The Increasing Importance of Geographical Proximity in Technological Innovation:

An Analysis of U.S. Patent Citations, 1975-1997[1]

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Abstract
In spite of increasing global flows of ideas, capital, goods and labor, recent research in urban economics and economic geography suggests that geographical proximity between innovators may be important to technological innovation. Many authors also claim that the rise of a knowledge-based economy and changes in the organization of the innovation process have actually increased the value of such proximity to innovation. Yet there is little empirical research on whether this latter proposition is valid. Using patent citation data, this paper investigates changes over time in inventors' dependence on locally-created knowledge. We find an increasing tendency for inventors to cite local patents at three geographical levels: the national, the state and metropolitan levels. This implies that inventors increasingly use domestic knowledge more than foreign knowledge, in-state knowledge more than out-of-state knowledge, and knowledge from the same metropolitan area more than knowledge from outside. Thus, proximity in the creation of economically-useful knowledge appears to be becoming even more important than was previously the case.

Keywords: proximity, patent citation, localized knowledge spillover, innovation, invention

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The Advantage of Geographical Proximity to Innovation: 'Not Dead Yet' or 'Increasingly Important'?

The last few decades have witnessed great increases in global flows of ideas, capital, goods and labor(Dicken 1992; Held et al. 1999; Scott 1998). In particular, information, at least in its codified forms, flows without much friction from one place to another. Almost weightless, it can reach most parts of the world with the speed of the internet or a courier service, and at low cost. Furthermore, the rapid transition to a "knowledge based" economy has increased the incentives to exploit knowledge produced in other parts of the world, since knowledge rents are increasingly important in contemporary competition (Lundvall and Johnson, 1992).

However, information is not equivalent to economically-useful knowledge, and the latter may experience considerable friction to distance. Along these lines, urban economists and economic geographers have suggested that geographical proximity between the people and organizations who produce knowledge may still be an important advantage in the production of economically-useful innovations (Acs 2002; Dicken 1992; Feldman 1994; Storper 1997). Innovations with a high technological content have been shown to be facilitated by the physical co-presence of key scientists and frequent interaction between related workers (Saxenian 1994; Zucker, Darby, and Armstrong 1998).

This would be the case if certain kinds of knowledge flow were subject to constraints related to the cost or feasibility of covering distance, or both (Acs 2002;

Audretsch and Feldman 1996; Feldman 1994; Glaeser 1999; Patel and Pavitt 1991; Porter 2000; Smith 1999; Storper 1997; Marshall 1890; Foray 1991) Indeed, a broad literature has emerged which sees innovation as a systemic process which depends on multiple interactions, which are structured around nodes and channels of various types, each involving different types of relations between innovating agents, and with different degrees of intensity and hence costs and feasibility of carrying them out over geographical space (Breschi, Lissoni, and Malerba 2003). Along these lines, Storper and Venables (2004) analyze local direct face-to-face contact, showing that it is not only an efficient technology of communication, but also a means for reducing moral hazards in relationships which are extremely uncertain, such as in the formation of joint projects to develop new knowledge, where complete contracts are impossible and bureaucracies too costly. Storper (1997) argues that relationships, which depend in varying degrees on geographical proximity, are the key untraded interdependencies that allow actors to coordinate in order to innovate.

Even more intriguing is the suggestion that the importance of proximity be actually increasing with the advent of an increasingly knowledge-based economy. In this view of things, contemporary information and communication technologies have permitted a much more flexible and rapid interaction between product and process change in many industries, necessitating constant innovation and introducing new "islands of complexity" in the economic process which require dense, person-to-person communication among potential innovators. Added to this is the opening up of new frontiers in basic technologies such as microelectronics, the internet and biotechnology, where constant innovation is at the heart of those industries' performance. Still others

claim that both long-distance and local interactions should intensify in the knowledge-based economy, with multinational firms increasingly embedding themselves in localized innovation systems and acting as long-distance links between such nodes in global networks(Verspagen and Schoenmakers 2002).

Yet this apparent continued importance of proximity seems paradoxical in today's world and is highly contested by certain analysts. If it is true that we are getting closer and closer to a condition where the friction of distance is dying, then the importance of proximity should be decreasing (Cairncross 1997). The problem is that any claim that the importance of proximity is rising cannot be arbitrated on the basis of existing research, because most studies of knowledge flows and related topics have employed data which do not allow tracking of historical changes in the geography of knowledge flows; they can only measure it at one point in time. This paper attempts to fill some of this gap using an historical patent citation data base which is geographically-specific. With the aid of the Jaffe, Trajtenberg, and Henderson Control (JTH Control), we investigate the historical changes in inventors' dependence on locally created knowledge at three geographical levels: country, the U.S. state, and the U.S. metropolitan areas.

The paper comprises four sections. It begins by reviewing empirical studies on the importance of proximity and formulates two main hypotheses. The next section explains data and methods that the empirical study will employ. Then it reports the results of the empirical study, and concludes by summarizing the findings and considering possible implications.

The Dearth of Empirical Research on the Changing Role of Geographical Proximity Over Time

Since the late 1980s, a number of studies have found evidence of the benefit of proximity in technological innovation. Employing aggregate data mostly at the state level and occasionally at the metropolitan level, this body of literature estimates a knowledge production function and finds some evidence for the importance of proximity.

The pioneering work is that of Jaffe (1989). He finds that for each U.S state, the number of patents by businesses is positively correlated with the R&D expenditure of universities located in the same state. Based on this finding, he infers with caution that there may be knowledge spillovers from universities to businesses. Similar results were obtained by Acs, Audretsch, and Feldman (1992) who replicated Jaffe with different data, the Innovation Count from the Small Business Innovation Data Base.

Kelly and Hageman (1999) control for the distribution of production so as to isolate the effects of knowledge spillovers. They hypothesize that in the absence of knowledge spillovers, the distribution of R&D activities (measured by the number of patents) should be analogous to the distribution of production facilities (measured by the number of workers). Employing a quality ladder model with patent counts at state level, they find that patenting is geographically clustered even after controlling for the location of employment.

These three studies employ the state as the geographical scale of research. However, as Breschi and Lissoni (2001) rightly point out, the state is not an appropriate

geographical unit for measuring knowledge spillovers because US states are administrative boundaries which do not neatly coincide with the boundaries of economic interactions. Moreover, economic policy at the state level is much less significant than that of the federal government. To complicate matters, US metropolitan areas sometimes extend across state boundaries.

More appropriate scales are the country and the metropolitan area. A country contains important institutions that participate in generating innovation, with important network effects among the actors within this "national innovation system" (Lundvall, 1992; Nelson, 1992). This notion is corroborated in numerous studies of trade, which show that national boundaries matter, even for the most ordinary kinds of trade and even when there are few language and customs barriers (McCallum 1995). By contrast, even though a metropolitan area does not coincide with boundaries of culture, public policy and currency, it nonetheless corresponds to the functional urban region defined by daily commuting patterns. Hence, for scientists and engineers, a metropolitan area roughly coincides with the geographical limit for meeting other scientists and engineers regularly and at low cost via face-to-face contact.

In addition to the problems related to geographical scale, previous studies neglect the effect of spatial interaction. As Lim(2003) and Smith(1999) point out, the spatial reach of knowledge spillovers is not always confined to one geographic unit, whether it be country, state or metropolitan area. Nearby units should be at least partial beneficiaries of knowledge spillovers. Anselin, Varga, and Acs (1997) respond to both of these problems. Building upon Jaffe (1989), they make two contributions. On one hand, for the first time, MSA level data are used; on the other hand, a spatial lag variable was

added to Jaffe's knowledge production function so as to capture the effect of interaction between spatial units. They then find evidence of knowledge spillovers at both state and MSA levels.

