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Abstract:
Despite the diffusion of communication tools and boundary spanning technologies, knowledge flows in innovation processes retain a distinct localized nature in many industries and geographical clusters emerge as critical areas to foster technological diffusion. In this paper we focus on the role of focal firms in industrial clusters as "gatekeepers" introducing external technological novelties in the cluster and enacting new useful knowledge production locally, thus enhancing international competitive capabilities of all firms in the cluster. We analyze a longitudinal dataset of 720 patents

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granted by USPTO between 1990 and 2003 to firms in the automatic packaging machinery industrial district of Emilia-Romagna in Northern Italy, and a matched-sample to control for the uneven geographical distribution of R&D and patenting activities. Our results show that firms within the cluster use local knowledge to a greater extent and more rapidly than knowledge from the outside than it would be expected given the geographic distribution of innovative activity in the industry. Moreover, focal firms use external knowledge to a greater extent than other firms operating in the cluster, and other (non focal) firms within the cluster use knowledge from focal firms to a greater extent than would be expected given the geographic distribution of innovative activity in the industry. Implications for research on the geographical distribution of innovation activities are discussed.

Key words: Innovation processes, Knowledge flows, Geographical clusters

JEL Codes: O18, O31, D83

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INTRODUCTION

The literature on knowledge spillovers argues that knowledge created within firms can be used by others economic agents, because pieces of that knowledge can be codified and transferred among firms, thus generating positive externalities and fostering innovative activities (Griliches, 1979). Extending this body of research with a greater attention to the specificities of knowledge flows and their impact at the firm level (e.g. Malerba et al, 2003), knowledge spillovers have been defined as public good bounded in space (Breschi and Lissoni, 2001). According to this approach, most of the knowledge flowing is mainly "tacit", context-specific and difficult to codify, and this is particularly true for innovative ideas. As a consequence, it can be primarily transmitted trough personal contacts and direct relationships requiring spatial proximity. Following the "Marshalllian" concept of "industrial atmosphere", it is argued that such knowledge flows better among organizations located in the same area (Krugman, 1991). Therefore geographical industrial clusters offer more innovation opportunities than scattered location (Breschi and Lissoni, 2000; Saxenian, 1991), and firms situated in regions characterized by knowledge agglomeration processes have greater opportunity to access that knowledge than their distant located competitors.

While the classic perspective on industrial district views the district as an environment inherently conducive to the creation of direct relationships, in which knowledge circulate spontaneously (Brusco, 1982; Marshall, 1919; Piore and Sabel, 1984), empirical studies, highlighted the presence of focal firms within industrial clusters - and in more general terms within local economic systems - playing a leading role for the transmission of technology and knowledge (Agrawal and Cockburn, 2002; Boari and Lipparini, 1999; Lazerson and Lorenzoni, 1999; Saxenian, 1991). They act as leading firms in the local innovation network, generating new knowledge and technologies, spinning out innovative companies, attracting researchers, investments and research facilities, enhancing others firms R&D activities, stimulating demand for new knowledge and creating and capturing externalities. In line with this latter view, we advance the hypothesis that the presence of focal firms in a cluster substantially increases spillovers at the local level, by creating technologically-advanced new knowledge and favouring the absorption and dissemination of external knowledge into the cluster.

We investigate these issues developing a set of hypotheses on the directionality and speed of knowledge flows within geographical clusters, as well as on the role of leading firms as "gatekeepers" driving the processes of new knowledge creation and diffusion within the cluster. Following previous studies using patent citations as a paper trail of geographic spillovers (Almeyda, 1996; Henderson et al., 1996; Jaffe and Trajtenberg, 1996; Malerba et al., 2003), our empirical analysis is based on a longitudinal dataset of 720 patents granted by USPTO between 1990 and 2003 to firms in the automatic packaging machinery industrial district of Emilia-Romagna in Northern Italy. Moreover, to control for the uneven geographical distribution of R&D and patenting activities, following Jaffe et al. (1993) we built a matched sample where, for each cited patent, we identified a corresponding control patent based on similarity in technology class and application date.

Our results show that firms within the cluster use local knowledge to a greater extent and more rapidly than knowledge from the outside than it would be expected given the geographic distribution of innovative activity in the industry. Moreover, focal firms use external knowledge to a greater extent than other firms operating in the cluster, and other (non focal) firms within the cluster use knowledge from focal firms to a greater extent than would be expected given the geographic distribution of innovative activity in the industry.

The rest of the paper is structured as follows. The next section introduces the theoretical background of the study, focusing on concepts related both to the diffusion of knowledge within cluster and the role played by leading firms, and developing five research hypotheses. We then illustrate the research setting describing the packaging industrial district, its leading firms. The following section presents the methodology implemented to empirically test our hypothesis. Finally we report and discuss the results and the concluding remarks.

THEORETICAL BACKGORUND AND HYPOTHESES

Knowledge generation and diffusion within industrial clusters.

The literature on industrial districts (Becattini, 1979; Brusco, 1982; Pyke et al., 1990) has argued that one of the explanations for the geographic concentration of innovative activities is that knowledge flows more easily and rapidly within the cluster boundaries than outside them. Developing these concepts, Krugman (1991) has derived three kinds of externalities that are important for clusters: 1) economies of specialization, 2) economies of labor pooling, and 3) technological externalities or knowledge spillovers. As for the latter, in industrial clusters, firms typically share a common set of values and norms that facilitates the development of multiple formal and informal relations in a complex mix of cooperation and competition (Brusco, 1982; Saxenian 1994). These interactions among actors are important, mutually beneficial, and widely observed, and they create a culture supporting the formation of dense networks of relationships. Moreover, they act as channels which facilitate the transfer and diffusion of knowledge, giving advantages in innovation development to firms belonging to clusters.

The existence of localized spillovers is the main reason why innovative activity tends to be geographically concentrated (Dahl and Pedersen, 2002). Spatial cluster are seen as social systems or networks where it is easier for information to circulate, where social contacts among firms facilitate the communication and the articulation of tacit knowledge, and where the risks of opportunistic behaviour and the related monitoring costs are lowered thanks to the marshallian atmosphere. Saying that spatial concentration is fundamental in the creation and development of clusters, simply means that we are talking about the reciprocal proximity of firms and institutions located in a defined spatial unit. Some authors (Torre and Gilly, 2000; Lemarié and Mangematin, 2000) have stressed two different dimensions of the "proximity" concept: geographic proximity and organizational proximity. While the former refers the external context, the latter is deeply rooted in the organizational interaction of firms participating in clusters. Both dimensions nurture the growth of the cluster, promoting innovation in a dynamic process developed trough multiple interactions and intense communication exchange among a diverse set of localized actors, such as customers, cooperating and competing firms, suppliers, venture capital firms, and knowledge centres (Wever and Stam, 1999).

