transfer Mode) network	• Polytechnic of Turin • University of Turin	• CSELT • CNR	• ITP	• Financial sector • Consultants • Telecommunications
Milan	• 1.096	• Codified, via R&D-production linkages	• Low	• Electronics • Mechanics • Health & life sciences	• Market entry via foreign direct investments and multinational corporations	• LSEs-SMEs relations	• Broadband network	• Polytechnic of Milan • Bocconi University • Catholic University	• CNR • ENEA • MIP • CATAS	• ASNM	• Financial market • Venture capital • Consultants • Telecommunications
Barcelona	• 249	• Tacit	• Not applicable/relevant	Clusters: • Mechanics • Electronics • Textile and clothing	• Market entry via foreign direct investments	• Specialised sub-contracting	•	• University of Barcelona • Pompeu Fabra	•	•	• Consultants
Vienna	• 173	•	• Not applicable/relevant	• Electronics • Automotive • Chemicals	• Foreign direct investments	•	• Broadband network	• University of Vienna • Vienna International School	•	•	• Consultants
Nice	• 335	• Tacit, via spin-off • Formali	• Determinant	• ICTs • Health &life sciences	• Foreign direct investments	• R&D-production linkages	• ATM (Asynchronous Transfer Mode)	• University of Nice-Sophia	• CERAM • Theseus • Eurecom	• Club des dirigents • Persean	• Venture capital • Telecomm

		sed, via training and management consulting		• Research • Environment	via multinationals • High rates of local starts-up and spin-off	• LSEs-SMEs relations	network • Broadband network • Mobile telecommunications	Antipolis • Ecole superiore de mines • CNRS	• Business service centres	association • Association Telecom Valley • ImeT • MITSA	unications • ETSI • W3C
Strasbourg	• Not relevant	•	• High	• Industrial automation • Automotive • Pharmaceutical • Agro-food • Electronics	• High rates of foreign direct investments via LSEs and multinational firms	• LSEs-SMEs relations • Industrial R&D-production linkages	• Broadband network	• Université Louis Pasteur • Université Robert Schuman • CNRS	• INSERM • INRA	•	• Financial market • Consultants • Telecommunications
Bruges	• 143	• Tacit, via spin-off and production linkages	• Not applicable/relevant	• Speech-and-voice technologies (cluster) • Mechanics • Agro-food	• High rates of local starts-up and spin-off • High rates of market entry, especially via multinational firms	• LSEs-SMEs relations • Specialised sub-contracting • Spin-off based linkages	• Broadband network	• Leuven Catholic University • R&D pole in software and computer sceinces	•	• Flanders language valley Foundation • GOM Regional Agency	• Venture capital • Financial market
Östergötland ***	• 323	• Highly formalised via training&R&D-production relationships	• High	Cluster: • Aerospace • ICTs • Electronics • Health & life • Software	• Foreign direct investments via multinational firms	• LSEs-SMEs relations • Specialised sub-contracting	• Mobile telecommunications	• Linköping University • Mjärdevi science and technology park	•	•	• Telecommunications • Consultants • Venture capital
Stockholm	• 744	• Highly formalised via training&R&D-production relationships	• High	Clusters: • ICTs • Biotechnology • Health & life sciences	• Foreign direct investments via multinational firms • High rates of market entry especially by means of local starts-up	• Industrial R&D-production linkages • LSEs-SMEs relations	• ATM (Asynchronous Transfer Mode) network • Broadband network • Mobile telecommunications	• University of Stockholm • Royal Institute of Technology • Stockholm School of Economics	• Kista Science Park	•	• Telecommunications • Consultants • Venture capital
Helsinki	• 553	•	• High	• ICTs	•	•	• Broadband	• Helsinki	• Network	• Helsinki	• Telecomm

				• Biotechnology • Environmental technologies • Industrial automation			network • Mobile communications	University	of business innovation centres	business development unit	unications •
Copenhagen	• 716	• Highly formalised via Training& R&D-production relationships	• Determinant	Clusters: • Biotechnology • Pharmaceutics • ICTs	• High rates of FDI by multinationals especially in the ICT sector • Local start-ups	• High levels of vertical integration due to the presence of big multinationals	• Broadband network • ATM (Asynchronous Transfer Mode) network • Mobile telecommunications	• Technical University • University of Roskilde • CAT • Symbion Science Park	• Technological innovation centre	•	• Venture capital • Consultants

* Number of patent applications to the EPO (European Patent Office) at regional level 1999, considering the top three leading regions of each Member State (Eurostat: 2001b)
** Qualitative assessments based on face-to-face interviews with local experts and online questionnaires to local centres for economic and statistical studies
***Metropolitan-scale region around the urban centre of Linköping

APPENDIX 2. The distribution of factors' values according to the intensity assessment