Another body of literature attempts to prove the existence of localized knowledge spillovers by showing that the technological characteristics of a place influence the technological characteristics of a firm located in that place. Patel and Pavitt (1991) reported that production of technology remains bounded by space in the sense that multinational firms are strong in patenting in the areas in which their home national economies are generally strong in innovation, and that both are highly correlated to the industries in which a particular economy is strongly export-oriented. This led them to conclude that there was a strong association between the organizational capacities of major multinationals and the national systems of innovation of their home countries.

Baptista and Swann (1998) apply similar reasoning to the sub-national level. They test whether firms in well-developed industrial clusters innovate more actively. They use a UK innovation database composed of 248 firms between 1975-1982, finding positive correlation between a firm's innovativeness and the region's employment in the same industrial sector. Using 1981 CURDS survey, Baptista (2000) shows that the presence of the early adopters of new technology is positively correlated with the overall efficiency of knowledge flow in that region. He estimates a duration model to find determinants of adoption of microprocessors and computer numerical control (CNC) devices, and concludes that the 'number of previous adopters of the technology in the region' is positive and significant.

These studies find evidence of local knowledge spillover through correlations

between the innovativeness of a region or a firm and that of its surrounding area. While acknowledging their value, it should also be pointed out that this evidence is at best indirect. Due to the aggregate nature of their data, they cannot study individual points of knowledge spillover.

An alternative is to use data on the individual interactions that might indicate the presence of knowledge spillovers. Jaffe, Trajtenberg, and Henderson (1993) pioneer this method, using patent citation data to track flows of information. After controlling for the existing distribution of inventive activities, they find that inventors tend to cite other patents from within the same geographical unit, be it a country, a state or a Metropolitan Statistical Area. Yet though this represents a considerable advance, it still uses panel data and therefore cannot illuminate *temporal* change in the importance of proximity. In this light, none of the research cited thus far can indicate whether the importance of proximity has been increasing or decreasing toward possible extinction, as so many "death of distance" authors suggest.

The rare studies that investigate temporal changes in knowledge spillover include Jaffe and Trajtenberg (1996) and Johnson, Siripong, and Brown (2002). Jaffe and Trajtenberg (1996) record the application year of cited patents and investigate changes in the locations of citing patents over time. They find that in the early years after a patent is approved, citations are made disproportionately by inventors in the same country (a localization effect). However, in later years, the proportion of foreign citations increases. This suggests that knowledge becomes available to people across long distance only after some time, thereby confirming the benefits of proximity in the production and timely acquisition of cutting-edge knowledge. However, they do not investigate whether the

localization effect of today is stronger than the past, as we do in the present research.

Johnson, Siripong and Brown (2002) attempt to find whether the distance between coauthors of patents and between a citing patent and a cited patent have increased over time. Controlling for the effects of technological fields and assignee types, they find so.

Johnson, Siripong and Brown (2002) investigate physical distance itself rather than the economic or innovation effects of proximity. They define distance as simple physical distance between two points. Thus, in their model, 2,000 miles is twice as distant as 1,000 miles. With today's transportation and communication, however, 1,000 miles and 2,000 miles are not appreciably different in the sense that they are within in a day's flying distance, with a total travel time difference which is not enormous. Moreover, the economic and innovation benefits of proximity are not linear to distance but instead resemble the shape of a Gaussian curve. To be within walking distance is very different from being slightly farther away. Likewise, partners within driving distance can exchange their information face-to-face at least once a day but people even slightly further away cannot and their marginal costs of contact rise very steeply in comparison to those where an overnight stay is not required. Also important are social, political and psychological boundaries. In this respect, as we shall see later on, metropolitan areas and national boundaries delimit discontinuous scales (i.e. going beyond whose boundaries involve important non-linear social, political and psychological costs). Therefore, distance should be defined as a discontinuous variable with distinctive threshold values.

Furthermore, Johnson, Siripong and Brown (2002) do not control for the existing

distribution of inventive activities. Therefore, some of the decreasing importance of distance they find is due to the long-term historical diffusion of inventive activities from the Northeastern region to the South and the West, which however two of the coauthors do report in another paper Johnson and Brown (2002).

Two Hypotheses

The preceding discussion enables us to formulate the two hypotheses which motivate the research reported here.

First Hypothesis: the importance of local knowledge flows, as measured by patent citations, is increasing over time. Our first hypothesis is that proximity is increasingly important for the same reason that journalists argue distance no longer matters. When the global market is integrated and there is greater cross-hauling between markets, there is greater competition in many local markets between the same or similar products from different places. Cost and quality avantages are eroded more rapidly through imitation and cross-penetration between markets, requiring firms to innovate if they are to create new advantages. Due to the resulting shortened life-cycles of products and production technologies, the flow of information accelerates, often making it impossible to make the investments in codification and standardization that would in turn make it possible to transfer knowledge efficiently over long distances. One possible way of coping with this situation is to keep all the necessary knowledge sources in-house. This turns out not to be a good solution because organizational rigidity and the uncertain trajectory of technology oftentimes makes in-house innovation less efficient (Powell

1990; Lundvall 1992). Another way is to interact with other nearby firms so as not to miss any valuable information (Cooke and Morgan 1993; Scott 1996). Firms also hedge on technological uncertainty by locating in large labor markets where pools of specialized labor are readily available (Almazan, Motta and Titman, 2003). In this light, improvement in communication and transportation technologies and the integration of the world market paradoxically result in a stronger localized flow of knowledge (Leamer and Storper 2001). The largest firms attempt to combine the two strategies, inserting themselves into localized innovation environments, but also creating networks through intra-firm trade that link regional nodes at a global scale (Dunning 2000; Verspagen and Schoenmakers 2002; Archibugi and Lundvall, 2003).

Second hypothesis: dependence on local interactions among innovators differs by assignee types. Different types of patent assignees should have different degrees of dependence on local knowledge spillover. For example, larger firms are probably better at overcoming the frictions of distance. With branches in many different parts of the world, they can substitute intra-organizational proximity for geographical proximity. In addition, they have the resources to send researchers and engineers around the world to acquire new information created via routinized relationships in distant locations. They usually have the means for greater investments, both technological and organizational, in communication, hence reducing uncertainty while raising understanding and lowering the marginal costs of efficient communication at a given level of complexity. Some authors have claimed, for example, that large firms can invest in the creation of long-distance "epistemic communities" that allow them to overcome the need for proximity (Lissoni 2003; Hakanson 2003). In contrast, individual inventors,

having fewer resources to access distant knowledge, can be expected to depend on local knowledge spillover to a greater extent than big firms or organizations.