However, proximity would not be such a key-issue for cluster development, if knowledge could be easily codifiable and transferable outside its context of generation. In fact, the more knowledge is easy to articulate and transmit, the more it can be standardized, codified and transferred through products, reports and other tangibles means across spatial boundaries. Conversely, when knowledge is mainly tacit, the above mentioned channels fail. Because tacit knowledge is encompassed in personal know-how and is context-specific, interpersonal direct contacts and interactions become fundamental. Geographic proximity can thus greatly enhance innovation any time it involves a large share of tacit knowledge, by favouring exchanging activity. As a consequence, industrial districts should be best placed to produce and diffuse that kind of knowledge.

A wide literature has tried to ascertain the extent to which research and innovation are spatially concentrated, by analysing the localized nature of knowledge spillovers. Zucker et al. (1997) explain the mechanisms by which people's ideas, skills, personal knowledge and know-how are transmitted and developed in technological innovations, as a result of a knowledge spillovers process. Similarly, Almeida and Kogut (1997) consider the inter-firm mobility of "star" patent-holders in order to plot the transfer of ideas in the semiconductor industry. Their results suggest that, in the development of new industries, knowledge generates externalities that tend to be geographically bounded. Martin (1999) claims that empirical studies of the geography of innovation provide clear evidence that knowledge spillovers play an important role in promoting the economic activities.

However, the analysis of geographic spillovers often proved to be difficult at an econometric level. Feldman (1998) reviews the literature on spillovers and location economies, revealing that the attempts to measure these effects have been almost indirect. For instance, it has been shown that innovation, even in non R&D-intensive sectors, is closely related to the amount of public and private research spending in the region (Feldman, 1994), or to the entire infrastructure devoted to technology transfer (Feldman, 1994; Llerena and Schaeffer, 1995).

One of the major problem of this stream of research is that of directly measuring the existence and geographical reach of these spillovers. The critical issue concerns how to keep track of flows of invisible and tacit knowledge in space. This task is particularly complicated by the fact that new knowledge is hard to articulate, often embedded in products, technologies and human know-how and thus being very difficult to recognize, to understand and to metabolize. Starting from the seminal contribution by Jaffe et al. (1993), over the last decade several studies have used patent citations as paper trails of knowledge flows. Patent citations indicate the borders of patent claiming, in the sense that if patent B cite patent A, then A represents a pre-existing piece of knowledge upon which B could not claim any right (Hall *et al.*, 2002). The underlying assumption in this literature is that patent citations document real knowledge flows. Hence, knowing the geographic origin of the citing patent (typically through the residence of the first inventor) and the origin of the cited patent as well, it is possible to construct a map of these flows.

Using patent citations, several studies have revealed some of the factors that condition spillovers. Jaffe et al. (1993) showed that citations are highly localized, given that patents cite others patents that originate in the same place with greater frequency. Using samples of U.S. Universities' and Corporate patents, they analyzed two cohorts of patents (those granted in 1975 and in 1980) and their citations, comparing the geographical location of citations with the originating patents they cite. To control for spatial distribution of citations (i.e. the fact that firms within the cluster intensely cite each others simply because they dominate patenting activity in the respective areas, rather than the positive effect of geographic proximity) they created a control sample of patents with the same application year and technological class (excluding patents that cited the cohorts patents). Each control patent was matched with a particular citing patent, allowing to compare the geographic location of control patents with that of originating patens cited by its counterparts in the dataset. Thus the authors found evidence that spillovers, as depicted from citations counts, are geographically localized.

The studies of Almeyda (1996) and Almeyda and Kogut (1997) adopt a similar methodology and present results consistent with the idea that knowledge flows are highly localized. They analyze patent citations of U.S. Semiconductor Industry to test the hypothesis that foreign firms create subsidiaries where knowledge is localized, ascertaining that the knowledge used by foreign subsidiaries in U.S. regions is predominantly locally created.

However, no previous attempt has been made to use patent citations in order to map knowledge flows in the specific context of industrial districts. Therefore, the first contribution we want to give is mainly of empirical nature, and relates to the use of patent citations in order to test the previously discussed arguments that knowledge flows more easily and rapidly within industrial cluster than outside them. Therefore we advance the following two hypotheses:

Hp.1: Firms within a cluster use local knowledge to a greater extent than would be expected given the geographic distribution of innovative activity in the industry

Hp.2: Firms within cluster use local knowledge more rapidly than knowledge from the outside

The role of focal firms in the innovation development processes within clusters.

Several empirical studies, highlighted the presence of focal firms within industrial clusters - and in more general terms within local economic systems - playing a leading role for the transmission of technology and knowledge (Saxenian, 1994; Boari and Lipparini, 1999; Lazerson and Lorenzoni, 1999; Agrawal and Cockburn, 2002).

Contrasting the classical perspective that views the district as an environmental conducive to the creation of direct relationship (Marshall, 1919; Brusco, 1982; Piore and Sabel, 1984), these empirical studies emphasize the following distinctive features that characterize several industrial districts. First, firms in the network are heterogeneous and not interchangeable in term of roles and tasks (Lipparini, 1995). Second, a few firms have a higher capability to design and manage a large and differentiated network of relationships with other firms (Lorenzoni and Baden Fuller, 1995; Dyer, 1996; Uzzi, 1997). Third, industrial districts are as much a product of larger firms acting as disseminators of technology and knowledge (Schmitz, 1995; Lazerson and Lorenzoni, 1999).

The development of many Italian districts showed how some firms and their network of organizations can play an important role in collective learning processes, acting as drivers for innovation development and cluster growth (Boari and Lipparini, 1999; Lorenzoni and Baden Fuller, 1995). Lorenzoni and Baden Fuller (1995) define these leading firms as “strategic centres” that can assure the survival and development of the entire district, thanks to their superior coordination skills and ability to helm other firms to innovation and new growth opportunity.

