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Regional Economic Effects of University Research: A Survey

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by

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ABSTRACT

Previous research is classified into four broad categories in this paper: the study of a university's impact on the location choice of high technology facilities, the investigation of university impact on the spatial distribution of high technology production, the analysis of the spatial pattern of industrial research and development activities, and the modeling of local knowledge transfers emanating from academic institutions.

It is found that the university effect on the location choice of high technology facilities depends on certain area characteristics. There is a strong evidence in the literature of local academic technology transfers. Regarding the effect of university technology transfer on local economic development, the evidence is still vague.

REGIONAL ECONOMIC EFFECTS OF UNIVERSITY RESEARCH: A SURVEY

I. Introduction

In 1938, Stanford University professor Fred Terman encouraged his student, Bill Hewlett, to start a company based on an idea in Hewlett's master's thesis project. As a consequence, Hewlett-Packard (H-P), now a Fortune 500 company, has become probably the first university spin-off firm in history. By demonstrating the advantages of being close to a university, H-P was the nucleus for Silicon Valley [Rogers and Larsen (1984)]. Route 128, the other major US high technology concentration in the Boston area, has been supported largely by an active local economic involvement of the Massachusetts Institute of Technology (MIT). By the 1960s, 175 firms were identified as being founded by MIT personnel [Dorfman (1983), Wicksteed (1985)]. Between 1988 and 1993, forty biotechnology companies were spun-off from MIT research laboratories [Parker and Zilberman (1993)]. Cambridge University in the United Kingdom has indirectly been the origin of virtually all the 355 high technology companies in the Cambridge area [Wicksteed (1985)].

Silicon Valley, Route 128, and the Cambridge Phenomenon are not brought up together only by chance in this introduction. These high technology centers illustrate a relatively new fact: the existence of knowledge based local economic development. They follow exactly the formula suggested by the theory of endogenous economic growth[1]: economic development is determined by technological change, and technological change is mainly a result of consciously planned, market motivated industrial research and development (R&D). More than that, there is an other important similarity among these high technology agglomerations: their endogenous economic growth has been in part due to excellent

[1] For more about the theory of endogenous economic growth, see, for example, Romer (1986, 1990, 1994), Lucas (1986), Benhabib and Jovanovic (1991), Grossman and Helpman (1994).

local universities that fostered economic development directly by transferring new technologies into industrial innovations. In addition, as being potential sources of future knowledge transfers and producers of human capital, they indirectly furthered local economic growth by attracting innovative new companies to the area.

The major question is whether university-generated local economic growth observed for certain areas can also be achieved by other regions. In other words, is local economic development nurtured by academic institutions a rule or an exception? If strong evidence is found that local university effects are substantial components of high technology activities, this knowledge will change the prevailing vision regarding the social role of universities dramatically. In addition to considering research and education at universities as having substantial long run and global impacts on societies, the new concept will emphasize the relatively short run and local economic functions of academic institutions as well. The whole issue of university financing will get a different perspective: local governments should consider their universities as potential factors in economic development and weight their investments in higher education institutions against possible future economic gains for the region. On the other hand, universities should be involved actively in regional economic issues, not only as academic institutions, but also as potential members of the local business community.

Starting in the early 1980s, this problem has yielded a wide array of studies in the fields of economics, regional science, and economic geography. Previous research is classified into four broad categories in this paper: the study of a university's impact on the location choice of high technology facilities, the investigation of university impact on the spatial distribution of high technology production, the analysis of the spatial pattern of industrial research and development activities, and the modeling of local knowledge transfers emanating from academic institutions.

The various case studies, surveys, and descriptions of existing high technology centers provide ambiguous evidence on the location impact. I suggest the hypothesis that the existence and intensity of the university effects depend on certain local area characteristics. In econometric studies, university impact on production is vague as long as the data mix non-routine functions (e.g., research and development, prototype manufacturing) with mass production. When non-routine activities are separated, strong location effects are detected. In terms of knowledge transfers, the knowledge production function approach captures the widest range of interactions. A strong university impact has been found both at the level of US states and MSAs.

In the second section, the concept of regional university knowledge effects is introduced. The findings of studies that concentrate on university impact on the location choice of high technology firms are reviewed in the third section. The fourth section reviews the analyses focusing on university impacts on the spatial distribution of high technology production. Research findings related to the university impacts on R&D location and technology transfers from local academic institutions are introduced in the fifth and sixth sections. A summary concludes the paper.