Method

Following the major recent studies on knowledge spillover such as Jaffe, Trajtenberg and Henderson. (1993), Jaffe and Trajtenberg (1996), Jaffe and Trajtenberg (2002), Johnson, Siripong and Brown (2002), Maurseth and Verspagen (2002), Koo (2002), Stolpe (2002) and Breschi and Malerba (2003), we will use patent citations as the proxy for knowledge spillovers[2]. A U.S. patent record documents previous patents that are relevant. These recognitions or citations are regarded as a "noisy" indicator of interactions that lead to invention and innovation (Breschi, Lissoni, and Malerba 2003; Hall, Jaffe, and Trajtenberg 2001). By comparing the address of citing patent and cited patent, one can see whether citations are locally made or not. We count the number of incidents where citing and cited patents were from the same geographic unit, or what we call Total Local Citation (TLC). Then, we divide TLC by the total number of citations,

[2] Two major limitations of patent citation data are recognized by scholars interested in innovation. Firstly, as Feldman (1994) points out, some patents are not commercialized and thus do not have any impact on market economy. However, when the topic of research is knowledge spillover rather than direct economic impact, it would ultimately be important to include un-commercialized patents because they might be sources of inspirations to future patents that have great impacts on economy. In fact, recent findings by Acs, Anselin and Varga (2002) suggest that patent data represent the geography of innovation as well. Secondly, there are limitations of citation as a proxy of knowledge spillover because patent examiners in the U.S. Patent and Trademark Office can add citations to past patents which they think relevant (Breschi, Lissoni, and Malerba 2003:4). If added by the examiners, a citation does not represent actual spillover of knowledge. This problem has partially resolved by recent case studies conducted by (Jaffe, Fogarty, and Banks 1998) and (Jaffe and Fogarty 2000). These studies confirm that citations are noisy but relatively reliable proxy for knowledge spillover.

deriving the Total Local Citation Percentage (TLCP). In so doing, we exclude citations in which the citing patent and the cited patent were assigned to the same assignee (self-citation). That is because self-citation is probably more the result of intra-organizational rather than geographically proximate spillover of knowledge.

However, one cannot simply take the distribution of citations as an indicator of knowledge spillovers. Disproportionate citation of local patents might merely reflect the uneven geographical distribution of R&D activities. In this sense, only when citations are more highly localized than is patenting activity as a whole can it be said that there is localization in knowledge spillovers and this requires that we control for the geographical unevenness of R&D activities. To this end, this paper employs the Jaffe, Trajtenberg, and Henderson Control (JTH Control). To construct this control variable, Jaffe, Trajtenberg and Henderson (1993) connected a patent with a "control patent" that belongs to the same patent class and has the same application year and closest grant date. They then counted the number of cases where a patent's geographic location coincides with that of the control patent (JTH Control Matching Frequency). The frequency of this coincidence is a proxy of the existing distribution of R&D activities. From the JTH control Matching Frequency, we calculated JTH Control Matching Percentage by dividing it with the number of total citations.

The Net Local Citation Percentage (NLCP) was then calculated according to the following formula:

Net Local Citation Percentage = Total Local Citation Percentage
– JTH Control Matching Percentage

If the NLCP at a certain geographic level is greater than zero, it suggests that inventors disproportionately cite past patents from the same geographical unit after controlling for the existing distribution of inventive activities. In other words, in the process of creating new technology, scientists and engineers depend more on knowledge created by other people in the same geographical unit than on knowledge in other units, assuming that existing inventive activities are evenly distributed across geographical space.

If the NLCP at a given geographic scale is less than zero, it means that inventions are disproportionately citing past patents from geographical units other than their own after controlling for the existing distribution of inventive activities. This implies that, when creating new technology, scientists and engineers depend disproportionately on knowledge created by people in other geographical units.[3] Thus, by measuring the evolution of NLCPs, we can determine whether this localization effect in knowledge spillovers is becoming stronger or weaker.

Data Construction and Exploratory Analysis

The main data set for this research comes from *The NBER Patent Citations Data Files*. This database contains information about patents, their inventors and citation records (Hall, Jaffe, and Trajtenberg 2001). For the present research, we used data from

[3] As explained by Jaffe, Trajtenberg, and Henderson (1993), the NLCP is a conservative measure of localized knowledge spillover. The existing concentrations of R&D activities are at least partially due to localized knowledge spillover. Therefore, if one estimates localized knowledge spillover after controlling for existing distribution of R&D activities, it will be a significant underestimation. In other words, if NLCP is positive even after controlling for the existing distribution of R&D activities, it is safe to conclude that there is localized knowledge spillover.

application years 1975 to 1997.

We linked each patent with all the patents it cited. One pair consisting of a citing patent and a cited patent is defined as the unit of analysis. These pairs were then grouped according to the application year of the citing patent, and in this way cohorts for each year were generated. If inventors in a certain year are dependent upon geographically proximate sources of knowledge, patents in that year should disproportionately cite patents from the same geographical area after controlling for uneven distribution of R&D activities. While Jaffe, Trajtenberg and Henderson (1993) grouped patents according to the application year of cited patents, we grouped them according to the citing patent because we are interested in determining whether the today's inventors are citing nearby patents more than did inventors in the past.

We also departed from the original Jaffe, Trajtenberg and Henderson (1993) method in that they control for citing patents, whereas we control for the geographic unevenness of cited patents; indeed, Jaffe, Trajtenberg and Henderson (1993) do not clarify why they choose to control for citing patents instead of cited patents, but we presume either serves their purpose. By controlling for the geographic unevenness of citing patents, they test whether the actual citing patents cite geographically proximate patents more than randomized hypothetical citing patents. Had they chosen to control for cited patents, they would have tested whether citations are directed to geographically proximate patents with a greater than random probability. Either way, they would have been able to determine whether geographically proximate patents are more likely to be cited. For our research, controlling for cited patents makes more sense because it allows us to take the distribution of R&D activities (citing patents) as given.

Twenty-three citing cohorts were constructed in this way; however, there are truncation problems at both ends. The address of the inventor at the metropolitan level is known only for patents granted between January 1, 1975 and December 31, 1999. Since the review process may take many years for some patent applications, approval decisions have not yet been made for a considerable portion of patent applications in the years just prior to 1999. Therefore, we removed patents applied for in 1998 and 1999. Even so, a higher portion of patent applications made in later years is still under review than that of earlier years.

At the opposite end of the data set, truncation is caused by citation lag. Jaffe, Trajtenberg and Henderson (1993) noted that the time lag between a citing patent and a cited patent varies significantly. Citations of a certain patent made within one or two years after the application is made are few. The third year onward, relatively stable numbers of citations are made each year until the eleventh year (See Figure 1, p. 587, Jaffe, Trajtenberg and Henderson, 1993). However, we are not able to estimate descriptive statistics of citation lag because patents will continue to receive citations in the future. Furthermore, the dataset contains address information of patents granted only since 1975. This means that addresses of patents granted prior to 1975 cannot be found even if the citations to those patents are made between 1975 and 1997. Due to this problem, for earlier citing cohorts substantial portions of citations are made to patents granted prior to 1975. For example, for 1975 citing cohorts, out of 335,499 citations made, 109,943 or 32.8% were citations to patents granted prior to 1975. These figures are 31.7% for 1976, and 30.0% for 1977, but fall to 8.0% in 1997 and 7.8% in 1996.

To compensate – at least partially – for this problem, we removed citations from

the database for which the lag is more than seven years. We chose seven years because it is safely after the peak in the distribution of citation lags. More than half of the citations should be made within seven years after application. In this way, data sets of 1982 to 1997 have citations for which the lags are zero to seven years. However, this measure is only partially effective for citations between 1975 and 1981. The longest citations lag in 1981 is six years rather than seven because 1974 patents are not in the database. The longest lag for 1980 citations will be five years, for 1979 citations four years and so forth. Therefore, in the first years covered by the database, an increasingly smaller proportion of the citations actually made are in the database. We cannot know with any certainty whether the truncation problem generates bias, though if the analysis of these cohorts generates results which are significantly different from those of other years, it could be due to truncation. In any event, this procedure leaves 23 cohorts of citations from 1975 to 1997.

The 23 cohorts were further categorized, using the assignee information of the citing patents, into five categories; Individuals, the Federal Government, Universities, the Top 500 most innovative firms and Other firms. There are also patents which do not have assignees. We labeled these patents "unassigned." As used here, "assignee" is a natural person or a legal person to which the legal ownership of the intellectual property rights have been transferred from the inventor. When a patent has no assignee, the inventor retains the intellectual property rights. If the inventor worked for a firm, a university or the federal government, the intellectual property rights are automatically transferred to the institution by which s/he is employed. As a result, the patents lacking assignees are very likely to be those developed either by an independent inventor, or by the owner of a

company. In this sense, it is safe to assume that the patents 'unassigned' to anybody are those developed by the smallest entities.