These organizations act as focal firms in the local innovation network, generating new knowledge and technologies, spinning out innovative companies, attracting researchers, investments and research facilities, enhancing others firms R&D activities, stimulating demand for new knowledge and creating and capturing externalities. For example, Lissoni (2001) showed how the mechanical cluster of Brescia (in the North of Italy) is largely dependent on few firms (e.g. the world-leader Lonati) that coordinate cluster activities, fostering incremental innovation and welfare for the whole district. Another example of leading firms’ centrality for cluster development is represented by Benetton (Peter, 1992; Camuffo and Costa, 1993), that developed many relationships with smaller producers and distributors in order to outsource and subcontract, stimulating efficiency and innovation development from its partners (Camuffo *et al.*, 2001).

Empirical evidence on the role of leading firms for the economic growth and innovation development of the local context is not restricted to Italy. For example, Richards (2004) shows that the Scandinavian clusters of wireless hardware did benefit from the huge growth of the two major companies Ericsson and Nokia. Although dominated by these two major players, the region saw the development of many mini-clusters of high-tech start-ups. Other authors explained the role of key firms in the development of clusters around the world, such as Fairchild Semiconductor Corporation and Intel in the Silicon Valley (Moore and Davis, 2004; Arora *et al.*, 2004; Athreye, 2004; Saxenian, 2004).

Based on this stream of literature, and with specific regards to the absorption, generation and transfer of knowledge within industrial clusters, we argue that focal firms might play a leading role in two ways. First, they act as engine of innovation, internally generating new and sophisticated knowledge by virtue of superior technological resources and capabilities. Those large firms can play a critical role for the whole district in which they are located, for instance in growing the skill base, nurturing technical competencies, offering technical and managerial training, encouraging spin-offs and assessing the necessary managerial connections. Second, by leveraging on their intellectual and social capital, they can act as "technological gatekeepers" for the whole district, thus enhancing the absorption of new information into the cluster and facilitating its internal dissemination.

Focusing on R&D units and projects, the literature on technology and innovation management (Allen, 1977; Tidd et al., 1997; Roberts and Fusfeld 1981; Katz and Tushman, 1981; Rothwell, 1990) has identified and labelled "technological gatekeepers" those key individuals within R&D systems who play a crucial role in scientific and technological information dissemination. A large proportion of these people attract colleagues from within their community who then turn to them for information and advice. By virtue of their comprehensive network of external contacts and their advanced knowledge base, the gatekeepers play an effective boundary-spanning role by bringing a considerable volume of relevant scientific and technical information into the organization. They are effective internal communicators and disseminate information to others within the R&D systems, via a gatekeeper network. Several empirical studies show that the presence of gatekeepers within R&D projects is positively linked to different measures of innovative project performance (Allen, 1977; Ancona and Caldwell, 1992).

At a different level, we argue that focal firms tend to present many characteristics similar to those of technological gatekeepers, acting as "bridges" linking the district as a whole to relevant external domains. By bridging "structural holes" (Burt, 1984) between different networks, they can greatly enhance the process of knowledge creation and sharing. More precisely, the gatekeeping role involves the undertaking of two different and interrelated tasks. On the one side, the ability of monitoring the external environment beyond the borders of the cluster in search of valuable new knowledge to be eventually absorbed and used. On the other side, the ability to diffuse the re-elaborated knowledge to the other firms which are co-localized in the cluster, through a process that might be deliberate or not.

As to the former dimension, it is well established in the innovation literature that, in the process of new knowledge search and acquisition, firms tend to largely rely on their past experience and existing knowledge stock (Dosi, 1988; Nelson and Winter, 1982). Firms can more effectively recognize and absorb new external knowledge when it is close to their knowledge base (Cohen and Levinthal, 1990). In the specific context of industrial clusters, thus, it is likely that focal firms are better equipped to reach beyond their existing geographic context in order to identify, absorb and elaborate new technical knowledge generated by other key-actors (i.e. competitors, suppliers, complementors, universities and research centers) of the innovation process. By virtue of their advanced technological assets and capabilities, they possess the necessary absorptive capacity to search and incorporate new knowledge (Cohen and Levinthal, 1990).

On the contrary, it is likely that other (i.e. non focal) firms operating in the cluster lack the amount and sophistication of technological capabilities required to overcome local boundaries in the use of new information. For instance, limits in size and scope of business activities might not allow them to reach sufficient economies of scale in order to justify the creation of internal research facilities. Moreover, the deployment of innovation processes which are incremental and market-driven in nature - a typical characteristic of small firms operating in many traditional industrial districts - might restrict their ability to draw upon the knowledge stock of another and distant firm. Such barriers might become particularly relevant in order to access new domains which are significantly novel and original, or lie at the frontier of technological development. Indeed, technological similarity enhances the likelihood of knowledge transfer between firms (Rosenkopf and Almeida, 2003).

As a consequence, we expect that focal firms, given that they are best positioned in relevant input and output markets, could have a higher ability to identify, filter and incorporate knowledge from outside the cluster. This higher propensity is not just a matter of amount of information absorbed, but also of its quality: it is likely that focal firms search for and use more original and novel knowledge from outside than other firms in the cluster. Based on the previous arguments, we thus advance the following two hypotheses:

H3: Focal firms use external knowledge to a greater extent than other firms operating in the cluster.

H4: Focal firms use more original external knowledge than other firms operating in the cluster.

The second step of the "bridging process" involves the diffusion of the new knowledge brought from outside and processed by focal firms to all the other firms co-located in the district. As we discussed above, we can argue that spatial proximity and interpersonal communication patterns of tacit knowledge diffusion facilitate knowledge flows from focal firms to non-focal ones. That is the other side of the coin: if the non-focal firms lack the ability of recognising significant and systemic innovation opportunities, or monitoring the external environment, then they can select an easier access to new knowledge base re-elaborated by focal firms, thus triggering processes of vertical and horizontal relationships between focal and non-focal firms (Lorenzoni and Baden Fuller, 1995).

