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Spatial patterns of inventors' mobility: Evidence on US urban areas*

Stefano Breschi[1], **Camilla Lenzi**[2]

[1] Department of Economics and KITeS-Cespri, Università Commerciale L. Bocconi, Via Sarfatti 25, 20136 Milan, Italy (e-mail: stefano.breschi@unibocconi.it)
[2] BEST (Building, Environment, Science and Technology) – Politecnico of Milan, Piazza Leonardo da Vinci 32, 20133 Milan (e-mail: camilla.lenzi@polimi.it)

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Abstract. This paper aims at contributing to the research on knowledge spillovers and their spatial extent by presenting new empirical evidence on a key mechanism driving and directing knowledge diffusion processes, namely, the mobility of knowledge and highly-skilled workers. The analysis is based on a rich data set on US inventors and their patents filed at the European Patent Office from 1978 to 2004. Findings indicate that two distinctive spatial patterns can be detected: inventors move both at short and large spatial distances (i.e., three hours and more than 8 hours driving distance, respectively) in similar proportions. Interestingly, in the largest innovative urban areas inventors' inflows and outflows primarily involve distant rather than neighbour areas.

JEL classification: 033, R23

Key words: Inventor, mobility, knowledge spillovers, geographical proximity

1 Introduction

The concept of localized knowledge spillovers has been vastly explored in researches on the geography of innovation. Localized knowledge spillovers, in fact, are found to explain much of the spatial concentration of innovative activities and the formation of clusters (Jaffe et al. 1993; Audretsch and Feldman 1996; Feldman 1999). However, far less attention has been devoted to the mechanisms through which knowledge flows actually travel. In the literature, two distinctive mechanisms have been proposed: first, social networks of people involved in the production of the new knowledge (Singh 2005; Breschi and Lissoni 2009); and second, the mobility of knowledge and skilled workers (Almeida and Kogut, 1999; Agrawal et al., 2006).

In this paper, we aim precisely at shedding new light on the latter mechanism and at providing new empirical evidence on its spatial patterns. To do so, we make use of a rich data

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set on US inventors and their patents filed at the European Patent Office (EPO) from 1978 to 2004. Focusing on US inventors is of great interest since not only because the United States is among the most prolific patenting countries in terms of number of inventors and number of patents granted, but also because the US labour market is believed to be more flexible as compared to European or Asian ones. Our approach is also consistent with a large body of empirical literature on knowledge spillovers mechanisms. Although being only a relatively limited fraction of all knowledge workers, *inventors* constitute a highly representative sample, since they are directly involved and responsible of the production of new knowledge and, thus, the best positioned to master and eventually transfer it in the new regions and firms they might move to. Our approach integrates the existing literature since, apart from a few studies exploiting smaller data sets on specific sectors (e.g., Trajtenberg and Shalem 2009 on the software industry) or countries (e.g., Faggian and McCann 2006, 2009 on UK graduates migration), very limited evidence is currently available on the spatial patterns of knowledge and skilled workers' mobility. Moreover, we differ and complement existing studies by adopting a fairly micro level unit of analysis (i.e., US urban areas: core based statistical areas [CBSAs]) and by looking at mobility patterns both across firms and in space.

Our findings indicate that while mobility across firms is to a large extent a local phenomenon, which prevalently occurs within a CBSA's boundaries, mobility in space involves a job change only in 50% of the cases; therefore, these two types of mobility overlap only partially. As to the inventors' spatial mobility in particular, migration flows mostly occur across more densely populated areas and follow two distinctive patterns, indicating a bimodal distribution of the geographical distance entailed by moves across space. In fact, inventors move both at small and large distances in similar proportions, with a relatively higher frequency of the latter as compared to the former. More interestingly, the most innovative CBSAs (in terms of inventors' population) appear to be more connected, via inventors' migration, to distant CBSAs rather than to closer ones. As a consequence, benefits (i.e., knowledge spillovers) arising from inventors' migration flows do not benefit neighbouring areas but distant ones. This result points to the relevance of external linkages established through inventors' mobility in space as a key channel to renovate and to augment the local knowledge base and to mitigate the potential risks of lock-in.

The remainder of the paper is organized as follows. Section 2 shortly reviews the literature on skilled workers' mobility and its impact on the localization of knowledge flows. Section 3 describes our data sources and how we define mobility across firms and in space by exploiting patent data. Section 4 provides some descriptive figures on the extent of both types of mobility while Section 5 focuses on the spatial patterns of US inventors' mobility. Section 6 concludes and highlights the main limitations of the study and proposes future research directions on the topic.

2 Related literature

Research on the geography of innovation in the last twenty years or so has been largely centred on the concept of localized knowledge spillovers which are deemed to explain why innovative activities are often found to be spatially clustered (Jaffe et al. 1993; Audretsch and Feldman 1996; Feldman 1999). The first test and proof of the spatial concentration of knowledge spillovers has been provided by Jaffe et al. (1993), the key assumption of this test being that scientific and technological knowledge is largely tacit so that face-to-face contacts are the necessary vehicle for its diffusion and geographical proximity a necessary condition for those contacts to take place. Nevertheless, the actual mechanisms through which knowledge is actually transmitted are not clearly described and measured in the Jaffe et al. (1993) test.

In the recent years, however, research has increasingly pointed to the role of knowledge and highly-skilled workers and their mobility patterns as carriers of knowledge diffusion, and, eventually, as a key driving force of regional innovation, development and growth (Almeida and Kogut 1999; Agrawal et al. 2006). Saxenian (1994) is one of the first to observe and to document that the high rates of job mobility in Silicon Valley are an influential source of agglomeration economies. The anecdotal and ethnographic evidence she provides is also supported by Fallick et al. (2006) who find a significantly higher rate of job mobility among college-educated employees in the computer industry in California. Moreover, Almeida and Kogut (1999) show that the localization of knowledge flows, as described in the patterns of patent citations among firms, is not universal but varies across regions; in particular, the degree of localization of knowledge flows is significantly and positively affected by the level of intraregional mobility of highly-skilled workers (i.e., major patent holders in the semiconductor industry). Agrawal et al. (2006) look at the mobility patterns of US inventors across space and observe that inventors moving across different locations still transfer knowledge to former colleagues active in the cities they have left. In fact, mobile inventors' patents are more likely to be cited by patents of the geographical area they come from rather than others: the citations they receive come disproportionately from their previous sites.[1] Related to this, knowledge flows across firms are more likely when firms are linked by the mobility of workers (Rosenkopf and Almeida 2003; Song et al. 2003).