II. University knowledge effects on the regional economy

Expenditure impacts of universities and knowledge effects of academic institutions are considered the two broad categories of local economic impacts of universities in Florax (1992). Although the mechanisms of university expenditure impacts (i.e., the effects of faculty, staff and student expenditures on local employment and production) do not differ essentially from the similar effects of any large expenditure generating local institutions such as military bases or office complexes, the term “university knowledge effect” pertains to the specific way academic institutions can influence local economic conditions.

Knowledge effects are facilitated via *local university technology transfers*. Technology transfer constitutes a possible direct effect of the university on the regional economy. That is, technologically useful ideas originated in university laboratories are transferred into new products or novel production technologies. There is an indirect effect of technology transfer on local economic development: firms may locate in the region to take advantage of new, economically useful ideas generated at universities.

Technology transfer is any process by which basic understanding, information, and innovations move from a university to firms in the private sector [Parker and Zilberman (1993)]. Technology may be transferred from the universities through different channels. Various channels of technology transfer are formal cooperation in R&D between academia and industry, university seminars, scholarly journal publications, faculty consulting, industrial associates programs, industrial parks, high technology firm spin-offs, technology licensing, the local labor market of scientists and engineers, and local professional associations of scientists.

Cooperation in research and development between industry and academia is a formal way to channel university expertise into industrial practice. Various solutions have been developed to tie university research to industrial needs. The most common forms are probably the following: industry sponsored contract research, long term university-industry research agreements, and industry financed university research centers [e.g., Audretsch and Stephan (1996), Brodsky, Kaufman, and Tooker (1980), Johnson (1984), National Science Board (1982), Peters and Fusfeld (1983), Wilson (1979)].

Faculty *consulting* in industry is described as the most pervasive academic - industrial connection [National Science Board (1982) p. 11]. This relationship is much more flexible than contracted research. [Brodsky et al. (1980) p. 65]. Scholarly journal *publications* are other possibilities for industrial researchers to be informed about the latest scientific achievements of their fields.

The first *industrial associates programs* were initiated by MIT and Stanford to intensify technology transfer to industry. Activities arranged exclusively for member companies include symposia, seminars, visits to the campus, and reports on current university research. Regular contacts with faculty members may facilitate technology transfer [Bruce and Tamaribuchi (1980) Peters and Fusfeld (1983)]. However, according to Peters and Fusfeld [(1983) p. 45], in most of the cases simple access to graduates is the prime reason why companies join the programs.

Cooperation in research and development, faculty consulting, scholarly journal publications, and industrial associates programs channel technological knowledge regardless of distance. However, the different means of technology transfer introduced in the rest of this section need spatial proximity.

The importance of a qualified work force distinguishes high technology production from other production processes [Malecki (1985)]. Access to graduate students, trained graduates, and supply of high level scientists and engineers represent major university - industry linkages [Cromie (1983) pp. 245-49, Johnson (1984) pp.71-76, National Governors Association (1983), National Science Board (1982) pp.29-30, Peters and Fusfeld, (1983) p. 93]. As a consequence, local *labor markets* of scientists and engineers promote technology transfer. Faculty scientists and engineers are more likely to move to nearby firms when changing jobs [Bania et al. (1992), Almeida and Kogut (1995)], and trained graduates may look for their first jobs in the area of the university [Malecki (1986), Jaffe (1989), Kelly et. al (1992)].

Besides local labor markets, several alternative forms of knowledge transfer exist. Technological knowledge can be disseminated from universities in *seminars* attended by scientists from industry. Other forms of knowledge transfers are *industrial incubators and industrial parks* designed to provide physical facilities to start-up companies. More than that, spatial proximity to the university makes it easy to access faculty consultants, and *university facilities* such as libraries and computer services [Johnson (1984)]. *University spin offs* are other important forms of technology transfer. Spin off firms are established to commercialize useful ideas developed by research at the university. These firms generated much of the economic growth in some high technology centers [e.g., Dorfman (1983), Saxenian (1985, 1994), Wicksteed (1985), Osborne (1990), Kelly et al. (1992), Parker and Zilberman (1993)]. *Licensing* technologies originated in university research laboratories can have significant impact on local development. Moreover, royalty incomes generated by these licenses may form a considerable portion of the university budget [Parker and Zilberman (1993), AUTM (1995)].