Because tacit knowledge diffusion and innovation development are facilitated by organizational proximity and deep relational contacts, increasing learning adoption drivers (Baptista and Swann, 1998), non-leading firm can go beyond their limits in size and scope of business activities and innovation creation processes, easily and faster, by fishing on the knowledge base created in the cluster, and moving towards new knowledge elaborated by focal firms (Baptista, 2000). Thus we can expect that in the specific context of industrial clusters, non-focal firms tend to largely rely to knowledge created by focal firms, even after controlling for the concentration of inventive activity within the industry. We thus present the following hypothesis:

H5: Other (non focal) firms within the cluster use knowledge from focal firms to a greater extent than would be expected given the geographic distribution of innovative activity in the industry.

RESEARCH SETTING

The setting for our analysis is represented by the Packaging Valley cluster in Northern Italy. It is located around the provinces of Modena and Bologna in the region Emilia-Romagna and presents the highest concentration on manufacturers of automatic packaging machinery in the country, as well as a diffuse network of specialized suppliers of parts and components. Out of the 900 firms operating in this industry in Italy, around 150 operate within Emilia-Romagna with the highest concentration in the bordering provinces of Bologna and Modena. Italian firms have grown rapidly over the past 15 years, exporting now over 85% of their sales, taking Italian products into second place in terms of export ranking behind the Germans (Boari et al., 2003). Firms in the cluster provide one third of the automatic machines operating world-wide to solve packaging problems (e.g. blistering, wrapping or filling machines).

In 1924 ACMA (Anonima Costruzioni Macchine Automatiche) was founded and suddenly lead to the creation of the so-called “Packaging Valley”, playing the role of incubator, trough spin-off processes (Porter, 1990). The district developed rapidly, and after the second world war, some of the major actors, such as ACMA, GD, SASIB, IMA, CAM, WRAPMATIC implemented international expansion and product differentiation strategies. Their technical competencies and their commitment to customer satisfaction the district to enter faster then international competitors the chemical, pharmaceutical and cosmetic markets, and to dominate the growing markets of packaging machinery for food and tobacco (Lipparini, 1995).

Foreign firms start to establish their subsidiaries in the district. The US Emhart acquired ACMA in 1962 (then bought by GD); the Swedish Tetrapack transferred in the 80's its strategic centers of packaging R&D in Modena. The recognition of high technical capabilities and knowledge created within the district not available anywhere else; the creation of trusty and interpersonal relationship networks enhancing tacit knowledge flows and fluid coordination mechanisms through producers, clients, suppliers and several supporting organizations (i.e. educational and financing institutes, firms specialized in designing, marketing and distribution, consulting and so forth); and the rising of some leading firms focusing their activities in assembling and R&D, while externalizing production and components to small specialized firms constituted an integrated system focused on developing innovation and technical and managerial packaging-specific know-how. This base of knowledge and culture, and the dynamic flows of interaction and relationships, attracted new firms from outside, which want to gather and benefit from the particular packaging "Industrial Atmosphere" (Capecchi, 1990).

The design and production of an automatic packaging machine are complex tasks, involving a wide variety of skills and competencies - typically mechanical, electronic, and chemical expertise - that have to be brought together in a non-trivial way. Firms in the cluster are at the cutting edge internationally in terms of technology and innovation, thus representing an ideal setting for our research. The distinctive competencies of these firms are based on their ability to create value for their customers through a process of incremental and architectural innovation (Lipparini and Sobrero, 1994), to enter market niches faster than their competitors, and to provide a wide range of integrated machines through acquisitions and collaborations with other firms (Lipparini, 1995; Lipparini and Lorenzoni, 1999). The share of European patents registered by packaging machinery producers of the Bologna area as the proportion of Italian patents (within the international class B65, i.e. packaging and filling machines) grew from 11% in the period 1979-1989, to 21% in the period 1990-1998. Over the same periods, the share of patents registered by Bologna's packaging machinery producers at the U.S. Patent Office grew from 31% to 40% of Italian patents registered within the same class (B65) (Boari, 1999).

DATA AND METHODS

Sample.

We first identified all firms operating in the packaging sector localized in the provinces of Bologna and Modena using information provided by different sources: institutional sources (Camere di Commercio); the AIDA database providing ownership and financial information on firms incorporated in Italy; the list of firms belonging to UCIMA (Unione Costruttori Italiani di Macchine

Automatiche), the Italian association of producers of automatic packaging machinery; previous research on this setting (Boari et al., 2003; Lipparini, 1995; Lorenzoni and Lipparini, 1999). At the end of this process the total number of firms identified from these sources was 136.

For each firms included in this initial set we then gathered data on all patents granted at the United States Patent and Trademark Office (USPTO) over the period 1990-2003. We decided to employ US patent data for several reasons. First, the US patenting system has been documented as comparatively more efficient than others, and offers protection in a larger market. As a consequence, non US companies have constantly increased their applications to the USPTO, in spite of the higher costs associated with the application process and, subsequently, with the patent maintenance fees (Kortum and Lerner, 1999; Jaffe, 2000). Second, patents granted in the US report information such as citations to previous patents that are necessary in assessing knowledge spillovers and their localization (Jaffe et al., 1993). A possible alternative strategy would have been to consider European Patent Office (EPO) data as well. While EPO effectively came into being in 1978, it wasn't until the beginning of the nineties that it became consistently and systematically considered as a relevant option all around Europe. On the contrary, while certain administrative changes occurred to the USPTO as well in the same period, its role and reputation were already well grounded. Moreover, as we rely on patent citation based measures, such data are hardly available consistently and systematically for European patents for the whole period considered in our empirical analysis (in particular for what concerns cited patents) again due to significant changes on this specific point in the reporting procedures of EPO.

Patent data for the period 1990-1999 were obtained from the NBER Patent Citations Data Files (Hall et al., 2002), while for the period 2000-2003 they were directly collected from the website of the USPTO. In assigning patents to companies, we used the AIDA database in order to reconstruct the actual corporate structures, thus including major subsidiaries. In the end, only 54 companies out of 136 owned at least one patent over the analysed period. They represent our final sample, totalling 720 patents granted.

For each patent we collected information related to application and grant year, assignee name, main U.S. technology class (defined at the three-digit level), inventors and their location. Moreover, we linked each patent with all the patents it cited. In doing that, we used data from applications year 1975 to 1997. Although citations might go back very far into the past, several key information, such as the address of the inventor at the metropolitan level, is known only for patents granted after January 1, 1975, since no publicly available electronic data are available prior to that date. Under such conditions, the number of cited patents is 2794. We then followed the Jaffe et al. (1993) methodology for the construction of a control sample of 2794 patents, by identifying for each cited patent a corresponding control patent, characterized by the same technology class and application year, as explained in greater detail in the following sections.