Therefore, one main conclusion emerging from these contributions is that knowledge flows and their geographical distribution tend to follow and to develop according to the mobility trajectories of those individuals that produce and possess it: knowledge always travels along with the people that master it. As far as moves occur in a specific geographical area, for instance, because of particularly efficient labour markets, knowledge flows are localized and access to it will remain constrained in bounded locations. On the contrary, if those people relevant to the knowledge creation process move far away from where they originally learned, researched, and delivered their inventions, knowledge flows will also involve distant geographical areas and working communities, and knowledge will diffuse in space. Also, the tacit and idiosyncratic attribute of knowledge relevant to innovative activities makes its transfer and diffusion strongly relying upon the presence of social and professional contacts and relationships (i.e., networks) among those people directly involved in and participating in the knowledge creation process. Despite social relationships being primarily developed at the local level, as far as they are well established, they are likely to persist also after people's separation and relocation to other regions and at a greater geographical distance. Thus, previous co-location not only allows for the generation of social relationships but also shape and direct the subsequent geographical distribution of inventors' mobility knowledge spillovers. In the end, knowledge flows and their spatial distribution depend upon socio-professional networks and the mobility of workers that activate them and their respective spatial extent (Agrawal et al. 2006; Breschi and Lissoni 2009).

Although the role of highly-skilled workers' mobility as knowledge carriers is well established in the literature, evidence on the phenomenon, its spatial extent, and its impact on firms' and regions' performance is only recently increasing and, unfortunately, suffers from limited availability of both matched micro data on employees and their employers, and on interregional migration flows. This data constraint is rather pressing. Indeed, to the best of our knowledge, only a few countries, namely Denmark and Sweden, collect matched data on employer and employee with time series coverage. Notwithstanding, those empirical works exploiting such rich data sources, presently, are not primarily concerned with spatial patterns of workers mobility, but rather on the effect of mobility patterns on firms' performance (see for instance Boschma et al. 2009 and Eriksson and Lindgren 2009 on Sweden; and Dahl and Reichstein 2007 on Denmark). Some evidence, although relatively indirect on the spatial mobility patterns of

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[1] For similar results, see also Song et al. (2001) on the Taiwanese case based upon USPTO data and a slightly revised version of Jaffe et al.'s (1993) methodology.

knowledge and skilled workers is available for the UK case, namely, on the migration of UK graduates entering into first employment (Faggian and McCann 2006, 2009). In particular, data suggest that mobility is more frequent among better educated people and graduates in better universities. Also, spatial migration flows are found to be directed by differences in nominal wages, regions with higher nominal wages net absorber of human capital flows and regions with lower nominal wages net losers of human capital. More interestingly, a centre-periphery pattern seems to emerge which reflects the rank order of the region within the national urban hierarchy, centred, in the UK case, on London.

The major strength of these studies is that they link micro data on mobility flows either at the firm or at the regional level to some measure of innovative performance, at the firm and regional level respectively. In both cases however, these types of data do not allow identifying in a very straightforward and clear-cut manner those individuals that are directly involved in and actively participate in the production of new knowledge and thus, are the best positioned to master and eventually transfer it in those firms and locations they move to.

On the other hand, the use of data on patents and their inventors allows overcoming this limitation by providing information on innovative activities performed at the individual level and deriving individual level information on career and (spatial) migration patterns for a large number of regions, countries, sectors and years. Eventually, this may enable us to detect how single individuals and their innovative activities contribute to the region (or alternatively firm) innovative performance. For instance, Trajtenberg et al. (2006) have developed a large data set on patents, and their inventors, filed at the United States Patent and Trademark Office (USTPO). The first test bed of this new and massive data set is on USPTO software inventors and their patents. Software inventors are, ultimately, found to be more mobile both across firms and in space (i.e., across regions) than inventors patenting in other technological fields. The ‘general purpose technology’ properties of software technology are in fact likely to require developers and inventors to have a rather wide and flexible range of skills that enable them to take on different job opportunities. In the end, however, very limited information is provided on the spatial patterns of software inventors’ mobility (Trajtenberg and Shalem 2009).

In fact, the use of patent data to track inventors’ career paths and moves in space might be enlarged to track migration flows across regions. Indeed, this potential application of patent data was already envisaged in the seminal paper by Almeida and Kogut (1999), although limited to top semiconductor inventors and major regions of semiconductor activities; unfortunately, very few contributions have followed this line of research (for an exception see Song et al. 2003). Therefore, the strategy we resorted to in this study is precisely the exploitation of information available in patent documents on the location of inventors. On the basis of a massive data set including the population of US inventors patenting at the EPO, we track inventors’ moves both across firms and regions (i.e., across US metropolitan and micropolitan urban areas) and describe spatial patterns of inventors’ migration flows.

3 Data sources and methodology

In this paper, we examine all patent applications at the European Patent Office (EPO) listing at least one US inventor (regardless the country of the applicant) from 1978 to 2004. The data set includes 554,235 inventors, who are responsible for 519,853 patent applications.[2] A specific

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[2] Please note that our sample comprises 98.3% of all inventors with US residence. For 1.7% of all inventors with US residence, we could not find reliable information on the residential address at the county level. For that reason, they were left out of the sample. Moreover, the inventors included in our sample are responsible for 519,853 patent applications, that is 99.2% of all patents by US inventors.

routine has been used in order to trace inventors with different addresses.[3] The routine adopted takes a conservative approach, which minimizes false positives (i.e., the probability of identifying two inventors as the same person, when they are not, is minimized), although there could be some false negatives (i.e., the data set can still include some cases in which the same person is listed as two different inventors). Thus, our estimates eventually provide a lower bound of the mobility phenomenon.