Knowledge transfer can be facilitated in a less formal manner via *local professional associations* [Bania et al. (1992)]. Even a more informal practice to change information is getting together in a local pub or restaurant [Saxenian (1994), Almeida and Kogut (1995)]. Although scientists do not tend to share their successful results, the unsuccessful ones are often enough to generate further research ideas [Saxenian (1994)].

III. University effect on the location choice of high technology companies

A closely situated university as a potential source of future knowledge can be a factor explaining high technology firms' location decisions. Several case studies, surveys, and descriptive works on existing high technology complexes have been conducted in the literature in order to weight the importance of university proximity among the other reasons of the location choice.

Location factors pertaining to the high technology industry are introduced in section III/A. A consensus seems to be reached among authors regarding all the location factors except for university presence. The different findings in case studies, surveys, and descriptive works of existing high technology centers are reviewed in section III/B.

III/A. Factors affecting high technology location

An overall agreement has been reached among authors regarding the main high technology business location factors. Availability of *qualified labor* is generally listed as the most important determinant [e.g., Browning (1980), Stafford (1980), Oakey (1981), Premus (1982), Malecki (1985, 1986), Rees and Stafford (1986), Galbraith and De Noble (1988)]. A related factor is *quality of life.* Pleasant working and living environment or cultural amenities attract professional workers [e.g., Premus (1982), Malecki (1985, 1986), Rees and Stafford (1986)]. *Technological infrastructure* is listed as the next location determining factor. Proximity to similar and related firms, availability of venture capital, and presence of business services define technological infrastructure. Proximity to similar firms gives easy access to labor [e.g., Kieruff (1979)]. Also, closely located related firms can provide a pool of technical knowledge and potential suppliers and buyers [e.g., Markusen (1983), Feldman (1994/A), Feldman and Florida (1994)]. Readily available venture capital serves the financial needs of new start-ups [e.g., Rees and Stafford (1986), Malecki (1985, 1986)]. Business services (e.g., testing laboratories, market-research firms, patent attorneys) provide important production and marketing information to high technology firms [Coffey and Polese (1987), Feldman (1994/A), Feldman and Florida (1994)]. Because high speed transportation can be crucial in high technology production, *communication linkages* such as access to highways and airports influence location choice [e.g., Browning (1980), Premus (1982), Malecki (1985, 1986), Markusen et al. (1986)].

Most of the studies found that proximity to *universities* determines significantly the geographic localization of high technology activities. Presence of a university was reported as a determinant location factor in Birch (1987), Hall (1987), Malecki (1980,1985,1986), and Rees and Stafford (1986), among others. However, there are counter evidences as well. For example, Howells (1986) found no signs for any significant university impact on the location choice of high technology firms in England. The problem of university location effects is addressed in detail in the next section.

III/B. Universities and the choice of high technology location: case studies, surveys, and descriptive works on existing high technology centers

This section reviews the literature on university impact on a high technology firm's location choice. The literature consists of three methodologically different classes of studies: surveys, descriptive analyses of existing high technology centers, and case studies.

Because of their in-depth nature, *case studies* are good sources of detailed information about a particular location decision [Glasmeier (1988), p. 291]. Detail is, however, not always an advantage, particularly not when generalized findings are more desirable. In this respect, good *surveys* are more appropriate sources of information. One of the major shortcomings of survey data is that they are collected after the location decision has been made. Because in many cases the person who is interviewed and the person who made the location decision are not the same, surveys reflect more what *would* be important than the real motivations behind the choice [Harding (1989), p.223]. *Descriptive works on existing high technology centers* are rich sources of knowledge about many interesting details of the life in these centers. Although the background information coming from the stories of different university-industry connections is definitely indispensable for any good research in the subject, the time- and space - specific nature of these studies makes generalization hard to accomplish.

Descriptive works of high technology concentrations emphasize the university role in the creation and expansion of these places [Dorfman (1983), Kelly et al. (1992), Osborne (1990), Saxenian (1985), Scott (1988), Wicksteed (1985)]. However, counterexamples exist, such as experience in England where high technology centers emerged without any university assistance [Breheny and

McQuaid (1987)]. Furthermore, growth in some US centers (Colorado Springs, Colorado, and Portland, Oregon) has been spontaneous and achieved without any help from a major research university [Rogers and Larsen (1984), pp. 248-249].

In the survey by Premus (1982), sixty percent of the surveyed US firms considered university presence an important factor in location. In Schmenner (1982), fifty-two percent of the firms reported proximity to a college as a desirable location factor. According to Lund (1986), university proximity is the fifth location determinant out of the 20 factors, and in the study by Malecki and Bradbury (1992), universities are on the seventh place (out of 22) among the location factors.