Knowedge institutions & features	**Internal knowledge (Firm-dependent)**				**External Knowledge (Product-dependent)**				**External Knowledge (Institution-dependent)**		
Regions	*Codification*	*Internal learning mechanisms*	*Digital communications*	*Inter-sectoral interactions*	*Industry dynamics*	*User-producer relationships*	*ICT infrastructures*	*University and research*	*Technology centers*	*Ex-ante co-ordination mechanisms*	*Knowledge intensive business services*
Bologna	***	***	-	***	*	****	-	***	**	**	**
Turin	***	***	*	***	**	***	***	***	*	**	***
Milan	****	**	*	**	**	*	**	****	**	-	****
Barcelona	*	*	-	***	*	*	-	**	-	-	*
Vienna	*	*	-	**	**	-	**	*	-	-	-
Nice	***	****	****	****	***	***	****	****	***	***	***
Strasbourg	-	-	***	***	***	**	**	***	*	-	***
Bruges	-	***	-	*	****	****	*	*	-	***	***
Östergötland	***	**	***	****	**	***	-	*	-	-	***
Stockholm	****	**	***	***	****	***	****	****	*	-	****
Helsinki	***	-	***	***	-	-	***	*	**	**	***
Copenhagen	****	**	****	***	***	*	****	****	*	-	***

- measures the factors' values according to five levels of intensity (* = low; ** = medium; *** = high; **** = determinant; - = not present/relevant)

APPENDIX 3. Knowledge bases and knowledge elements in 12 European metropolitan areas as resulting from equations (1), (2), (3) and (4) (Percentages out of the total stock of technological knowledge in brackets)

	Knowledge bases			Total stock
	Internal knowledge (firm dependent)	External knowledge (product dependent)	External knowledge (institutions dependent)	Technological knowledge
Bologna	0.6666 (32.01)	0.6664 (32.00)	0.7497 (36.00)	2.0827 (100.00)
Turin	0.7777 (31.82)	0.9163 (37.50)	0.7497 (30.68)	2.4437 (100.00)
Milan	0.7777 (35.45)	0.5831 (26.58)	0.833 (37.97)	2.1938 (100.00)
Barcelona	0.2222 (25.01)	0.4165 (46.87)	0.2499 (28.12)	0.8886 (100.00)
Vienna	0.1111 (16.00)	0.4998 (72.00)	0.0833 (12.00)	0.6942 (100.00)
Nice	1.2221 (35.21)	1.1662 (33.60)	1.0829 (31.20)	3.4712 (100.00)
Strasbourg	0.3333 (19.05)	0.833 (47.62)	0.5831 (33.33)	1.7494 (100.00)
Bruges	0.4444 (25.01)	0.7497 (42.18)	0.5831 (32.81)	1.7772 (100.00)
Östergötland	0.8888 (45.08)	0.7497 (38.02)	0.3332 (16.90)	1.9717 (100.00)
Stockholm	0.9999 (34.29)	1.1662 (40.00)	0.7497 (25.71)	2.9158 (100.00)
Helsinki	0.6666 (36.37)	0.4998 (27.27)	0.6664 (36.36)	1.8328 (100.00)
Copenhagen	1.111 (41.24)	0.9163 (34.02)	0.6664 (24.74)	2.6937 (100.00)

	Internal knowledge factors			External knowledge factors (product dependent)			
	Codification	Internal learning mechanisms	Digital communications	Inter-sectoral interactions	Industry dynamics	User-producer relations	ICT infrastructures
Bologna	0.3333 (50.00)	0.3333 (50.00)	0 (0.00)	0.2499 (37.50)	0.0833 (12.50)	0.3332 (50.00)	0 (0.00)
Turin	0.3333 (42.86)	0.3333 (42.86)	0.1111 (14.29)	0.2499 (27.27)	0.1666 (18.18)	0.2499 (27.27)	0.2499 (27.27)
Milan	0.4444 (57.14)	0.2222 (28.57)	0.1111 (14.29)	0.1666 (28.57)	0.1666 (28.57)	0.0833 (14.29)	0.1666 (28.57)
Barcelona	0.1111 (50.00)	0.1111 (50.00)	0 (0.00)	0.2499 (60.00)	0.0833 (20.00)	0.0833 (20.00)	0 (0.00)
Vienna	0 (0.00)	0.1111 (100.00)	0 (0.00)	0.1666 (33.33)	0.1666 (33.33)	0 (0.00)	0.1666 (33.33)
Nice	0.3333 (27.27)	0.4444 (36.36)	0.4444 (36.36)	0.3332 (28.57)	0.2499 (21.43)	0.2499 (21.43)	0.3332 (28.57)
Strasbourg	0 (0.00)	0 (0.00)	0.3333 (100.00)	0.2499 (30.00)	0.2499 (30.00)	0.1666 (20.00)	0.1666 (20.00)
Bruges	0.1111 (25.00)	0.3333 (75.00)	0 (0.00)	0.0833 (11.11)	0.3332 (44.44)	0.3332 (44.44)	0 (0.00)
Östergötland	0.3333 (37.50)	0.2222 (25.00)	0.3333 (37.50)	0.3332 (44.44)	0.1666 (22.22)	0.2499 (33.33)	0 (0.00)
Stockholm	0.4444 (44.44)	0.2222 (22.22)	0.3333 (33.33)	0.2499 (21.43)	0.3332 (28.57)	0.2499 (21.43)	0.3332 (28.57)
Helsinki	0.3333 (50.00)	0 (0.00)	0.3333 (50.00)	0.2499 (50.00)	0 (0.00)	0 (0.00)	0.2499 (50.00)
Copenhagen	0.4444 (40.00)	0.2222 (20.00)	0.4444 (40.00)	0.2499 (27.27)	0.2499 (27.27)	0.0833 (9.09)	0.3332 (36.36)