On the other hand, 'individual' as an assignee type is the case when the intellectual property rights are transferred to an individual from the inventor. Since a patent developed by a firm is less likely to be sold to an individual, it is reasonable to assume that patents assigned to 'individual' are the ones developed by as small entities as those 'unassigned.' The technological or other differences between these two assignee types are not clear.

Patents assigned to University, Firms or the Federal government are highly likely to be the ones developed by researchers working for those institutions. Among university assignees, the University of California is ranked first with 2768 patents granted between 1975 and 1999. The Massachusetts Institute of Technology and University of Texas follow U.C. with 2151 and 1007 patents respectively. Among non-US universities, the University of British Columbia is ranked first with 229 patents and ranked 24th overall. Hebrew University of Jerusalem is ranked 2nd among foreign universities and 39th overall. To our surprise, no Japanese, German or French universities are ranked among the top fifty (see Appendix 1).

The "Top 500 firms" are those to which the most patents are assigned. This group of firms includes IBM, ranked first with 26,340 patents, and General Electric, ranked second with 25,868 patents. Hitachi is ranked first among non-U.S. firms and third overall. As expected, Canon, Toshiba, Eastman Kodak, AT&T, Du Pont, Motorola, Mitsubishi, Siemens and other well-known innovators are ranked highly (See Appendix 2).

"Other Firms" include the firms that have less patents granted between 1975 and 1999 than the top 500 firms. Some of the "Other Firms" have as many patents as 467 but many have only one patent.

Figure 1. Share of Each Assignee Category in Citations

Figure 1 shows the share of each assignee category among all the citations made. The share of top 500 innovative businesses in overall citations decreased from 61% in 1975 to 24% in 1997. This result is consistent with the frequently advanced notion that the innovation process has been reorganized since the 1970s, away from the so-called "linear innovation model" in which large firms were expected to internalize many steps in the R&D/innovation process, toward an innovation process involving external, or inter-organizational relationships between many different actors, and involving a back-and-forth movement between science, R&D and commercialization. Such a change should involve just the kind of result we report, i.e. a decline in the percentage of patenting by the biggest firms. It may equally be the case that externalization of R&D by big companies during the period under examination exhibited a strongly local bias.[4]

Other noticeable changes include a rise of university patenting (0.4% in 1975 to 1.4% in 1997) and decline of both the federal government (2.4% to 0.5%) and unassigned (15.7% to 12.0%). These changes may stem from the increasing commercialization of

[4] Some authors argue that knowledge-intensive projects are more likely to be assigned to teams within companies because incentives for knowledge and data production are better aligned in the firm's internal labor market (Azoulay, 2003). Yet in true innovation, where projects are ill-defined, external contacts may be necessary as firms search for the right project team (Storper and Venables, 2004). Local bias in outsourcing R&D may represent the best compromise of externalization with the benefits of proximity for coordination.

R&D. Universities are becoming more and more active in commercializing their inventions and thus attempt to protect their intellectual property rights by patenting their inventions. Independent inventors should attempt same thing. Since they are not able to transform their inventions into commercial products, they are more likely to sell their intellectual property right to an entrepreneurial entity who can. Furthermore the increasing investments required for successful R&D may leave less room for individual independent inventors.[5]

Findings and Discussion

1. The Importance of Proximity Increases over Time

Figure 2 shows historical changes of NLCP at three geographical levels. At all three levels, the NLCP increases. At the country level, NLCP increases from 2.3% in 1975 to 11.4 % in 1997. At the state level, 1.9% to 5.3%, at the MSA level, 0.9% to 4.3% during the same period.

Figure 2. Net Local Citation Percentage (Distribution of Citation Matches after Controlling for Existing Distribution of Inventive Activities) at Three Geographic Levels.

The increase in citation activity at the national level is very clear. This result tends to confirm the position of Lundvall (1992) and Nelson (1993) who hold that

[5] There is a debate over whether this represents a capital market failure, however, especially in those countries which have weak venture capital sectors.

national systems of innovation generate distinctive national trajectories of technological development, even in the face of considerable international technology spillovers and imitation[6]. While globalization accelerates the exchange of products, a firm tends to have centers of R&D in its home country where it has better access to information sources and dense relational networks (Patel and Pavitt 1991). Moreover, if certain countries, especially the United States, increasingly concentrate global R&D, then this national effect should be especially present in the data we analyzed. In any event, this research suggests that the national effect is likely to remain in place for some time.

Proximity effects appear to be at work at the metropolitan level as well. This finding is consistent with the arguments made in Acs (2002), Braczyk, Cooke, and Heidenreich (1998), Cooke and Morgan (1998), and Fischer et al. (2001), that is, that systems of innovation exist not only at the national level but also at the metropolitan level. Most importantly, it shows that this effect has been increasing in recent years, to the point where metropolitan level interactions represent a non-negligible share of patent citations, at least in the USA. It may reflect big-firm outsourcing of innovation, the intensification of science-to-firm relationships, or a more decentralized form of firm-firm innovative networks, but more research is necessary to answer such questions of causality.

2. Knowledge spillovers are weak at the state level

The state level findings are more puzzling. Our findings are consistent with prior research on the existence of knowledge spillovers at the state level, but we cannot

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[6] Cantwell and Iammarino (2001) show that MNEs interact with national strengths and weaknesses in this regard, adapting their strategies to such local economies.

say for sure whether the state is actually a significant geographical unit of knowledge spillover or the apparent significance is merely a lagged effect of knowledge spillovers that take place within metropolitan areas within states.

To determine whether there are knowledge spillovers at the state level, the effects of metropolitan knowledge spillovers must therefore be removed. To achieve this, we removed all cases where there is either a citation match or a control match at metropolitan level. This generates a hypothetical dataset where there are no metropolitan level knowledge spillovers and no metropolitan level of coincidental match of inventive activities. With this hypothetical database, we can then calculate the NLCP of each year at the state level.

Figure 3. Net Local Citation Percentage at State Level after Removing Metropolitan Citation Matches

As shown in Figure 3, after removing the lagged metropolitan effects, the localized knowledge spillover at the state level is very close to zero. The NLCPs of all years are greater than zero and they are statistically significant, but the size of NLCPs are very small (See Table. 1). Furthermore, some portion of the NLCP in the hypothetical data is actually knowledge spillover from a metro to nearby metros, which is correlated with distance regardless whether or not two metros belong to same state. Therefore, there is very likely insignificant citation activity at the state level although we cannot estimate this with certainty. It implies in addition that if data are available at the metropolitan scale, then there is little to be gained by further analysis at state level.

3. Dependence on Geographically Proximate Knowledge Spillovers increases for most assignee categories

Figure 4 shows changes for each assignee category. A prominent feature of Figure 3 is that the NLCP increases for most of inventor categories. However, due to yearly fluctuations, it is difficult to ascertain whether such increases are statistically significant. To smooth random fluctuations, we calculated weighted averages of the NLCP of the first five years and the last five years; we then conducted t-tests with these two ratios in each assignee category at three geographical levels.

Figure 4. Net Local Citation Percentage by Assignee Types at Three Geographic Levels.

Fourteen out of the eighteen series of NLCP display statistically significant increases at 99% confidence level (See Table 1). Among the other four, which do not show statistically significant increase, three are at state level and one at MSA level. At the state level, the NLCP series of 'Unassigned' and 'Federal Government' decrease and those for individual inventors do not show statistically significant change. At the metropolitan level, the NLCP of Federal Government are unchanged by this procedure.