Most of the studies that concentrate on specific regions of the US report similar results. In the survey by Galbraith (1985), forty percent of the firms in Orange county, California, prefer university proximity, while Galbraith and DeNoble (1988) report that forty-six percent of the establishments in Southern California believe that a nearby university raises the attractiveness of their location. Based on a survey on high technology firms in Washington state, Haug (1991) reports that eighty percent of large firms considered universities a major location factor.

Similar to the findings of descriptive studies of high technology concentrations, findings of surveys suggest that a university effect is not equally important everywhere. Howells (1984) concludes that pharmaceutical research laboratories in England do not consider university as a relevant locational factor. Only 2.6% of the firms indicated proximity to other research establishments (including universities) as the primary reason for location. Nearly three-quarters of the surveyed laboratories believe that presence of a university is not a significant factor in location. In a study by Gripaios et al. (1989), only nine percent of the companies indicated any university effect in the Plymouth region, England. For the Denver - Boulder agglomeration in Colorado, Lyons (1995), without reporting further details of the research results, concludes that closeness to a university is listed among the least important site selection determinants.

Surveys, case studies, and descriptive works on the history and structure of existing high technology centers stress the importance of universities in business location. Although universities are reported as important location determining factors in many areas, university impact differs across regions. Based on the literature, the following paragraphs raise the hypothesis that spatial variations in the university effect are associated with several characteristics, such as individual differences among firms, cultural traditions, industrial characteristics, ownership status of the firm, firm size and city size.

As reported in case studies [Glasmeier (1988), Harding (1989)], *individual differences* among firms regarding their actual reasons for location search (e.g., whether it is determined by cost considerations, need for qualified personnel, or demand for university expertise) determine the importance of a university in site selection. Contrasting characteristics in *cultural traditions* may generate substantial variations among countries. A remarkable difference exists between the US and the British experience. With the exception of Cambridge University [e.g., Wicksteed (1985)] and Oxford University [e.g., Lawton-Smith (1990)], academic institutions do not attract considerable industry activity in England. Because universities in the UK found it simpler to deal with large companies [Howells (1986, p. 473)], academic institutions prefer to make connections with large businesses, regardless of the geographic location of the firms.

Differences in sectoral characteristics may determine the way *industries* can take advantage of close university expertise. Industries showing significant university impact in the studies are electronics [Jaffe (1989), Bania et al. (1993)], microelectronics [Rees (1991), Robinson (1985)], biotechnology [Haug (1991), Acs et al. (1994/B)], and aerospace [Acs et al. (1994/B)]. For chemical and instruments, evidence is ambiguous. Although Galbraith and De Noble (1988) and Haug (1991) found significant university effect in the chemicals industry, the results of Acs et al. (1994/B) do not reinforce it. Strong university effect was given in Acs et al. (1994/B) in the instruments industry, but not in the papers by Jaffe (1989) and Bania et al. (1993).

Ownership status of the firm may provide an additional factor to explain regional variations in a university effect. Malecki (1986) clarifies the missing university effect for some newly emerging high technology areas. Because established high technology firms move only large production plants to new areas and retain their R&D staff in their headquarters places, these new centers are dominated by production plants of large firms. Because mass production does not need university expertise, location of branch plants is affected by traditional factors instead of university presence. This finding is reinforced by Galbraith and De Noble (1988). According to their study, for headquarters the proximity to universities is the sixth site selection criterion out of the possible 32 factors, while branch plants do not list universities among the reported first ten location attributes.

Firm size turns out to be significant in explaining the existence of a university effect. Firms with more than one hundred employees [Rees (1991)] or with sales exceeding ten million dollars [Galbraith and De Noble (1988)] are more probable to choose business sites near a university. Lund (1986) shows that R&D laboratories employing less than five hundred workers tend to be more sensitive to the proximity of universities or other external research centers than their larger counterparts. *City size* also may be associated with the intensity of a university effect. According to Malecki and Bradbury (1992), firms located in large cities find a close university a more important factor than small city respondents.

Note that a missing university effect in location choice does not necessarily preclude the emergence of this effect after companies have settled down in the area. Studies concentrating exclusively on the determinants of the location choice fail to give attention to this phenomenon. University-industry links can emerge after the high technology industry has already established itself in the region, but these links may not be necessary factors of the location choice [Scott (1988), Goldstein and Malizia (1985), Lyons (1995)].