(Appendix 3, following)

External knowledge factors (institutions dependent)			
University and research linkages	Technology centres	Ex-ante co-ordination	KIBS
0.2499 (33.33)	0.1666 (22.22)	0.1666 (22.22)	0.1666 (22.22)
0.2499 (33.33)	0.0833 (11.11)	0.1666 (22.22)	0.2499 (33.33)
0.3332 (40.00)	0.1666 (20.00)	0 (0.00)	0.3332 (40.00)
0.1666 (66.67)	0 (0.00)	0 (0.00)	0.0833 (33.33)
0.0833 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)
0.3332 (30.77)	0.2499 (23.08)	0.2499 (23.08)	0.2499 (23.08)
0.2499 (42.86)	0.0833 (14.29)	0 (0.00)	0.2499 (42.86)
0.0833 (14.29)	0 (0.00)	0.2499 (42.86)	0.2499 (42.86)
0.0833 (25.00)	0 (0.00)	0 (0.00)	0.2499 (75.00)
0.3332 (44.44)	0.0833 (11.11)	0 (0.00)	0.3332 (44.44)
0.0833 (12.50)	0.1666 (25.00)	0.1666 (25.00)	0.2499 (37.50)
0.3332 (50.00)	0.0833 (12.50)	0 (0.00)	0.2499 (37.50)

APPENDIX 4. Knowledge processes in 12 European metropolitan areas as resulting from equations (5), (6), (7) and (8) (Percentages out of the total stock of technological knowledge in brackets)

	Knowledge production orientations			
	Communication-oriented knowledge production	**S&T-oriented knowledge production**	**Market-oriented knowledge production**	**Product-oriented knowledge production**
Bologna	0.4999 (24.00)	0.4165 (20.00)	0.4999 (24.00)	0.6664 (32.00)
Turin	0.8609 (35.23)	0.3332 (13.64)	0.5832 (23.87)	0.6664 (27.27)
Milan	0.4999 (22.79)	0.4998 (22.78)	0.7776 (35.45)	0.4165 (18.99)
Barcelona	0.1111 (12.50)	0.1666 (18.75)	0.1944 (21.88)	0.4165 (46.87)
Vienna	0.2777 (40.00)	0.0833 (12.00)	0 (0.00)	0.3332 (48.00)
Nice	1.4719 (42.40)	0.5831 (16.80)	0.5832 (16.80)	0.833 (24.00)
Strasbourg	0.4999 (28.58)	0.3332 (19.05)	0.2499 (14.28)	0.6664 (38.09)
Bruges	0.5832 (32.82)	0.0833 (4.69)	0.361 (20.31)	0.7497 (42.18)
Östergötland	0.5555 (28.17)	0.0833 (4.22)	0.5832 (29.58)	0.7497 (38.02)
Stockholm	0.8887 (30.48)	0.4165 (14.29)	0.7776 (26.67)	0.833 (28.57)
Helsinki	0.7498 (40.91)	0.2499 (13.63)	0.5832 (31.82)	0.2499 (13.63)
Copenhagen	0.9998 (37.12)	0.4165 (15.46)	0.6943 (25.77)	0.5831 (21.65)

APPENDIX 5. The structure of the questionnaire

1. The structure of the local economic system:
    1.1. The relative weight of manufacturing and service sectors, as measured by the number of firms and employees;
    1.2. The relative weight of the diverse classes of firms, as measured by the number of firms and employees;
    1.3. The characteristics of local firms, with a special focus on the organizational structure, the use of new communication technologies and the strategy of management of human resources;
    1.4. The presence and weight of specific local industrial clusters or districts, as measured by the number of relevant firms and employees.

2. The industrial dynamics of the local economic system:
    2.1. The level of labor mobility, as measured by the ratio between the number of entries in the labor market and the number of exits out of the total local workforce;
    2.2. The level of foreign direct investments, as measured by both the amount of turnovers of new foreign firms and the number of new foreign firms;
    2.3. The relevance of processes of mergers and acquisitions, as measured by the number of operations in the area;
    2.4. The importance of local start-ups, as measured by the ratio between the number of new firms and the number of incumbents.

3. The institutional and infrastructural context:
    3.1. The quality of the local endowment of scientific and technological infrastructures, as measured by the number of academic and technological centers cooperating with the business community;
    3.2. The quality of the local ICT infrastructure as measured by the types of telecommunication channels and networks characterizing the area;
    3.3. The quality of local public and/or collective institutions, such as chambers of commerce, business associations, agencies for development, business incubators and innovation centers, as measured by their number and variety;
    3.4. The quality of the local sector of knowledge intensive business services (KIBS), as measured by the variety of services locally available.