Measures and Analysis.

Establishing Focal Firms in the Cluster. We identify four focal firms within the cluster that are worldwide leading players in production of packaging machinery and in innovative processes development. These four firms own the 65% of USPTO district's patent. The remaining 35% is divided by the other more than 130 firms who can account at least one patent granted in US.

The first one is ACMA, which is the progenitor of the whole district. That is, many important firms in the Packaging Valley were founded by people with managerial and technical background and expertise accrued in ACMA. The second one is GD S.p.a, international leader in the manufacture of automated machinery, which has worldwide 3,000 employees and facilities located in Bologna, Offanengo (MN) (Italy), Dallas (USA), Richmond (USA), San Paulo (Brazil), Maidenhead (England) and Langenfeld (Germany). It is important to note that GD, is the third patentee for USPTO patents granted to all Italian firms (Malipiero, 2004). Actually GD, with its 545 patents, owns the 45% of the whole district's patents, while ACMA, which is the second firm for district patents, have only the 8% of share with its 102 patents. Although ACMA was acquired by GD in 1986, thus creating an international colossus in the packaging industry, we decided to treat them disjointedly because they still apply for patent separately. The third focal firm is IMA, whose founder came from experiences in ACMA and then GD. It is the market leader in filter bag tea and pharmaceutical products packaging machines, with more than 1.800 employees and branches in USA, UK, Germany, France, Austria, Spain, Portugal, China and Japan, and eastern Europe. Its innovative activity, as depicted from US patents is very significant, with 81 patents, which means a share of 6% of district's patent activity. Then we identify the fourth focal firm in Tetrapack S.p.a., a Swedish big firm leader in food packaging, which is present in the region since 1963. In 1980 the firm establish in Modena one of its biggest facilities for final assembly, that in 1992 became its worldwide centre for R&D. With 51 patents the firm own a share of 4% of district's patent activity.

Patent Data and Citations. We used patent citations data in order to investigate cluster's firms dependence on locally-created knowledge and the role played by focal firms. Patent data provide detailed and easily accessible information regarding the date, the geographic location and technological domain of an invention. In addition, they include a list of citations to other previous patents, in order to delimit the scope of the property rights awarded by the patent itself. Previous literature (Trajtemberg, 1990; Jaffe *et al.* 1993; Almeida, 1996; Appleyard, 1996; Almeida and Kogut, 1999; Jaffe et al., 1993; Malerba *et al.*, 2003) has extensively interpreted the existence of such links between patented innovations as a trace of knowledge spillovers: the fact that patent B cites patent A can be seen as a "paper trail" of knowledge flowing from A to B (Hall et al. 2002).

However, the use of patent citations presents some major limitations. Alcàcer and Gittelman (2004), not denying the presumption that patents trace out knowledge flows, provided empirical evidence that citations data are a noisy indicator of knowledge flows, intensely biased from administrative and bureaucratic processes during the application procedures. The major problem is the contamination of citations by patent attorney and patent examiners, which do not represent knowledge spillovers, but bias the measure of localization effects (Jaffe *et al.*, 1993; Alcàcer e Gittelman, 2004). More recent case studies conducted by Jaffe et al. (1998; 2001), however, confirm that citations are a noisy but relatively reliable proxy for knowledge spillovers. In particular, by comparing the location of the citing and the cited patent, it is possible to infer whether spillovers are locally bounded or not. Localization (i.e. the use of knowledge created by others in the same provinces – or region – of cluster firms) can thus be captured as the joint condition that the citing and the cited patent belong to the same geographic location, as explained in greater detail in the following section.

Beyond that, citation-based measures can also be constructed to capture other dimensions of the patented innovations. We refer in particular to two main measures. The first one is represented by backward citation lags – defined as the time difference between the application year of the citing patent and that of the cited patents. The shorter this measure, the more recent is the knowledge base upon which the patent builds and the speed of its transfer. We adopt this variable in the test of Hypothesis 2, in order to capture the rapidity with which previous knowledge is used. The second one is the number of citations made, which we take as a proxy of the originality of the patents (Trajtemberg *et al.*, 1999). Because this measure is deeply correlated with the number of citations made (Hall *et al.*, 2002), we use that last indicator as a proxy to measure of the "uniqueness" of patents, testing Hypothesis 4.

Statistical Test for Localization of Knowledge Flows. Operationally, in order to measure the frequency of localization, we geographically matched the patents from cluster firms with the cited patents. We first counted the number of citations where citing and cited patents were from the same geographic unit, and then divided it for the total number of citations. In so doing, we first referred to the two provinces of Bologna and Modena, where the packaging district is localized, and eventually repeated the analyses at the regional level (Emilia-Romagna)[2]. We first calculated the above

[2] Following the standard procedure in the literature, we assigned a patent to a given location on the basis of the address of the first inventor (Jaffe et al., 1993).

mentioned frequencies with reference to the total number of citations, and then we excluded self-citations (i.e. the citing and the cited patent belonging to the same assignee).

However, in considering such frequencies, it is necessary to consider that high level of citations at the local level might simply reflect the pre-existing concentration of technological activity, rather than the positive effect of geographic proximity, in determining knowledge search and acquisition. In other words, we should take into account the fact that the provinces of Bologna and Modena have a high concentration of packaging machinery firms, patenting a lot. Therefore, it might be that they intensively cite each other simply because they dominate patenting activity in the respective areas. It is thus necessary to assess whether citations are more highly localized than it is patenting activity itself, in order to test our first hypothesis.

To this purpose, following previous studies (Almeida, 1993; Almeida and Kogut, 1999; Jaffe et al., 1993; Sonn and Storper, 2003), we built a matched-sample of patents in order to control for the uneven geographical distribution of R&D and patenting activities. We followed the methodology developed by Jaffe et al. (1993) in the construction of a control sample: for each cited patent, we identified a corresponding control patent based on similarity in technology class and application date. More precisely, for each control patent, we randomly picked a control patent with the same application year and in the same technical subclass at the 3-digit level[3].