IV. Universities and the spatial distribution of high technology production: econometric studies

Besides the indirect effect of technology transfer on the location choice of high technology facilities, its direct impact on local production has gained substantial research interest in the literature. In this category of studies, research is concentrated on the factors influencing the spatial distribution of high technology production. Among the effects of several other location determining characteristics of a geographical area, attention has been paid to the role of universities in this respect. Research designs of these studies are summarized in tables 1 and 2.

Several signs indicate the presence of high technology production in a geographic area. Number of high technology plants, investment of firms, number of new startups, and employment in high technology companies are used in the surveyed studies to signal the presence of production facilities. Markusen et al. (1986) carried out the first regression based research that considers universities as potential determinants of high technology location. Both Markusen et al. (1986) and Glasmeier (1991) detect production by the number of plants in the area. Manufacturing equipment investments and investments in buildings indicate the presence of firms in Florax (1992) and Florax and Folmer (1992), while percentage of new startups measures high technology activities in Bania et al. (1993). In Audretsch and Stephan (1996), common location of an academic institution and a firm is a direct measure of university impact: the fact that a biotechnology firm is located in the same region as the university scientist with whom the firm has a formal connection is considered evidence of the importance of university proximity for the high technology firm in question. High technology employment reflects production in Markusen et al. (1986), Herzog et al. (1988), Glasmeier (1991), Beeson and Montgomery (1993), and Acs et al. (1994/B).

Markusen et al. (1986) searched for the factors that govern high technology location choice. The study was carried out with data on 264 metropolitan statistical areas (MSAs). The following location conditions were considered in the analysis: climate, educational options, freeway density, and business services. University R&D funding is included to test whether the presence of research universities is positively related to high technology location [Markusen et al. (1986), p. 147][2]. University research does not turn out to be an important factor in the distribution of firms among MSAs. Its insignificant coefficient indicates no meaningful connection between plant location and university research activity.

Glasmeier (1991) analyzes the factors determining the spatial distribution of high technology plants among cities and their adjacent rural communities. The study concentrates on the relative importance of city characteristics in plant decisions: factors motivating the choice of adjacent rural communities, and characteristics governing location in the cities. The analysis is based on data for 247 metro areas in the US. Labor market characteristics, access and agglomerative features, a measure of poverty, and quality of life variables were included as possible explanatory factors of location. Universities were regarded as determinants of the quality of life in the area: they provide ongoing training for employees and sponsor cultural events. As such, they may attract the high technology labor force, which was considered a major factor in firms' location. Access to universities was measured by the number of four year colleges in the metro area. According to the study, presence of colleges in the MSA affects firms located in the MSA but not companies situated in adjacent rural communities: in the regression of MSA companies, the university variable enters the equation with a positive and significant parameter, while the parameter of the same variable for firms situated in MSA adjacent rural communities is insignificant.

An alternative way to test for an academic impact on the spatial distribution of production facilities is to analyze university effects on the level of investments. Florax (1992) and Florax and Folmer (1992) assumed that investments of manufacturing firms are affected by the production of research-based knowledge and human capital at universities [Florax (1992), p. 191]. Panel data on forty regions of the Netherlands provided the empirical base of these studies. Two variables are designed to stand for the university effect: one measures contagious distribution of knowledge, while the other stands for hierarchical knowledge distribution. In the contagious case, knowledge distribution is concentrated around the originating source, and it decays with distance. For the hierarchical case, knowledge diffuses at first among central places, and it trickles down to lower order locations at a later stage [Florax (1992), p.184]. Their results do not evidence that university proximity determines investment decisions: neither investments in buildings nor equipment investments were affected by contagiously dispersed knowledge from academic institutions. The only significant university effect in the studies does not necessarily need a closely located academic institution: manufacturing equipment investment is affected by hierarchical knowledge distribution from universities.

Bania et al. (1993) searched for the local characteristics governing the probability of new firm openings. The analysis was based on 25 large metropolitan areas in the US, and it concentrated on two high technology industries: Electrical and Electronic Equipment, and Instruments and Related

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[2]Markusen et al. (1986) represents the first study that controls for the university effect in location. Previous attempts have searched only for the impacts of traditional location factors (such as labor cost, taxes) on high technology location choices. See for example Armington (1986).