For each of the 554,235 inventors for which we could find information on their residential address, we next collected information on the core based statistical area (CBSA) in which an inventor's county of residence is located.[4] Those counties not belonging to any CBSA have been collectively classified as nonmetropolitan areas.

Using the data set just described, two types of mobility can be identified. First, cross-firm mobility: according to this definition, a mobile inventor is one who has been listed in the patent documents of two or more firms. In a similar way, a *move* is recorded when an inventor is found to be listed in the patent document(s) of applicant A at time t and, next, in the patent document(s) of applicant B at time T, where T > t. In such a case, one can say that the inventor moved from applicant A to applicant B at some point between times t and T. It has to be pointed out that this definition of mobility requires considering only those moves occurring between employers where employment relationships turn into the production of patented knowledge. On the contrary, those moves occurring between employers where no patented knowledge is produced are not observed, thus leading to the risk of underestimating the actual number of moves.[5] Nevertheless, this is not a major concern in the present research since we are primarily interested in the spatial patterns of inventors' mobility. Second, spatial mobility: this applies to those inventors who have changed location over time, namely, inventors with a different address at the county level in different patents. According to this definition, a *move* is recorded when an

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[3] In particular, we have implemented the Massacrator@ routine. This is a Structured Query Language (SQL) routine that compares all inventors with the same name and surname, but different addresses, in pairs. The routine compares information on each inventor in the pair, namely biographical information, the technological contents (i.e. the International Patent Classification (IPC) code) and applicant of each inventor's patents, citation relationships and co-inventorship ties between the inventors in the pair. The greater the similarities in the information set of the inventors in a pair, the greater the probability that two inventors may indeed be the same person. Massacrator computes a cumulative 'similarity score' for each pair of inventors with the same name and surname, but different addresses, according to the similarities in the criteria listed above. The greater the similarity in the criteria, the greater the score and probability that the two inventors are actually the same person. The threshold value of the score for accepting identity between two individuals has been set to a relatively high value to ensure a rather conservative approach in coupling individuals. For full details on the routine, see Lissoni et al. (2006).

[4] The term 'core based statistical area' (CBSA) identifies collectively the so-called metropolitan and micropolitan statistical areas. These are geographic entities defined by the US Office of Management and Budget (OMB) for use by Federal statistical agencies. A metropolitan area contains a core urban area of 50,000 or more population, and a micropolitan area contains an urban core of at least 10,000 (but less than 50,000) population. Each metropolitan or micropolitan area consists of one or more counties and includes the counties containing the core urban area, as well as any adjacent counties that have a high degree of social and economic integration (as measured by commuting to work) with the urban core. For this paper, we have adopted the June 2003 definition of CBSAs, which comprises 370 metropolitan areas and 565 micropolitan areas. For fuller details and maps, please see URL: http://www.census.gov/population/www/metroareas/metroarea.html.

[5] For example, assume that inventor X moves from applicant A where she files patent 1 at time t, next to C where she does not file any patent, and finally to B where she files patent 2 at time t + 3. By looking exclusively at patent data, we are not able to observe the moves from A to C and from C to B. Neither were we are able to observe whether inventor A was active in another company (without fling any patent) before joining A or in another one (without fling any patent) after joining B.

Also, this definition of mobility treats affiliation to a patent's applicant as a formal labour relationship whereas, especially in the case of university professors, patents might simply result from a consultancy or a research contract and not from a more stable and long-lasting employment relationship. In such a case, a move could be recorded, while actually no move took place. Additionally, from patent data we might observe that inventor X moves from applicant A where she files a patent at time t to B where she files a patent at time T, with T > t, being B the merger of A with another firm; in such a case, patent data would indicate that a move occurred from A to B, whereas, actually, no move took place. In both these cases, thus, patent data may even overestimate the actual number of job moves. For a discussion of these issues, see Lenzi (2009) and Laforgia and Lissoni (2006).

inventor is found to have filed patent document(s) at time t in county A and, next, patent document(s) at time T in county B, with T > t. In such a case, one can say that the inventor moved from county A to county B at some point between times t and T. Moreover, we observe an inter-regional move if county A and B belong to different CBSAs, whereas we observe an intra-regional move if both county A and B belong to the same CBSA.

According to the two definitions of mobility given above, we are able to observe mobility in the data only for inventors with at least two patents.[6] In what follows, we look therefore at the sample of inventors with two or more patents in order to assess the rate of inventors' mobility and to describe its spatial patterns. Out of the 554,235 inventors considered, 338,034 (62.1%) had only one patent in their career, while 206,201 (37.9%) had more than one. This skewed distribution is consistent with the so-called Lotka's law affirming that scientific (and technological) productivity is highly concentrated in a few individuals responsible for the bulk of new advances being made (Lotka 1926; Narin and Breitzman 1995).

4 The extent of US inventors' mobility

Firms are interested in retaining their best talents by implementing specific strategies to discourage their mobility such as the provision of economic incentives or the introduction of covenants not to compete in contracts (Hyde 1998, 2003). It is thus interesting to observe that the rate of cross-firm mobility is greater than the rate of interregional mobility; in fact, cross-firm mobility is both more likely and more frequent (Table 1). Cross-firm mobile inventors (i.e., inventors with patents with at least two different firms) represent around 35% of all inventors with two or more patents (71,777 out of 206,201). On the other hand, interregional mobile inventors (i.e., inventors with patents in at least two different CBSAs) are just 10% of all

Table 1. Number of companies and CBSAs 'visited' (only inventors with two or more patent applications)