We then examined the frequency with which these control patents came from the provinces of Bologna and Modena (or from the region Emilia-Romagna), and compared these frequencies to those from the citations made by cluster firms' patents. As stated by Jaffe et al. (1993, p. 18): "If it were true that citations are close to originating patents only because of the technological areas they represent, then the frequencies with which citations and controls match the originating patents by geographic area should be the same".

To rephrase it more formally, we initially test the following null hypothesis:

$$H_0: P_{cit} = P_{con} \qquad [1]$$

versus the alternate hypothesis:

$$H_a: P_{cit} > P_{con} \qquad [2]$$

[3] We slightly departed from the original methodology of Jaffe and al. (1993) in two ways. First, they controlled for citing patents, whereas we control for the uneven geographic distribution of cited patents, as done by other studies (Almeida, 1996; Almeida and Kogut, 1999; Sonn and Storper, 2003). Second, they chose the control patent with the same application year and the same technology class of the original one, and the closest grant date, whereas we randomly picked a control patent with the same application year to the original one in the same technology class.

using the t-statistic:

$$t = \frac{p_{cit} - p_{con}}{\sqrt{\left[p_{cit}\left(1 - p_{cit}\right) + p_{con}\left(1 - p_{con}\right)\right] / n}} \qquad [3]$$

where P_{cit} is the probability that a citation comes from the same geographic unit (provinces of Bologna or Modena; region Emilia-Romagna) as the originating patent from cluster firm and P_{con} is the corresponding probability for the control patent (Jaffe et al., 1993).

We adopted a similar methodology to test the hypothesis related to the propensity of other firms (i.e. non focal) from the cluster to use knowledge from focal firms. Even in this case, we have to consider the uneven distribution of technological (and patenting) activity in the cluster, in particular for what concerns a potential high concentration of inventive activity among focal firms. We therefore drawn a smaller set of patents from the original control group, including all those patents matched to citations made by patents from non focal firms in the cluster. We then examined the frequency with which these latter control patents belonged to focal firms, and compared these frequencies to those from the citations made by other firms' patents.

RESULTS

Table 1 reports the descriptive statistics for the patent citations in our sample, by identifying those related to focal firms and to other firms in the cluster. Figure 1 shows the evolution of patenting activity by firms from the packaging cluster over the period 1990-2003. On average, the number of patent granted nearly doubled, passing from 37 patents granted in year 1990 to 73 patents in year 2003. This rise is in line with a more general trend of patenting activity in the region Emilia-Romagna, reflecting similar phenomena at the national and international level. It is also noteworthy that the packaging cluster represents a major engine of innovation within the regional system, as showed by the large share of regional patents which can be attributed to it: over the 1990-2003 period, in fact, around 30% of regional patents in the U.S. were assigned to firms operating within the cluster (Malipiero, 2004).

For what concerns the technological specialization of the cluster, Figure 2 exhibits the shares of patents assigned to the main technological fields, using the 6 main categories of the aggregate NBER classification. The "Others" field is largely dominant, with a share of 46%, followed by the Mechanical field (42%). The large share of the former heterogeneous class is mainly due to the sub-category "Receptacles" (representing 36% of total patents), which specifically addresses packaging products and processes. The balance between the different categories has not changed consistently over time, thus suggesting a rather stable focalization of the cluster on traditional competences.

The main results of the tests related to Hypothesis 1 are reported in Table 2. The number of citations corresponds to the total number of citations made by patents granted to firms within the cluster. “Citations matching (%)” and “Control matching (%)” correspond, respectively, to the percentage of citations and controls that belong to the provinces of Modena or Bologna (Column A) or the region Emilia-Romagna (Column B). Hypothesis 1 is confirmed both at the province and at the regional level. For every geographical level, the citations are quantitatively more localized than the controls. Although the proportion of citation matching decreases from 13% to 5% (from 14.33% to 5.58% at the regional level) when self-citations are excluded, the difference still remains wide. Citations are more than 7 times likely to come from the same provinces then control patents (around 8 times from the same region); roughly 3 times more likely excluding self-cites. In both cases the t-test is significant at the 1% level. These findings confirm those of Jaffe and al. (1993) regarding the spatial proximity of knowledge spillovers and provide a strong empirical support to the existence of an “industrial atmosphere” that facilitates the transfer of technical knowledge within the cluster.

We then turn to test Hypothesis 2 concerning the rapidity of knowledge flows within the cluster. Table 3 and table 4 show that, on average, citations to patents which are closer in terms of geography (respectively in the provinces of Modena and Bologna or in the region Emilia-Romagna) occur earlier than citations to patents that are further. However, if we exclude self-citations from the analysis, the difference largely shrinks. In this case, therefore, the large initial gap is mainly due to the shorter time required to a firm to use its own knowledge base rather than recurring to external sources. However, the difference still remains statistically significant.

Before moving to the tests concerning Hypotheses 3, 4, and 5, it is interesting to reflect on the distribution of patenting activity between focal firms and other firms in the cluster, as shown in Figure 1, it is clear that inventive activity within the cluster is strongly concentrated, with the 4 focal firms holding around 70% of the patents granted over the period 1990-2003. A leading role is by large played by the firm G.D., which is also the overall top-patenter in the region Emilia-Romagna over the same period (Malipiero, 2004), followed by A.C.M.A., IMA and TetraPak. The remaining 50 patenting firms in the sample hold just 30% of total patents. As explained before, the other 82 firms initially identified in the Packaging Valley do not patent at all, and therefore are not represented in our sample. This simple evidence confirms our predictions that the process of technical knowledge generation and accumulation within the cluster is not fragmented and distributed across a myriad of interacting firms, but largely driven by a limited number of leading firm, at least in this specific context. It can be interpreted as a proof of the existence of focal firms acting as engines of innovation for the whole district.

We now turn to analyze whether such firms play a "gate-keeping role" in bringing new and advanced technical knowledge into the cluster, elaborating and diffusing it to other firms, as predicted by Hypotheses 3, 4 and 5. Tables 5 and 6 show that the percentage of patent citations made outside the cluster is lower for focal firms as compared to other firms. However, it becomes higher if we exclude self-citations from the analysis. In this case the difference is statistically significant, thus supporting our expectations. We then analyze whether there exists also a difference in the quality of the knowledge absorbed from outside the cluster, in addition to its quantity. Table 7 shows that patents cited by focal firms are on average more original than those cited by other firms in the cluster, as highlighted by the mean number of citations made, an indicator which is strictly correlated to the "originality" index defined by Hall et al. (2002). However, the difference is not significant at conventional statistical levels. Therefore, Hypothesis 4 does not find a statistically significant support from our analyses.