Table 2. t-test Results of Changes in Ratio of Net Local Citations by Assignee Type

None of these four outliers detract from our general finding of increasing NLCP. This can be seen by discussing each in turn. First of all, the relative stability of Individual (no change) Unassigned (small decrease) is likely attributable to the very high level of

in-state knowledge spillovers in 1975. The NLCP of Individual and Unassigned are consistently higher than any of the other categories; therefore, these categories are closer to the 'saturation' point of in-state knowledge spillovers. This interpretation is supported by the behavior of NLCP series of Individual and Unassigned at country and MSA levels. The changes of Individual at both level (2.9% at country level and 2.0% at MSA level) are lower than those of Total (4.4% at country level and 2.5% at MSA level). In addition, the changes of Unassigned at both level (3.4% at country level and 1.7% at MSA level) are lower than those of Total. Indeed, three out of the four outliers are at state level which – as was argued earlier – is the least relevant scale for potential spillovers.

The important case of no-increase in spillovers at a more relevant geographical scale is that of the Federal Government at the metropolitan level. However, this case reflects the specificities of the Federal Government as an inventor rather than any general phenomenon. The federal government's research activities are less subject to market forces than other economic actors, and less so even than universities (who must compete for their research funding). Federal government research also might depend less on locally-created knowledge because it allocates its resources through national political processes and bureaucracies, and to some extent it is insulated from time and price pressures present for other assignee types. Military R&D, which comprises an important part of the federal government's research, has also at times been deliberately isolated, as in the location of certain national laboratories such as Los Alamos.

In sum, saturation theory, the less important role of states as a geographical unit and the specificities of federal government research policies lead us to conclusion that none of the four outliers represents a significant exception to the general finding that

geographically-proximate knowledge spillovers appear to be increasing. However, the outliers do open up interesting questions for further research.

4. Inventors of Different Assignee Types Depend on Localized Knowledge Spillover to Different Degrees

Our findings lend partial support to Hypothesis 2. As seen in Figure 3, the NLCP of different assignee types are considerably different and the difference between assignee types is persistent over three geographical levels. At all three geographical levels, inventors in the categories of 'unassigned' and 'individual' have greater than average dependency on locally created knowledge. On the other hand, top 500 firms and other firms are below average in this regard, as expected. While large firms may be able to overcome distance in communication by investing in building contact networks, an independent inventor or small entity is likely to be more confined to nearby sources. The difference between Top 500 firms and other firms is unclear, however. Figure 3 shows that the difference between these two categories is not systematic at any of three geographical levels. In some years, Top 500 firms are more dependent on locally created knowledge while for other years, they are less dependent.

Some Implications for Research and Policy

One of the most important and earliest empirical claims that multinational enterprises appeared to be deeply linked, for their most innovative (patented) activities, to their home territories was made by Pavitt and Patel in their widely-cited 1991 article.

Since then, there has been considerable empirical confirmation of the effect of geographical proximity in innovation, through the research of Jaffe, Trajtenberg, and Henderson (1993), Feldman (1994), Anselin, Varga, and Acs (1997), Audretsch (1998) Baptista (2000, 2001) and most recently Maurseth and Verspagen (2002). Until now, however, there has been no indication of the time trend of this phenomenon, i.e. whether it has increased with the appearance of new forms of organization of the innovation process and with the complex effects of ICTs on the contemporary economy. Hence, it has been difficult to weigh the importance of findings that geographical proximity exists. Our research adds this critical missing element, finding that inventors cite local patents *increasingly over time*. This is confirmed for all assignee categories except the federal government: Top 500 Most Inventive Businesses; Other Businesses; Universities; Individuals; Unassigned. In other words, in spite of the increasing global flow of ideas, proximity appears to have become even more important than it was in 1975, and a threshold was crossed in the late 1980s or early 1990s toward greater geographically-localized citation activity.

There are some differences between assignee categories. Unassigned and Individuals were more dependent on locally created knowledge than businesses but the "Pavitt-Patel" effect is still present for businesses and it is increasing over time along with the other assignee categories. Our finding thus calls for nuancing the claim that these very large businesses are somehow able to internalize complex knowledge flows and extend them over large distances, and even to do away with the effect of locality in their innovative processes.

A number of authors have advanced the notion that localized interaction in

innovation could generate geographically-differentiated technological trajectories, implying that there are strong geographical barriers to, and lags in, the technological diffusion process, and evolutionary feedbacks within geographically-bounded environments. This idea, of course, goes against the grain of long-term technological convergence through imitation and adoption, or at least suggests that the world, at any given moment, is in an out-of-equilibrium state when it comes to technology (Rigby and Essletzbichler 1997). Our analysis cannot confirm or reject such wider notions, but it does suggest that more research is merited on the relationship between the geographically-uneven and partially-bounded creation of technology and the geography of technology diffusion are key defining aspects of technological evolution as a whole, dynamics that are much more complex than most models tend to suggest.

Nothing in this analysis is intended to deny that communication and transportation technologies are making long distance interactions easier than ever. Rather, we believe the "the demise of distance" argument and our emphasis on the importance of proximity are complementary in understanding the contemporary geography of innovation. This is because each argument deals with a different dimension of the innovation process.

On one hand, there is no question that today's scientists and engineers can communicate at long-distance more easily (Johnson, Siripong, and Brown 2002). Located in different parts of the world, Route 128 in Massachusetts, Silicon Valley in California, Shinju Science Park in Taiwan, Bangalore Software Park in India and other high-tech centers of the world are all well-connected with one another. Compared to fifty years ago, when the high tech centers were close to each other, principally in the

Northeast and Midwest of the U.S, the distance between high-tech centers are surprisingly long. In this sense, there is an ongoing "death of distance" in that the centers of knowledge creation are farther and farther away from one another.

On the other hand, the findings here lend additional support to the notion that there are constraints to long-distance interaction and consequent advantages to proximity, in the creation of certain types of patentable knowledge, and that these may be increasing over time. There is now a considerable literature on this issue, focusing on various hypotheses about the precise nature of such constraints, including our own earlier contributions to that debate (Storper and Venables 2004 Forthcoming; Storper 1997).

In any case, it may be that certain innovation processes involve both globalization and localization. High-tech centers located at great distance are well connected but they might be specialized in different technologies, with knowledge spillovers inside the centers becoming increasingly important. However, in order to answer this question with any assurance, further research will need to disaggregate the dynamics described here, and especially to do so on a *filière* or technology "field" level.

This paper's findings also imply that if proximity plays an increasingly important role in the innovation process, then there is room for additional reflection about whether public policy should take this explicitly into account. Most technology policies are meant, by design, to be indifferent to location, precisely because they want to stimulate knowledge diffusion, competition, and avoid generating rents, although certain aspects of US federal policy toward knowledge creation (especially in agriculture) have a history of funding localized knowledge creation and then encouraging its non-localized diffusion (Storper 1995a, 1995b). Along these lines, there appears to be some reason to

think that bcal governments who attempt to attract inward investment should privilege those activities that can create synergy with existing industries, regardless of whether the resulting rents would be captured locally or not. In any event, the evidence presented here, that the importance of localized technological interactions are increasing and not decreasing, and that this is true of even the very biggest firms, should now be taken into account in assessing the virtues of different types of policy approach.