Number of companies	Number (%) of inventors	Number of CBSAs	Number (%) of inventors
1	134,424 (65.2)	1	185,536 (90)
2	50,353 (24.4)	2	19,310 (9.4)
3	13,697 (6.6)	3	1,235 (0.6)
4	4,694 (2.3)	4	111 (0.1)
5	1,724 (0.8)	5	7 (0)
>5	1,309 (0.69)	>5	2 (0)
Total	206,201 (100)		206,201 (100)

Note: The table reports the number of companies and CBSAs 'visited', that is, for how many companies an inventor was listed as inventor, or in how many CBSAs she was found to be located. Please note that this might differ from the number of 'moves' across firms or across CBSAs. For instance, a move from CBSA X to CBSA Y and then a move by the same inventor from CBSA Y to CBSA X implies only two CBSAs visited. This is different from the case of a move from CBSA X to CBSA Y followed by a move from CBSA Y to CBSA Z, which results into three CBSAs visited. However, the difference between the two is negligible since the vast majority of mobile inventors had only one move. Also, this table does not consider moves occurring within the same CBSA. Only inventors with two or more patent applications have been considered.

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[6] Inventors with only one patent during their career, by definition, have only one location (address). Yet, inventors with only one patent may have more than one affiliation (i.e. applicant) if the patent has been applied for by two or more organisations (i.e., co-patents). We have excluded these cases from the computation of cross-firm mobility.

Table 2. Cross-tabulation cross-firm vs cross-region mobility

	Inter-regional mobile inventors		Total
	No	Yes	
Cross-firm mobile			
No	–	9,973 (12.2%)	9,973 (12.2%)
Yes	61,085 (74.7%)	10,692 (13.1%)	71,777 (87.8%)
Total	61,085 (74.7%)	20,665 (25.3%)	81,750 (100%)

Note: The table cross-tabulates the number of inventors who have either changed company or CBSA (or both). Percentages reported among parentheses refer to the overall number of cross-firm and/or spatially mobile inventors.

inventors with two or more patents (20,655 out of 206,201).[7] In addition to this, 4.3% of all inventors with two or more patents (8,991 inventors out of 206,201) moved at least once within the same CBSA, that is, they moved but remained in the same geographical area. Only 814 inventors that made a move within the same CBSA, also made a move between CBSAs.

Overall, 14% of all inventors with two or more patents made a move either between CBSAs or within CBSA or both (28,842 inventors, i.e., 20,665 + 814 + 8,991). However, interregional mobility is more frequent than intraregional mobility. Considering all inventors that made a move either between CBSAs or within CBSA or both, 69% of them can be classified as interregional mobile inventors (i.e., they moved at least once between different CBSAs), while only 31% of them are intraregional mobile inventors. Several motivations can affect the decision not to move and partly explain this result, for example the loss of primary social networks (i.e., family and friends), the risk of lower income and worse working conditions and salary, differences in public facilities such transport infrastructure, school system and health care facilities.

Table 2 tabulates cross-firm and spatial mobility, by focusing on inventors that either moved across firms or changed location. Forty percent of inventors with two or more patents (81,750 out of 206,201) either changed company or moved across CBSAs. We observe that the vast majority of cross-firm mobile inventors (85%, i.e., 61,085 out of 71,777) changed job remaining within the same CBSA (i.e., they never changed location). Together with Table 1, this result indicates that cross-firm mobility is to a large extent a local phenomenon, probably depending on the existence of a highly localized and fluid labour market as well as on lower search costs at the local scale, as several contributions have stressed (Saxenian 1994; Hyde 1998, 2003; Almeida and Kogut 1999; Fallick et al. 2006). Also, spin-off generation out of existing organizations, which entail a particular case of cross-firm mobility where a job change takes place *via* the creation of a new company, frequently occurs at the local scale; new entrepreneurs are actually interested in staying close to previous employers to benefit from existing and established linkages with suppliers, customers and local sources of knowledge (Sorenson 2003; Buenstorf and Klepper 2009).[8]

From Table 2 we also note that slightly more than 50% of the inventors that changed CBSA also changed company (i.e., 10,692 out of 20,665). The remainder of spatially mobile inventors changed CBSA but not company. This is compatible with two opposite patterns of spatial mobility. On the one hand, if a move takes place at the very local scale, for instance to a location at a manageable working distance, changing region does not require changing job; on the other

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[7] Benchmarking this value is extremely difficult. Nonetheless, the results reported in the text seem to be fairly consistent with US population migration data, showing that only about 12% of people with age between 25 and 39 move across states, and that about 9% of people with age between 25 and 64 move across states (US Census 2000, URL: http://www.census.gov/prod/2003pubs/censr-12.pdf).

[8] We thank an anonymous referee for suggesting this possible explanation of cross-firm mobility in space.

Table 3. Cross-firm and inter-regional mobility by technological field

Field	Number of cross-firm mobile inventors	Percentage of cross-firm mobile inventors	Number of inter-regional mobile inventors	Percentage of inter-regional mobile inventors
Electronics & ICT	15,150	26.7	4,967	8.7
Scientific instruments	16,256	37.2	4,273	9.8
Basic materials chemistry	16,148	39.0	4,928	11.9
Drugs & biotechnology	14,300	46.8	3,929	12.8
Industrial processes	7,746	31.9	2,188	9.0
Mechanical engineering	5,212	28.3	1,344	7.3
Consumer goods	2,766	30.6	663	7.3

Notes: The table reports the number and percentage of inventors who have changed company or have changed CBSA over their career by technology field. Percentages are calculated with respect to the overall number of inventors with two or more patents in each technology field. To allocate inventors to technology fields, the field of the first patent has been used. Inventors whose first patents were in more than one field have been counted as many times as their fields. This explains why the sum of the number of 'movers' is larger than the number of movers from Table 1.

hand, if the move is to a very distant location but, for instance, the inventor works for a multinational company, changing location does not entail changing company, but simply to move from one company's facility to another. Overall however, cross-firm and spatial mobility seems to capture rather different aspects: only 13% of inventors are mobile both cross-firm and in space. In fact, while cross-firm moves is to a large extent a local phenomenon, both within and across CBSAs moves are only partly related to job moves, meaning that spatial mobility and relocation might be also motivated by other drivers than the decision to change job.