On the other hand, results reported in Table 8 support Hypothesis 5. They show a higher proportion of citations from other (non focal) companies made to focal firms' patents than control matches. Thus, patents belonging to focal firms are cited locally more than would be expected by the distribution of inventive activity in the industry. This result is significant at the 1% level either including or excluding self-citations.

CONCLUSIONS

This paper has introduced a new empirical perspective on the analysis of knowledge diffusion and innovation development within industrial clusters. Using patent citations data from the packaging machinery cluster in the region Emilia-Romagna, we gave empirical support to two main hypotheses derived from the literature, i.e. that knowledge flows more easily within cluster boundaries and that leading firms play an important role in the knowledge diffusion process within clusters.

Our results strongly support the idea that knowledge flows are geographically localized within the cluster. This can be taken as an empirical evidence about the existence of an "Industrial Atmosphere" which nurtures the innovation processes. Moreover, our findings seem to substantiate the existence of a significant and positive leading-firm effect that influences knowledge creation and dissemination within the district. Inventive activity is proved to be strongly concentrated in the cluster and fostered by few large players that dominate patenting activity. Thus we can conclude that innovation diffusion processes, as depicted by knowledge flows traced by patenting activity, appear to be mediated by some leading firms within the cluster.

These findings are statistically significant at the district level, sustaining the role of focal firms as engine of innovation within the cluster, and at the regional level, highlighting the importance of the whole district activity in increasing innovation development and external competitiveness. Our study is thus conservative, because we controlled for pre-existing concentration of innovation activity, by constructing a control sample to spillovers effects, and because these findings are relevant considering self citations as well as not considering them (Jaffe *et al.*, 1993).

Some limits afflict the present study. For instance, the use of patent citations data is not immune to some biases. Patents are indeed considered just a *proxy* of innovation output, and citations are noisy indicators in capturing knowledge spillovers, as documented by previous literature. As said before, one of the major problems is the contamination of citations by patent attorney and patent examiners, which do not represent knowledge spillovers, but biased the measure of localization effects (Jaffe *et al.*, 1993; Alcàcer e Gittelman, 2004). In other words, it is possible that some non-focal firms patents citations referring to external well-known patents could be added not by district patentees, but just because the former patent has technological affinities to other well grounded patents, inhibiting supplementary analysis.

Moreover, to test our fourth hypothesis we used the number of citations made as a proxy of the originality of patents. Yet, the Originality indicator, is defined as the percentage of citations made by a patent belonging to a specific three-digit technological class, out of the total number of classes (Trajtemberg *et al.*, 1999). The larger is Originality, the broader are technological roots of underlying research. Thus, further effort have to be done in order to refine our research.

Another limit concerns the external validity of this study. Our conclusions refer to a single geographical cluster of firms. Yet we have considered a specific local context where innovation activities and relationship ties are very intense and substantially concentrated, while in other different context may not. Thus, further research is needed in order to overcome methodological issues – i.e. the use of biased citations data, considering, for example, data on citations received as well as data on citations made – and to assess theoretical propositions.

TABLES AND FIGURES

Table 1 – Descriptive statistics

	Number of patents	Number of Cited patents+	Mean cited patents	% of self-citations
Focal firms	499	2010	4.02	10.4%
Other firms in the cluster	221	964	4.36	5.08%

+Patents belonging to focal firms and to other firms might cite the same patents.

Table 2 – Means test of localization of knowledge within the cluster

	(I) All citations		(II) Excluding self-citations	
	Province-level analysis (Bologna and Modena)	Regional-level analysis (Emilia Romagna)	Province-level analysis (Bologna and Modena)	Regional-level analysis (Emilia Romagna)
Number of citations	2794	2794	2535	2535
Citations matching (%)	13.03%	14.35%	4.97%	5.58%
Control matching (%)	1.72%	1.79%	1.50%	1.58%
Difference (%)	11.31%	12.56%	3.48%	4.01%
t-statistic	16.56*	17.71*	7.02*	7.71*

Significant at the 1% level

Table 3 – Means test of speed of knowledge use within the cluster: citations made to patents from Bologna and Modena vs. citations made to all other patents

	(I) All citations			(II) Excluding self-citations		
	Citations made to patents from Bologna and Modena	Citations made to all other patents	t-test	Citations made to patents from Bologna and Modena	Citations made to all other patents	t-test
Citation Backward Lag (years)	67.032	95.164	-8.31**	83.237	95.634	-2.33*
N. observations	364	2430		139	2396	

**Significant at the 1% level

*Significant at the 5% level

Table 4 – Means test of speed of knowledge use within the cluster: citations made to patents from Emilia Romagna vs. citations made to all other patents

	(I) All citations			(II) Excluding self-citations		
	Citations made to patents from Emilia-Romagna	Citations made to all other patents	t-test	Citations made to patents from Emilia-Romagna	Citations made to all other patents	t-test
Citation Backward Lag (years)	66.084	95.164		81.602	95.830	
N. observations	401	2393	-9.14**	156	2379	-2.82*

** Significant at the 1% level

** Significant at the 5% level

Table 5 – Propensity to use knowledge from outside the cluster (Modena and Bologna): focal firms vs. other firms in the cluster

	(I) All citations			(II) Excluding self-citations		
	Focal firms	Other firms in the cluster	t-test	Focal firms	Other firms in the cluster	t-test
Total citations+	2010	964		1800	915	
Citations made outside Bologna and Modena (%)	85.32%	87.24%	-1.44	93.67%	91.36%	2.16*

+Patents belonging to focal firms and to other firms might cite the same patents.

* Significant at the 5 per cent level for the one-tailed test

Table 6 – Propensity to use knowledge from outside the region Emilia-Romagna: focal firms vs. other firms in the cluster

	(I) All citations			(II) Excluding self-citations		
	Focal firms	Other firms in the cluster	t-test	Focal firms	Other firms in the cluster	t-test
Total citations+	2010	964		1800	915	
Citations made outside Emilia-Romagna (%)	83.78%	86.41%	-1.91	93.05%	90.49%	2.24*

+Patents belonging to focal firms and to other firms might cite the same patents.