Products. Two sets of factors were assumed to determine firm opening rate: traditional economic factors (such as labor cost, degree of unionization), and technical infrastructure measured by total university research, number of research universities, and percent of employed scientists or engineers. The number of research universities was included to test whether the contribution of research to startups diminishes as the number of institutions in an SMSA increases.

The university research contribution was positive and statistically significant for the Electrical and Electronic Equipment industry, although for Instruments, the research impact was insignificant. Because the variable, number of universities entered with insignificant coefficients into the regressions of both high technology groups, no evidence was found for the negative relationship between startups and the number of institutions.

As summarized in Table 2, econometric studies do not provide unequivocal support for the existence of university effects on the local high technology labor market[3]. According to Markusen et al. (1986), university research does not affect the distribution of high technology jobs across all MSAs. This effect seems to be sensitive to sample selection. Acs et al. (1994/B) tested the influence of university R&D on high technology employment, concentrating on 37 MSAs. For this smaller set of places, university research turns out to be a determining factor of labor location. Although university research does not seem to affect high technology labor location across all cities [as it was found in Markusen et al. (1986)], higher education availability (measured by the number of four year colleges) may drive this labor force into the MSAs [Glasmeier (1991)].

Evidence of the effects of university presence on the spatial distribution of high technology production is weak in the above reviewed econometric studies. Neither Markusen et al. (1986) nor

Florax (1992) and Florax and Folmer (1992) found any indicators of local university impacts on the spatial distribution of plants or investments. Although a positive effect was found on Electrical and Electronic Equipment industry new firms in Bania et al. (1993), this result was based on a relatively small set of selected 25 MSAs. In Glasmeier (1991), four year colleges, as part of local amenities, exert a positive effect on the spatial distribution of high technology production among MSAs, but not among MSA adjacent rural communities.

Does this weak evidence regarding the location impact of academic institutions suggest missing university knowledge effects? It is proposed in this paper that this vague academic effect is a consequence of an inappropriate data aggregation. Studies in the literature [e.g., Malecki (1986), Galbraith and De Noble (1988)] emphasize that although non-routine functions of companies such as R&D, prototype manufacturing, or small volume production can draw heavily upon university expertise, routine functions such as mass production do not need university assistance. Variables that intended to represent production facilities in the reviewed studies measure both the presence of routine and non-routine production activities in the area. Number of firms in the MSA, manufacturing investments by local companies, firms opening rate, or high technology employment indicate both the presence of mass production and the local existence of non-routine activities such as prototype manufacturing or small volume production. As a consequence of this “noise” in the data, evidence of local university effects is weak: the possible significant university effect on the spatial distribution of non-routine functions might be canceled out by the insignificant academic impact on the location of routine activities. This hypothesis is supported by the findings of studies where non-routine activities

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[3] Surveys find weak university effect as well. According to Shapiro and Harding (1982) university is only the sixteenth labor location factor out of the 17 possibilities. A more recent study by Malecki and Bradbury (1992) reports that university proximity is in tenth place among the 22 location factors.

are clearly separated from the data. The strong university impact on industrial R&D location is demonstrated in the next section. Evidence regarding small volume production and the spatial distribution of professional employment is presented below.

Biotechnology is a new, knowledge-based industry predominantly composed of small firms. Location of biotechnology companies is primarily explained by the location of the researcher who is actively contributing to the basic science [e.g., Zucker et al. (1994, 1995)]. The extent to which the location of university scientists determines the location of biotechnology firms is analyzed by Audretsch and Stephan (1996). (The research design of this study is summarized in table 1.) They point out that knowledge transfer from universities strongly influences biotechnology company location. University researchers affiliated with firms as either founders or chairs of advisory boards are likely sources of technology transfer. It is found that companies where university researchers hold such positions locate near the universities. Furthermore, it was evidenced that a university scientist having been awarded a Nobel prize significantly increases the probability that biotechnology firms locate near the university.

Industry level labor force data mix information on routine and non-routine activities. University proximity may affect the location behavior of the highly skilled workforce but not the workers associated with mass production. This hypotheses is reinforced by some evidence regarding professional labor location. (Regression results of the following studies are exhibited in table 2.) The spatial distribution of percentage of scientists and engineers in the workforce seems to be governed by university proximity. According to the study by Beeson and Montgomery (1993), not only does university research affect location of this highly qualified workforce, but also the teaching function of universities attracts it as well (as measured by the number of degrees awarded in the fields of science and engineering).