Table 3 reports the proportion of all inventors with two or more patents who moved across companies or CBSA, by technological class of the first patent. The rate of cross-firm and cross-region mobility differs across technological fields, being particularly high in pharmaceuticals and in chemistry.[9] This is actually consistent with findings suggesting that the rate of cross-firm mobility is higher in more knowledge and technology intensive fields (Pacelli et al. 1998).

5 Spatial patterns of US inventors' mobility

In this section we focus our attention on the spatial patterns of US inventors' mobility. To this purpose, we examine the spatial moves of inventors, where a move is defined as each single event of CBSA change (i.e., from CBSA A to CBSA B), and its spatial extent, regardless if this move also entails a cross-firm move. Our data indicate that 10% of US inventors in the sample (i.e., 20,665 inventors) have moved at least once from one CBSA to another. Overall, they experienced 22,379 moves, meaning that most of them moved only once. In fact, 90% of them (i.e., 18,673 out of 20,665 inventors) who changed CBSA, experienced only one move in their career (this is consistent with data in Table 1 on the number of CBSAs 'visited').

Table 4 tabulates moves according to the type of CBSA of origin and destination, whether micropolitan or metropolitan CBSA. The vast majority of all moves are across metropolitan CBSAs; inflows and outflows from metropolitan CBSAs to micropolitan CBSAs (and vice versa) as well as inflows and outflows from metropolitan CBSAs and nonmetropolitan areas (and vice

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[9] It is worth mentioning that in these fields the propensity to patent per inventor is greater as compared to others. The greater the number of patents per inventor, the greater the number of events observed for each inventor and thus the probability in detecting a move either across firms or CBSAs. Therefore, there might be a positive bias and risk of inflation of the rate of mobility in those technological classes characterized by a greater propensity to patent.

Table 4. Number of inventors' moves between CBSA (% of all moves between CBSA)

	Destination			Total
	Metropolitan	Micropolitan	Nonmetropolitan	
Origin				
Metropolitan	19,643 (87.8%)	967 (4.3%)	443 (2.0%)	21,053 (94.1%)
Micropolitan	910 (4.1%)	77 (0.3%)	54 (0.2%)	1,041 (4.6%)
Nonmetropolitan	240 (1.1%)	45 (0.2%)	–	285 (1.3%)
Total	20,793 (93.0%)	1,089 (4.8%)	497 (2.2%)	22,379 (100%)

Note: The table reports the cross-tabulation by origin and destination of inventors' moves according to the type of CBSA.

versa) largely balance each others. Also, nonmetropolitan areas are almost excluded from inventors' spatial moves since they account for a very limited proportion of migration patterns.

Several factors can explain such a result. First, many contributions point to the pivotal role of larger urban areas as the engine and preferential location of innovative activities, and consequently of knowledge and highly-skilled workers such as inventors (Berry and Glaeser 2005; Bettencourt et al. 2007; Carlino et al. 2007). Therefore, although only 50% of regional moves are associated to cross-firm moves across CBSAs, inventors, in deciding the area to relocate to, may consider moving to those CBSAs with a greater supply of job opportunities, that is, in larger metropolitan areas. Also, the population size of metropolitan CBSAs is, by definition, greater as compared to the population size of micropolitan CBSAs and of nonmetropolitan areas; thus, the greater the population size, the greater the probability of observing a move. Additionally, better connections in terms of commercial relationships and communication and transport networks among metropolitan CBSAs as compared to other regions can facilitate accessibility and thus, moves across them rather than towards micropolitan or nonmetropolitan regions (Limtanakool et al., 2007). Still, and interestingly, this result seems to suggest that inventors' migration flows occur prevalently at a higher level in the functional hierarchy of urban areas (i.e., among metropolitan CBSAs, which are most likely to rank higher in the urban hierarchy). That is, only metropolitan CBSAs are in the position to benefit and eventually take advantage of the highly-skilled workers' (i.e., inventors) mobility knowledge spillovers. In fact, this is consistent with findings on spatial patterns of mobility of UK graduates entering their first employment (Faggian and McCann 2006, 2009).

Speculatively, this would imply a greater attraction and concentration of inventors' mobility knowledge spillovers and their beneficial effects to local inventiveness and development within metropolitan CBSAs. Additionally, because of the cumulative effects of agglomeration economies, this process might eventually reinforce over time and sharpen the divide between more central and highly ranked areas in the national urban and functional hierarchy as compared to more peripheral and lower ranked ones. Ultimately, this would point to an increase of relative advantages of geographical proximity within a few selected areas combined with an increase of disadvantages of geographical peripherality (McCann 2008) and, eventually, to an increase in within country inequality and divergence at the local and urban level as reported by Brakman and van Marrewijk (2008). Also, this is consistent with view that while the costs of moving goods across space have dramatically fallen in recent years, those of moving people have not, leading to an increase of people concentration in a few metropolitan areas to reap the advantages stemming from agglomeration economies, especially in services (Glaeser and Kohlhase 2003).

Table 5. Spatial extent of moves between and within CBSA

	All moves	Excluding moves from/to Alaska, Hawaii and Puerto Rico
Driving time (hours)	13.7 (18.3)	13.3 (13.6)
Driving distance	873.4 (942.4)	867.2 (931)
Geodetic distance	739 (802.1)	733.949 (792.8)

Note: The table reports the average distance of inventors' moves, where distance is defined in terms of driving time, driving distance and geodetic distance. Standard deviation in parentheses.

Finally, this is consistent with the view that spatial transaction costs of knowledge have increased over time and more than offset the fall of spatial transmission costs, suggesting a renovated role for geographical proximity. In fact, the quantity, variety and complexity of the knowledge to be exchanged and transacted and its tacit and idiosyncratic features require more and more face-to-face contacts, and thus accessibility and spatial proximity to the relevant places where this knowledge is produced, to make its transfer effective. In this perspective, human and intellectual capital can be increasingly considered fixed and local assets unevenly distributed across space and primarily concentrated in a few and, likely, dense populated areas (Zucker et al. 1998; Berry and Glaeser 2005).