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Table 1. t-test Results of Net Local Citations at State Level after Removing Lagged Metropolitan Effects, by Assignee Type and Year

Year	# of Citations	Total Citation Match (A)	Control Match (B)	NLCP (A-B)	t score * of NLCP
1975	113,649	6.05%	3.68%	2.37%	26.28
1976	109,854	5.13%	3.21%	1.93%	22.60
1977	109,496	4.33%	2.70%	1.63%	20.76
1978	115,335	3.74%	2.36%	1.37%	19.14
1979	116,720	3.22%	2.11%	1.11%	16.58
1980	119,547	2.63%	1.85%	0.78%	12.94
1981	117,473	2.49%	1.81%	0.68%	11.36
1982	119,528	2.33%	1.72%	0.61%	10.65
1983	115,323	2.26%	1.74%	0.52%	8.89
1984	124,344	2.32%	1.70%	0.62%	11.06
1985	132,506	2.15%	1.63%	0.52%	9.81
1986	145,602	2.30%	1.58%	0.72%	14.16
1987	163,398	2.26%	1.60%	0.66%	13.62
1988	186,386	2.35%	1.63%	0.71%	15.62
1989	204,722	2.33%	1.58%	0.75%	17.29
1990	224,347	2.46%	1.57%	0.90%	21.34
1991	243,642	2.60%	1.67%	0.93%	22.56
1992	278,990	2.73%	1.82%	0.91%	22.74
1993	317,722	2.76%	1.82%	0.94%	24.97
1994	378,444	2.79%	1.85%	0.93%	26.93
1995	483,666	2.93%	1.91%	1.02%	32.56
1996	462,121	2.87%	1.95%	0.91%	28.66
1997	374,226	3.02%	1.96%	1.06%	29.34

* t-scores all significant at 99% confidence level. (Critical point: 2.58)

Table 2. t-test Results of Changes in Ratio of Net Local Citations by Assignee Type

Geographical Unit	Assignee Type	1975-1979 Ratio	1975-1979 # of Citations (A)	1993-1997 Ratio	1993-1997 # of Citations (B)	Change (A-B)	t-statistics of (A-B)
Country	Unassigned	10.2%	120,635	13.6%	333,192	3.4%	30.53*
	Individual	10.9%	7,763	13.8%	20,932	2.9%	6.41*
	Fed. Gov	7.0%	13,815	12.2%	16,775	5.2%	15.13*
	University	6.7%	4,163	13.9%	47,516	7.2%	13.08*
	Top 500 Firms	5.9%	396,243	10.7%	866,701	4.8%	86.09*
	Other Firms	5.3%	92,518	10.5%	1,161,686	5.2%	50.22*
	Total	6.7%	635,137	11.1%	2,446,802	4.4%	102.11*
State	Unassigned	7.1%	116,238	6.7%	322,379	-0.3%	3.77*
	Individual	8.0%	7,316	7.6%	20,020	-0.4%	1.06
	Fed. Gov	3.7%	13,549	2.5%	16,473	-1.3%	6.39*
	University	2.1%	4,124	4.4%	47,200	2.3%	7.11*
	Top 500 Firms	2.2%	368,743	4.8%	772,331	2.5%	64.70*
	Other Firms	2.1%	88,458	4.6%	1,051,804	2.4%	33.84*
	Total	3.3%	598,428	5.0%	2,230,207	1.7%	55.22*
MSA	Unassigned	3.8%	113,663	5.5%	313,805	1.7%	22.49*
	Individual	3.9%	7,109	5.9%	19,415	2.0%	6.38*
	Fed. Gov	1.8%	13,255	1.8%	16,183	-0.1%	0.35
	University	1.2%	4,064	3.4%	46,573	2.2%	7.61*
	Top 500 Firms	1.0%	364,049	4.0%	762,827	3.0%	88.08*
	Other Firms	1.1%	86,990	3.8%	1,037,581	2.7%	41.49*
	Total	1.6%	589,130	4.1%	2,196,384	2.5%	92.20*

* t-statistics valid at 99% significance level (Critical point: 2.58).