Migration behavior of a qualified workforce seems to follow a pattern determined by university activities. In Beeson and Montgomery (1993), in-migration of this workforce depends on both research and teaching activities of local universities. Herzog et al. (1986) studied the out-migration choice of scientists and engineers. They found that university availability at the place where this highly educated workforce currently lives does not affect out-migration choices. In other words, professional workers seem to consider university resources in the targeted area [Beeson and Montgomery (1993)], but their migration decision may not depend on available higher education choices in the abandoned place [Herzog et al. (1986)].

V. University research and the spatial distribution of industrial research and development

A major lesson from the studies surveyed in the preceding section is that in order to make an assessment of university knowledge impacts on the regional economy, a careful modeling approach is needed. Instead of testing for university effects on local production directly, research should focus on some specific, knowledge intensive activities of local companies. In other words, the appropriate approach is to model university knowledge effects on non-routine functions of local production such as research and development or small scale manufacturing.

There are two major areas of research that separate knowledge intensive production activities of local companies from regional mass production. The first attempt focuses on the impact of universities on the spatial distribution of industry research and development, while the second approach models local technology transfers from universities. The current section introduces the R&D studies, and the following section reviews the technology transfer models.

The family of studies that concentrate on R&D location gives strong evidence of university effects. According to their findings, private research and development tend to concentrate around places where universities are actively involved in research. This conclusion of the studies is unequivocal at different levels of spatial aggregation. Significant private and university research co-location is reported equally by studies carried out at state, metropolitan area, and intra-metropolitan area levels. The results of these studies are summarized in Table 3.

The studies considered here search for local university effects on either the distribution of industrial R&D among US states [i.e., Jaffe (1989), Feldman (1994/A), and Feldman and Florida (1994)] and MSAs [Bania et al. (1992), Anselin et al. (1997/A,B)] or the location choice of private research laboratories within a metropolitan area [Sivitanidou and Sivitanides (1995)].

Based on private R&D expenditures data for 29 states and eight years, Jaffe (1989) tested the state level impact of university research on firms’ R&D activity. University research expenditures measured the academic impact in the industrial R&D equation. Its positive and highly significant coefficient suggested a strong university impact on R&D location. A state analysis by Feldman (1994/A) and Feldman and Florida (1994) replicated Jaffe’s findings.

Using R & D microdata at the metropolitan area level, Bania et al. (1992) studied the effect of university research on industry research lab employment (as a proxy for private R&D activities). They found that university R&D attracts industry research into the region. Additionally, they concluded that state technology programs are associated with higher levels of private research activities.

Applying spatial econometric methodology to study the effects of university research on the spatial distribution of high technology R&D lab professional employment among 125 US MSAs, Anselin et al. (1997/A, B) evidenced a highly significant university effect on research lab location. Industrial research has a strong tendency to cluster spatially: research laboratory employment within a 50 mile distance range is positively associated with the spatial distribution of R&D professionals. No similar evidence was found with respect to a university effect: academic impact on location does not extend the boundaries of MSAs (Anselin et al. 1997/A).

Sivitanidou and Sivitanides (1995) proxied research lab location by R&D property rents in the greater Los Angeles area. Assuming a positive relation between property rent and demand for the given property, it was found that factors determining property rent influence location as well. The study concentrates on both the research and education functions of universities. As a new element in the literature, they searched for not only location impacts of research activity by universities, but possible effects coming from small, teaching oriented colleges as well. A distance decay in the university effect was found for both functions. According to their findings, proximity to higher education institutions increases property rent, suggesting a positive effect on location.

VI. Models of technology transfer: patents, innovations, and knowledge production

Three approaches have been developed in the literature to estimate the role of local university knowledge transfers in the process of innovation. Jaffe et al. (1993) and Almeida and Kogut (1995) study the spatial patterns of university patent citations in order to determine whether there is a strong tendency of these citations to locate in a geographic proximity to the originating academic institution. Mansfield (1991, 1995) represents a different research methodology. His analysis is based on a survey of industrial researchers regarding the importance of previous university research results for their innovations. In Jaffe (1989), the third approach was introduced: the study of university effects within the knowledge production framework.

As Jaffe et al. (1993, p. 578) point out, citation of patents is one of the rare forms of documentation of knowledge flows. Patent citations uncover previous ideas on which the patent has been developed. By matching company citations of university patents by states and MSAs, Jaffe et al.