* Significant at the 5 per cent level for the one-tailed test

Table 7 – Originality of knowledge used from outside the cluster: focal firms vs. other firms in the cluster

	(I) All citations			(II) Excluding self-citations		
	Focal firms	Other firms in the cluster	t-test	Focal firms	Other firms in the cluster	t-test
Total citations outside Bologna[+] and Modena	1715	841	1.06	1684	833	1.11
Average number of citations made	8.537	8.271		8.575	8.285	

[+]Patents belonging to focal firms and to other firms might cite the same patents.

Table 8 – Propensity to use knowledge from focal firms by other firms in the cluster (controlling for the geographic distribution of inventive activity)

	(I) All citations	(II) Excluding self-citations
Number of citations[+]	964	915
Citations to focal firms' patents from patents by other firms in the cluster (%)	5.18%	5.46%
Citations to focal firms' patents from patents in the control group (%)	0.31%	0.33%
Difference %	4.87%	5.13%
t-statistic	6.61*	6.84*

[+]Patents belonging to focal firms and to other firms might cite the same patents.

* Significant at the 1 per cent level

Figure 1 – Patenting activity in the packaging machinery cluster of Modena and Bologna, 1990-2003

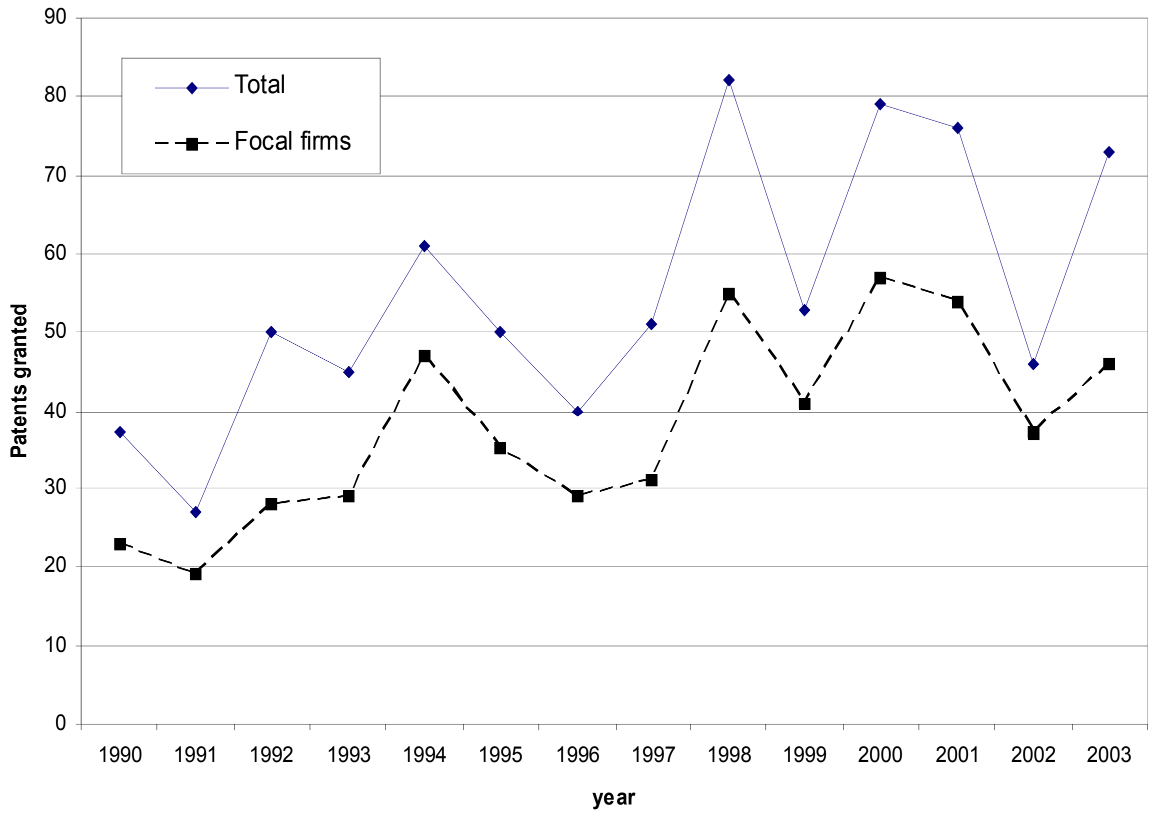
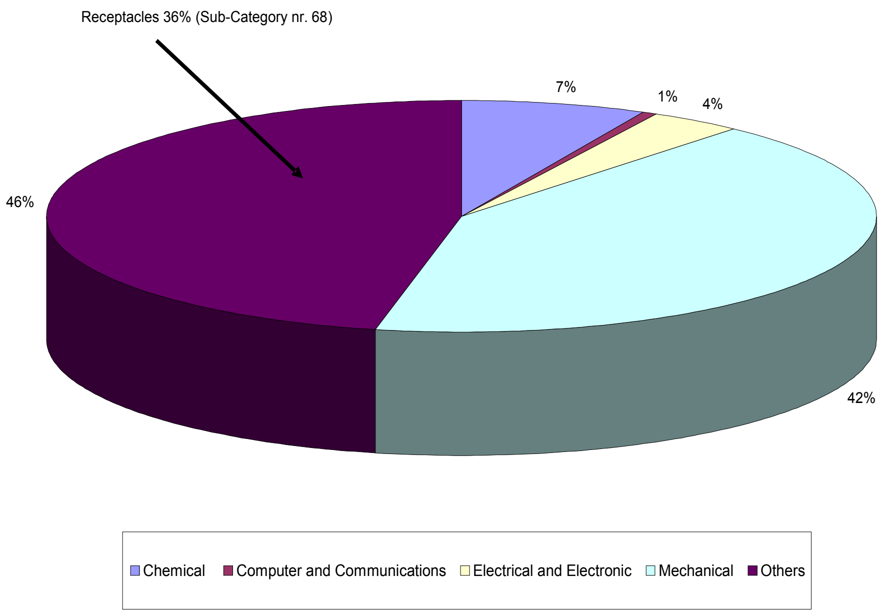


Figure 2 – Breakdown of patents assigned to firms from the cluster by technology category (period 1990-2003)



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