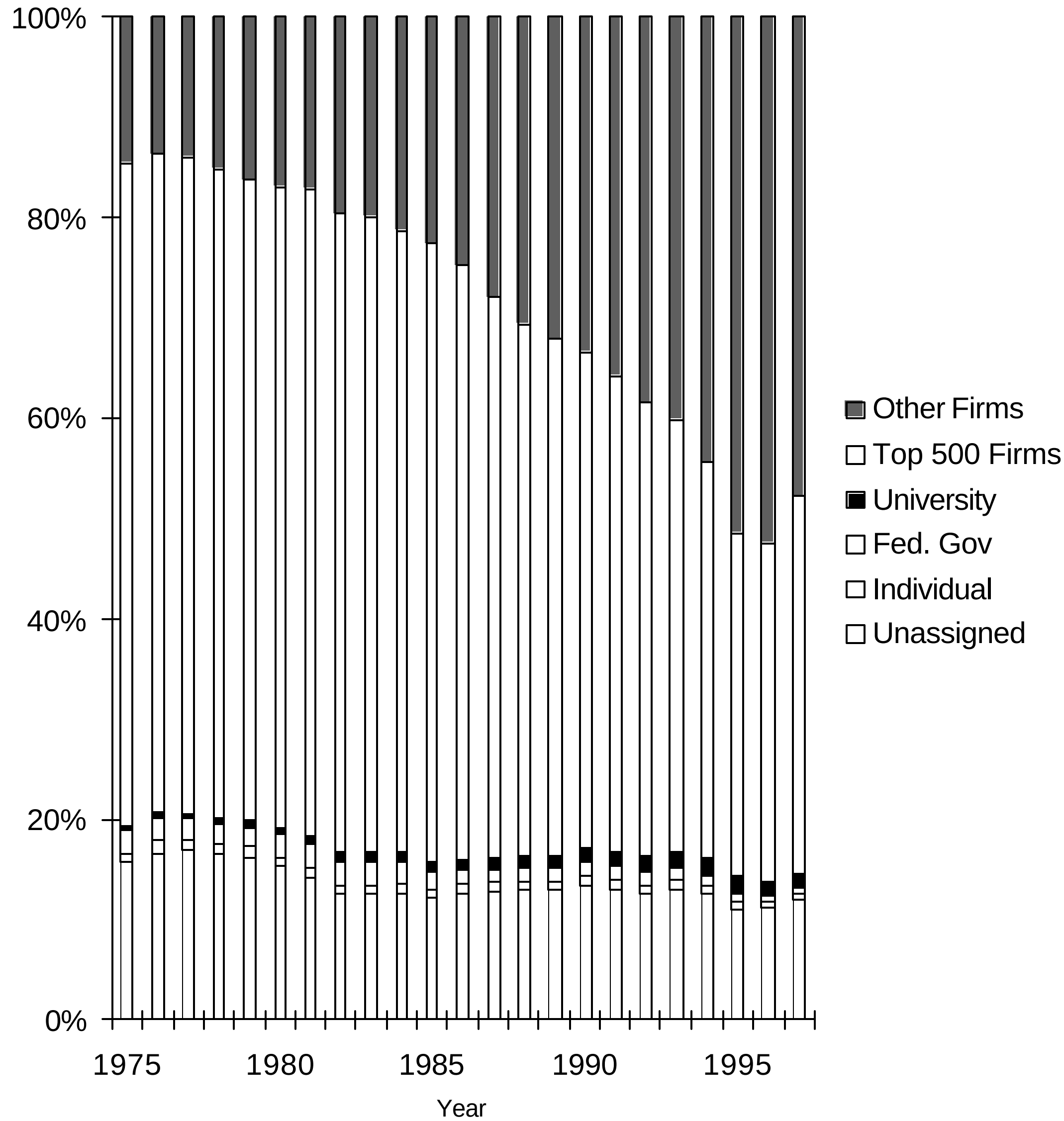


Figure 1. Number of Citations by Assignee Category of Citing Patents

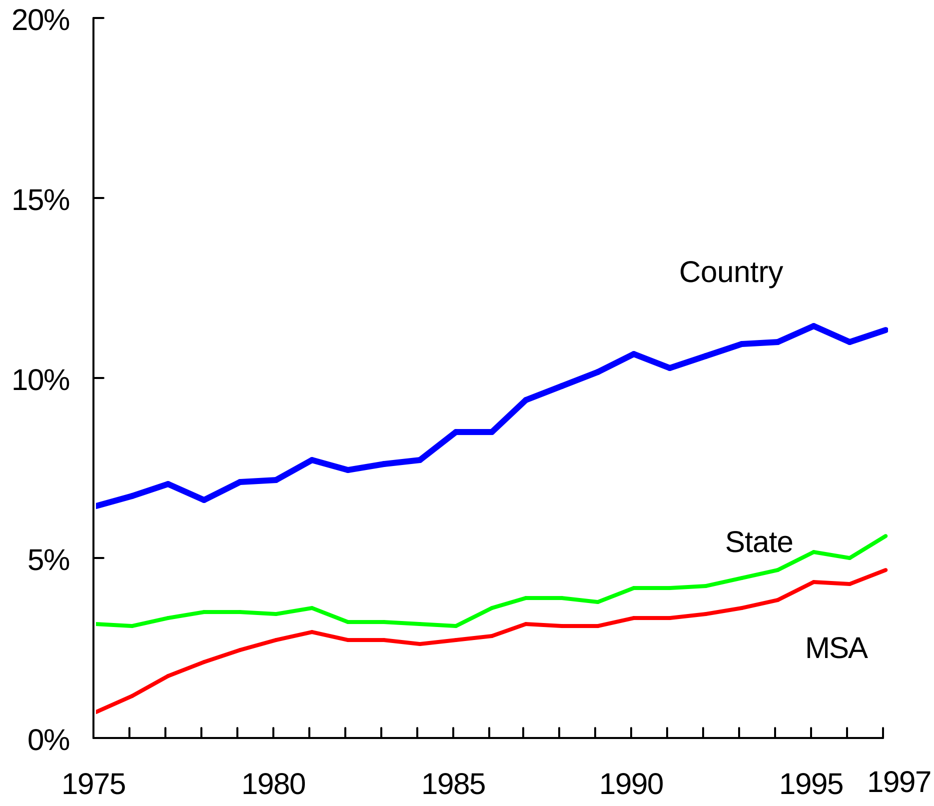


Figure 2. Net Local Citation Percentage (Distribution of Citation Matches after Controlling for Existing Distribution of Inventive Activities) at Three Geographic Levels.

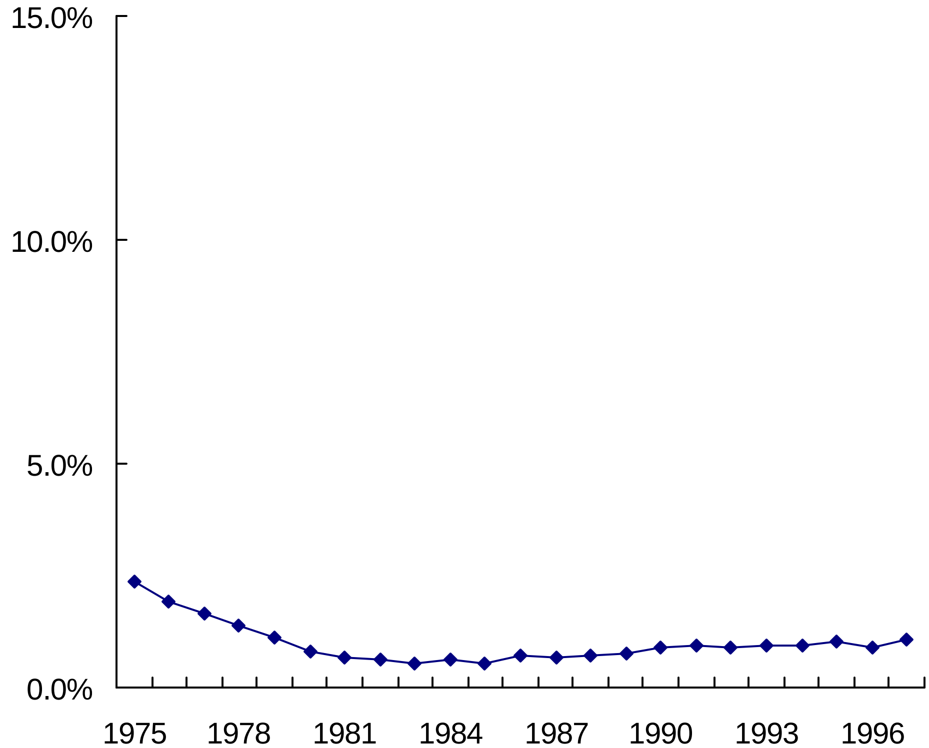
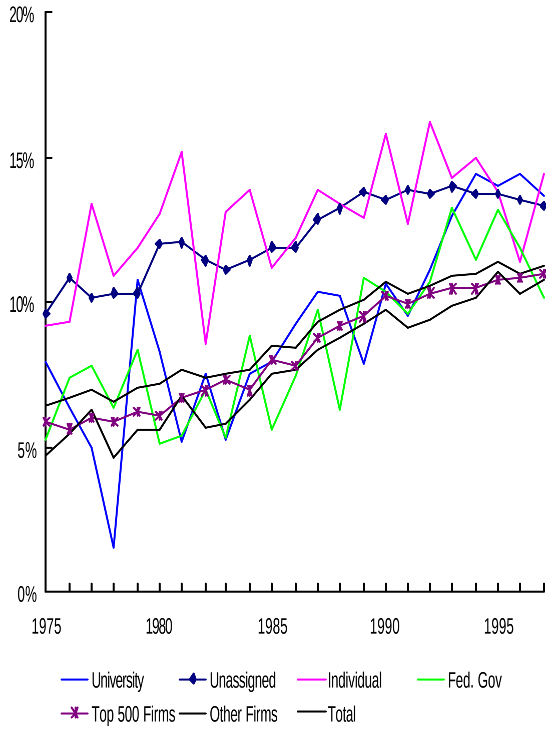
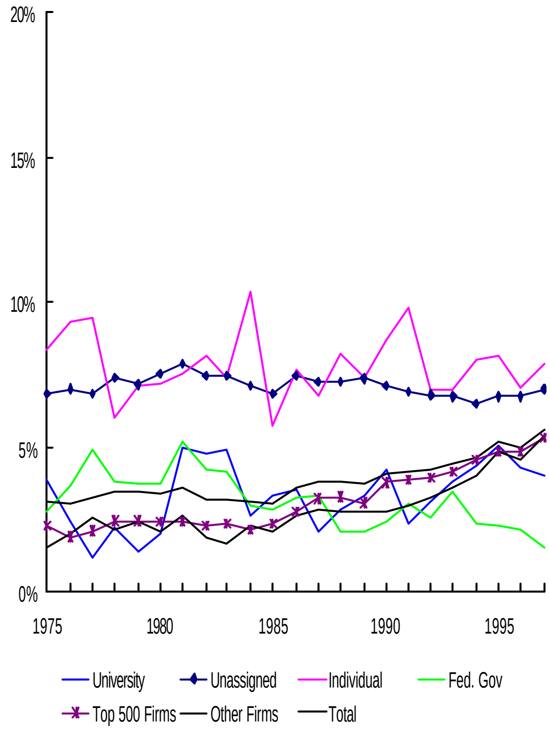