Several empirical works emphasize that spatial moves occur often at small geographical scales rather than at large one (see among the others Saxenian 1994; and Fallick et al. 2006). Combining this with the results reported in Table 4, it is also to be expected that a considerable amount of inventors' mobility flows across CBSAs (especially metropolitan ones) should occur across rather spatially close CBSAs. Table 5 reports the average distance of inventors' spatial moves. Information on the zip code as reported in the inventors' addresses in patent documents is used to make these calculations and two notions of distance are applied:

1. Driving distance (in miles) and driving time (in hours) by using the Google Maps Application Programme Interface (API).
2. The geodetic distance (in miles) using latitude and longitude of the zip code centroid by using the *geodist* function in Statistical Analysis System (SAS).

Not surprisingly, driving distance is larger than geodetic distance. However, the rather high average values as well as the large standard deviations, according to all measures of distance used, somehow contrast with the intuitions and expectations from the results of previous works (see among the others Saxenian 1994; and Fallick et al. 2006).

To better understand this, Figure 1 plots the whole distribution of inventors' moves across CBSAs by both driving and geodesic distance and by driving time (excluding moves to and from Hawaii, Alaska and Puerto Rico). The plot highlights a sort of bimodal distribution. In fact, 33% and 37% of all moves (according to driving and geodesic distance respectively) are within 200 miles, whereas 50% and 45% of all moves (according to driving and geodesic distance respectively) occur at a distance greater than 500 miles; similarly, 26% of all moves are to locations within 2 hour driving time, 30% within 3 hours, but 50% to locations above 8 hour driving time. This result indicates that US inventors' mobility across CBSAs is characterized by two distinctive spatial patterns: moves occur either at a rather short distance or at very large distances. Also, and surprisingly, large distance moves seem to be even more frequent than short distance ones.

However, CBSAs can differ in the spatial patterns of inventors' moves (Almeida and Kogut 1999). In fact, some can be surrounded by other CBSAs thus supporting an intense pattern of

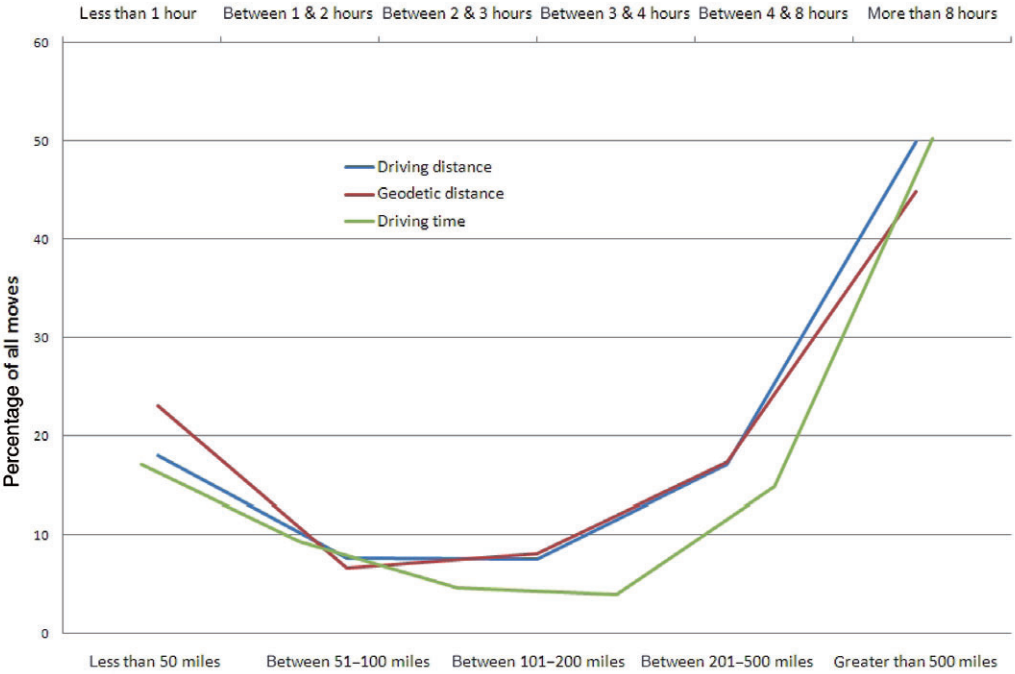

Fig. 1. Spatial extent of inventors' moves

moves from and to neighbour CBSAs; because of the functional distribution and hierarchy across metropolitan and micropolitan CBSAs, presumably, this would especially apply to micropolitan CBSAs, which might need to be closely connected to neighbour CBSAs, especially the metropolitan ones. Differently, and also because of the uneven geographical distribution of CBSAs on the US territory, others can be relatively more isolated and thus linked to other CBSAs only through long distance inventors' moves. Moreover, some can experience greater inventors' outflows than inventors' inflows, being 'net losers' of skilled workers, whereas others can show greater inventors' inflows than inventors' outflows, thus being 'net absorbers' of skilled workers. To investigate this issue, we have calculated for each CBSA$_j$ to what extent moves in and out CBSA$_j$ to other CBSAs are local, that is, within 100 miles driving distance.[10] In particular, we computed two indexes defined as follows:

1. LIN$_j$ = (fraction of moves *to* CBSA$_j$ *from* other CBSAs within 100 miles)/(fraction of all moves between all CBSAs that are within 100 miles);
2. LOUT$_j$ = (fraction of moves *from* CBSA$_j$ *to* other CBSAs within 100 miles)/(fraction of all moves between all CBSAs that are within 100 miles).

If LIN$_j$ or LOUT$_j$ is greater than 1, then CBSA$_j$ has a higher than expected propensity, respectively, to receive or to make 'local' (i.e., short distance) moves. Table 6 reports the two indexes for the top 15 largest CBSAs in terms of innovative population (i.e., the total number of inventors).

Interestingly, only a few urban areas benefit from incoming flows of inventors from surrounding CBSAs, namely the two major CBSAs in California and New York. On the contrary,

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[10] The 100 miles threshold to define local moves is to some extent arbitrary. However, results do not change appreciably if one chooses slightly larger or smaller values.

Table 6. Propensity to local moves

	LIN	LOUT	Number of inventors
New York-Newark-Edison, NY-NJ-PA	1.31	1.07	44,483
San Jose-Sunnyvale-Santa Clara, CA	2.00	1.60	28,903
Boston-Cambridge-Quincy, MA-NH	0.62	1.00	28,471
San Francisco-Oakland-Fremont, CA	1.80	1.91	25,211
Chicago-Naperville-Joliet, IL-IN-WI	0.18	0.19	22,396
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	1.04	1.36	20,420
Minneapolis-St. Paul-Bloomington, MN-WI	0.14	0.21	17,991
San Diego-Carlsbad-San Marcos, CA	0.40	0.27	14,468
Seattle-Tacoma-Bellevue, WA	0.11	0.36	13,257
Houston-Baytown-Sugar Land, TX	0.38	0.66	12,790
Detroit-Warren-Livonia, MI	0.72	1.01	11,914
Rochester, NY	0.31	0.29	10,894
Dallas-Fort Worth-Arlington, TX	0.07	0.22	9,899
Washington-Arlington-Alexandria, DC-VA-MD-WV	0.54	0.57	9,045

the other CBSAs benefit from long distance moves, especially Dallas, Seattle and Minneapolis. Also, only a few CBSAs benefit neighbouring CBSAs by means of outgoing flows of inventors, namely the two CBSAs in California, New York and Philadelphia. On the contrary, the other CBSAs primarily generate long distance moves, especially Chicago, Minneapolis and Rochester. Overall, thus, only the two Californian CBSAs, together with the New York area show localized (i.e., short distance) patterns of inventors' mobility. On the other hand, all the other largest metropolitan regions tend to rely upon incoming and outgoing flows of distant inventors.

Interestingly, but not surprisingly, these data point to the existence of a better integrated and more flexible labour market for skilled individuals (i.e., inventors) in Silicon Valley (i.e., the first two Californian CBSAs) as compared to other CBSAs; this is, ultimately, the well known localized knowledge diffusion effect of Silicon Valley documented by several empirical contributions (see for example Saxenian 1994; Hyde 1998, 2003; Fallick et al. 2006). This supports the findings from Figure 1 on a bimodal distribution of spatial patterns of inventors' mobility and the view that the local pattern of mobility is to a great extent driven by the unique speed and permeability of the Silicon Valley labour market. This also supports Almeida and Kogut's (1999) argument on the geographical concentration of knowledge flows which is found to be a region specific and not a universal phenomenon. In particular, this relates to their findings on intraregional (i.e., localized) inventors mobility as a key determinant of the different and greater degree of knowledge flows localization in Silicon Valley as compared to other regions. Regions, ultimately, have different patterns of spatial diffusion of knowledge externalities, which are much more concentrated in Silicon Valley than anywhere else, because of specific social institutions, namely a highly dynamic, entrepreneurial and spatially-bounded labour market for highly-skilled workers (i.e., inventors). On the contrary, it is possible to speculate on the characteristics of labour market for highly-skilled workers in those CBSAs showing lower levels of short distance moves. Again following Almeida and Kogut (1999), a possible interpretation is that they are dominated by the presence of large firms with an established internal labour market. In such a case, skilled workers might resort to move to a distant location and try to enter an external labour market when they are not willing or do not have the opportunity to build their career in the firm's internal labour market. Interestingly, the values of LOUT indicate that only a few of the most innovative CBSAs, but the two in California and New York, benefit neighbouring regions with inventors' mobility knowledge spillovers. On the contrary, these benefits will accrue to distant regions which, according to findings in Table 4, are mostly metropolitan

CBSAs. Thus, potential positive external effects on proximate CBSAs inventiveness and growth are crowded out in favour of more distant CBSAs. On the other hand, only the two Silicon Valley and New York CBSAs may eventually generate positive externalities on neighbours' inventiveness and growth via inventors' migration.

Also, the ranking of LIN and LOUT does not change very much. This is in fact somehow challenging. Indeed, according to the Christaller urban functional hierarchy, we might have expected, for the most innovative CBSAs (which presumably rank in the top of the urban hierarchy), LIN taking values greater than 1 (meaning that the CBSA attracts and imports external, but relatively local human capital [i.e., inventors] from neighbouring and hierarchically lower ranked CBSAs) and LOUT taking values lower than 1 (meaning that the CBSA exports human capital [i.e., inventors] to distant and hierarchically equally or higher ranked CBSAs). What is remarkable here instead is that LIN also takes values lower than 1, suggesting that the most innovative CBSAs absorb external skilled human capital via migration from distant CBSAs. This indicates that the most innovative CBSAs (excepting the two in California and New York), do not play a central role in attracting and directing inventors flows towards their relative neighbouring CBSAs while, on the contrary, they are pretty well and, more relevantly, directly connected to distant CBSAs. Rather, it seems that the network of CBSAs linked through inventors' migration flows involve only upper ranked CBSAs within the urban functional hierarchy and bypass local intermediate CBSAs. Quite interestingly, most of the top 15 innovative CBSAs appear to be in the list of the US 'global cities', that is, they belong to the network of world major urban centres that are found to preferentially interact with similar globally-oriented cities (also in other countries) rather than with smaller urban centres serving local markets with local goods (Sassen 2001, 2002). Interestingly, US global cities appear to be linked to other US global cities to a greater extent as compared to European or Asian counterparts (Taylor and Lang 2005).