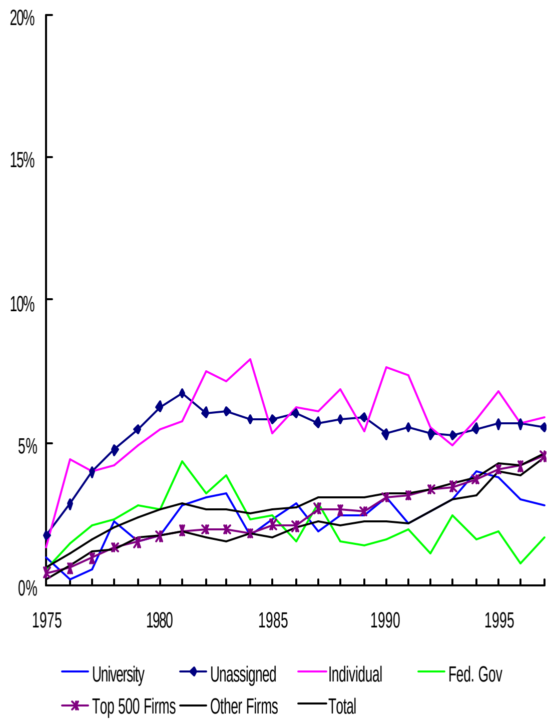
Figure 2. Net Local Citation Percentage at State Level after Removing Metropolitan Effects.



a. Country



b. U.S. State



c. MSA

Figure 3. Net Local Citation Percentage by Assignee Types at Three Geographic Levels.

Appendix 1. Top 50 Inventive Universities 1974-1997.

Rank	Name of University	Patent Assigned
1	UNIV. OF CALIFORNIA, THE REGENTS OF	2768
2	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	2151
3	UNIV. OF TEXAS	1007
4	STANFORD UNIV.	961
5	CALIFORNIA INSTITUTE OF TECHNOLOGY	852
6	IOWA STATE UNIV. RESEARCH FOUNDATION INC.	667
7	JOHNS HOPKINS UNIV.	590
8	UNIV. OF MINNESOTA, THE REGENTS OF	556
9	UNIV. OF PENNSYLVANIA	439
10	UNIV. OF MICHIGAN	406
11	UNIV. OF FLORIDA BOARD OF REGENTS	385
12	RESEARCH FOUNDATION OF STATE UNIV. OF N.Y.	374
13	COLUMBIA UNIV.	328
14	HARVARD COLLEGE, PRESIDENT AND FELLOWS	327
15	MICHIGAN STATE UNIV.	320
16	OHIO STATE UNIV.	276
17	WASHINGTON UNIV.	273
18	NORTH CAROLINA STATE UNIV.	273
19	UNIV. OF WASHINGTON	257
20	DUKE UNIV. INC.	254
21	NORTHWESTERN UNIV.	234
22	ROCKEFELLER UNIV.	234
23	UNIV. OF PITTSBURGH	232
24	UNIV. OF BRITISH COLUMBIA	229
25	UNIV. OF UTAH	223
26	UNIV. OF NORTH CAROLINA	221
27	NEW YORK UNIV.	219
28	UNIV. OF SOUTHERN CALIFORNIA	217
29	TEXAS A&M UNIV. SYSTEM	211
30	UNIVERISTY OF IOWA RESEARCH FOUNDATION	205
31	YALE UNIV.	200
32	BOSTON UNIV.	200
33	UNIV. OF ILLINOIS	195
34	UNIV. OF NEBRASKA, THE BOARD OF REGENTS OF	191
35	THOMAS JEFFERSON UNIV.	189
36	RUTGERS UNIV.	189
37	UNIV. OF KENTUCKY RESEARCH FOUNDATION	187
38	UNIV. OF UTAH RESEARCH FOUNDATION	186
39	YISSUM R&D CO. OF HEBREW UNIV. OF JERUSALEM	181
40	UNIV. OF ROCHESTER	179
41	UNIV. OF MARYLAND	175

42	UNIV. OF DELAWARE	174
43	CURATORS OF THE UNIV. OF MISSOURI	166
44	UNIV. OF AKRON	160
45	BAYLOR COLLEGE OF MEDICINE	157
46	PRINCETON UNIV.	151
47	UNIV. OF TENNESSEE RESEARCH CORPORATION	151
48	UNIV. OF CHICAGO	144
49	EMORY UNIV.	143
50	KANSAS STATE UNIV. RESEARCH FOUNDATION	143

Data: Authors' estimation based on *NBER Patent Citation Data*

Appendix 2. Top 500 Inventive Firms 1974-1997 (Part).

Rank	Company Name	Patent Assigned
1	INTERNATIONAL BUSINESS MACHINES CO.	26340
2	GENERAL ELECTRIC COMPANY	25868
3	HITACHI, LTD	19055
4	CANON KABUSHIKI KAISHA	18771
5	TOSHIBA co.	16881
6	EASTMAN KODAK COMPANY	16032
7	AT&T CORP.	14836
8	U.S. PHILIPS co.	14573
9	E. I. DU PONT DE NEMOURS AND COMPANY	13735
10	MOTOROLA, INC.	13681
11	MITSUBISHI DENKI KABUSHIKI KAISHA	13407
12	SIEMENS AKTIENGESELLSCHAFT	13324
13	NEC co.	12461
14	BAYER AKTIENGESELLSCHAFT	12188
15	WESTINGHOUSE ELECTRIC CORP.	11970
16	MATSUSHITA ELECTRIC INDUSTRIAL CO.	11776
17	GENERAL MOTORS co.	11659
18	XEROX co.	11638
19	FUJI PHOTO FILM CO., LTD	11401
20	SONY co.	10774
21	DOW CHEMICAL COMPANY	10045
22	FUJITSU LIMITED	9054
23	TEXAS INSTRUMENTS, INCORPORATED	8910
24	MINNESOTA MINING & MANUFACTURING	8860
25	CIBA-GEIGY co.	8535
26	BASF AKTIENGESELLSCHAFT	8339
27	RCA co.	7887
28	HOECHST AKTIENGESELLSCHAFT	7826
29	PHILLIPS PETROLEUM COMPANY	7346
30	ROBERT BOSCH GMBH	7197
31	MOBIL OIL CORP.	6972
32	HEWLETT-PACKARD COMPANY	6322
33	UNISYS co.	6273
34	SHELL OIL COMPANY	6210
35	NISSAN MOTOR COMPANY, LIMITED	6177
36	SHARP co.	5984
37	ALLIED-SIGNAL INC.	5911
38	EXXON RESEARCH + ENGINEERING CO.	5703
39	FORD MOTOR COMPANY	5688
40	RICOH COMPANY, LTD.	5678
41	SAMSUNG ELECTRONICS CO., LTD.	5597

42	HONDA MOTOR CO., LTD.	5583
43	TOYOTA JIDOSHA K.K.	5520
44	MONSANTO COMPANY, INC.	5449
45	UNITED TECHNOLOGIES co.	5386
46	IMPERIAL CHEMICAL INDUSTRIES PLC	5170
47	HUGHES AIRCRAFT COMPANY	5150
48	AMERICAN CYANAMID COMPANY	4939
49	PROCTER + GAMBLE COMPANY	4927
50	ROCKWELL INTERNATIONAL CO.	4819
498	CONTAINER CO. OF AMERICA	468
499	DAI NIPPON PRINTING CO. LTD	468
500	MONTECATINI EDISON S.P.A.	467

Data: Authors' estimation based on *NBER Patent Citation Data*