Finally, the reliance of most innovative US CBSAs on skilled human capital (i.e., inventors) external to the CBSAs itself points to the role played by extra-local linkages and by accessibility to external sources of knowledge as in the form of migration flows. Despite this, spatial proximity can reduce the costs of new knowledge acquisition and favours mutual understanding and implementation of new practices; excessive reliance on pure local knowledge sources may turn to be detrimental and degenerate in lock-in. Human capital migration involving distant areas can, conversely, mitigate these risks (Boschma 2005; Simonen and McCann 2008; Eriksson and Lindgren 2009).

6 Conclusions

In this paper, we have explored one of the key mechanisms driving the process of knowledge diffusion, namely the mobility of inventors, and described its spatial patterns.

Consistently with several studies in the field (Almeida and Kogut 1999; Agrawal et al. 2006), we made use of patent data on inventors to track their mobility across firms and in space. In particular, we took advantage of a rich database on US inventors patenting at the EPO from 1978 to 2004 and defined as cross-firm mobile inventors those inventors holding at least two patents assigned to two different applicants and as spatially mobile inventors those inventors who appeared on at least two patents in two different locations (i.e., residence addresses reported in the patent documents).

Our findings, although based on rather simple descriptive figures, provide a first comprehensive outlook on skilled workers' mobility and appraisal of its spatial patterns on the basis of a large scale data set and at a fairly micro level unit of analysis, namely, urban areas.

Our results suggest that while cross-firm mobility is to a large extent a local phenomenon, which prevalently occurs within a CBSA's boundaries, cross-region mobility involves a job change only in 50% of the cases. This suggests that the two types of mobility are quite distinctive phenomena that only partially overlap. Regarding the spatial patterns of inventors' mobility, not surprisingly, they involve almost exclusively metropolitan CBSAs, consistently with the observation that innovative activities are centred on major urban areas and so also those people involved and responsible for such activities.

More interestingly, two distinctive spatial patterns emerge, thus indicating a bimodal distribution of the geographical distance entailed by moves across space. In fact, inventors move both at small and large distances in similar proportions, with a relative prevalence of the latter on the former.

In particular, the most innovative metropolitan CBSAs (in terms of inventors' population) appear to be more connected via inventors' migration to distant CBSAs rather than to closer ones. Only two Californian metropolitan CBSAs (i.e., San Jose and San Francisco) and New York considerably exchange human capital (i.e., inventors) with neighbouring areas, pointing to the existence of a strongly localized, integrated and flexible labour market for highly-skilled workers in Silicon Valley as suggested by Almeida and Kogut (1999). This also indicates that, in general, benefits (i.e., knowledge spillovers) arising from the migration of highly-skilled human capital do not benefit neighbouring areas but distant ones, pointing to the existence of crowding out effects. Finally, this also highlights the relevance of external linkages established through inventors' migration as a key channel to renovate and to augment the local knowledge base and to mitigate the potential risks of lock-in (Boschma 2005; Simonen and McCann 2008; Eriksson and Lindgren 2009).

As to the limitations of the present research, these relate to two aspects. First, the definition of mobility adopted, which relies exclusively on patent data, identifies a lower bound of the actual number of inventors' moves across firms and in space, as we discussed in Section 3. This is stressed further by the use of EPO data for US inventors; since not all patents filed at the USPTO are also filed at the EPO, US inventors are underrepresented using EPO data and this may lower the possibility to observe an inventor's move across firms or in space. In this regard, our findings are conservative and census data, matching employers and employees in a time series perspective, can represent valuable complements to patent-based data sets to inspect further spatial patterns of skilled labour mobility.

Second, the analysis presents purely descriptive figures with the specific aim to providing a first outlook on the spatial patterns of mobility. As a consequence, an analysis of the determinants of such patterns is not presented here, although it certainly would add value to researches on knowledge spillovers mechanisms and migration patterns. This certainly represents one of the most interesting and promising directions for future work and a fairly natural extension of the present study.

Another interesting research direction to explore envisages the mapping of the network of skilled human capital (i.e., inventors) migration flows across urban areas to detect the emerging structural properties of such a network and to examine the impact of these network properties on urban areas innovative performance. This would definitely enhance our understanding of the impact of highly-skilled workers and their mobility as knowledge carriers on regional innovation and growth.

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Patrones espaciales en la movilidad de inventores: datos de áreas urbanas de los EE.UU.

Stefano Breschi, Camilla Lenzi

Resumen. El objetivo de este artículo es contribuir a la investigación sobre *spillovers* de conocimiento y su amplitud espacial ya que presenta nuevas pruebas empíricas sobre un mecanismo clave para impulsar y dirigir los procesos de difusión de conocimiento, concretamente la movilidad de conocimiento y de mano de obra altamente especializada. El análisis está basado en un conjunto de datos exhaustivo sobre inventores estadounidenses y las patentes inscritas por ellos en la Oficina Europea de Patentes desde 1978 a 2004. Los resultados indican que se pueden detectar dos patrones espaciales distintivos: los inventores se mueven tanto a distancias cortas como largas (concretamente tres horas y más de ocho horas en automóvil, respectivamente) en proporciones similares. Es interesante mencionar que, en las áreas urbanas innovadoras más grandes, los flujos de entrada y salida de inventores están asociados principalmente a áreas lejanas en vez de a áreas vecinas.

JEL classification: 033, R23

Palabras clave: inventor, movilidad, *spillovers* de conocimiento, proximidad geográfica

要約
本論文の目的は、知識拡散プロセスを促進し方向づける主たるメカニズム、すなわち、知識および高技能労働者の移動について、新たな実証結果を提示し、知識スピルオーバーとその空間的な規模の研究に貢献することである。本分析は1978年から2004年にかけて欧州特許庁に特許を出願した米国技術開発者とその特許に関する豊富なデータに基づいて行われた。分析は2つの特徴的なパターンがあることを示している。発明家は、短い距離および長い空間距離を同様の割合で移動する（たとえば、短距離では3時間、長距離では8時間以上のドライブ距離）。注目すべきは、最もイノベーションが活発な都市部では、発明家の流入・流出は近隣ではなく主に遠距離である。