(1993) found strong evidence that citations of university patents are localized geographically around the academic institutions. However, replicating the same procedure for the semiconductor industry, Almeida and Kogut (1995) reported no signs of a similar spatial concentration pattern of university patent citations. Contrasting results may come from differences in the sample sizes and from different industrial scope [Almeida and Kogut (1995), p. 15].

The studies in Mansfield (1991, 1995) are based on a survey of industrial researchers to observe the geographic patterns of university effect on their innovations. For basic research, spatial proximity turns out to be less important than for applied R&D. Knowledge transfers are locally mediated in the information processing and drug industries.

Although an analysis of citation patterns may shed light on knowledge transfers, a large fraction of possible technology transfers is still not discovered [Jaffe et al. (1993), p. 584]. Empirical tests based on the idea of knowledge production function detect a wider range of technology transfers. The knowledge production function of Griliches [Griliches (1979, 1986)] relates knowledge produced by the firm to industrial research. This notion provides a wide flexibility of applications. Not only the impact of a firm's own research can be analyzed, but also knowledge transfers among private research laboratories can be accounted for [Jaffe (1986)].

In the area of technology transfers from universities, this framework was first applied by Jaffe (1989). It is conceptualized as a Cobb-Douglas type function that includes two major factors of knowledge production: R&D carried out by private corporations and university research. Because the intensity of local technology transfer (that is channeled, among other means, through university seminars, publications, contract consulting, use of university facilities, industrial parks, university spin-offs, worker mobility, professional associations, friendly connections) seems to be highly correlated with university research activities, university research expenditures appear to be a good proxy for potential knowledge transfers. In Jaffe (1989), industrial research activities were measured by R&D expenditures, while economically useful new knowledge was proxied by number of patents.

In Jaffe (1989), the analysis of the university effect on knowledge production was based on data of 29 US states. A data impediment explains the choice of the spatial unit: states represent the lowest level of aggregation of industrial R&D expenditure data. This impediment became the source of the major shortcoming of the analysis in Jaffe (1989). As illustrated in the previous section, local university knowledge transfers are mediated within a relatively small geographic area. This area can be a county or an MSA, but not the state: this geographical unit is generally too large to account for local university-industry interactions. To improve his model, Jaffe introduced a coincidence variable to capture MSA level university impacts on state level knowledge production. Both private and university research are estimated with significant coefficients in the model, suggesting a strong university effect on the production of industry patents at the state level[4]. However, the evidence of local (i.e., MSA-level) university knowledge transfer is weak in the study [Jaffe (1989), p 968].

Relevance of patents as proxies for economically useful new technological knowledge has been a subject of debate in the literature [Griliches (1990)]. The fact that there are inventions that are never patented and many patents are never developed into innovations marks the shortcomings of this measure. The right proxy for knowledge should be based on some kind of innovation measure. Counts of product innovations introduced to the US market in 1982 are the only existing such data. Acs et al. (1991) used this data set to test the robustness of Jaffe's (1989) findings. Instead of number of patents,

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[4]Additionally, Jaffe (1989) reports the elasticity of corporate patents with respect to university research expenditures which is almost 0.6 [Jaffe (1989), p. 968]. There are other attempts in the literature to calculate the overall returns on publicly financed research expenditures. According to the study by Nadiri and Mamuneas (1994), the social rate of return on publicly financed research and development was between 0.058 and 0.087.

product innovations were applied to measure economically useful new knowledge in Acs et al. (1991). The rest of the data was the same as in Jaffe (1989). Although the state level impact of university research activities on new knowledge creation gained a stronger evidence [the coefficient on the university research variable was higher and more significant than that of Jaffe (1989)], there was still weak evidence of local (MSA level) university effects.

Also, applying innovation data, Acs et al. (1994/A, C) test university impact on the knowledge production of large and small firms. The results show that technology transfer from universities plays a more decisive role in the innovative activity of small rather than large firms.[5] Adding agglomeration features to the model and applying innovation data, Feldman (1994/A), and Feldman and Florida (1994) provide strong evidence of university knowledge transfers at the state level. Audretsch and Vivarelli (1994) replicated the Jaffe (1989) study for Italy, using patent data. Evidence was given that, similar to the US case, Italian universities are also active in technology transfer. On average, small firms utilize university research results more frequently than large companies [Audretsch and Vivarell (1994), p. 23].

Although the study by Audretsch and Feldman (1996) does not use the knowledge production framework, it shares the research interest with the previous papers: a search for university knowledge transfer. The study focuses on the effects of university research on the spatial concentration of innovative activity in the US. The Gini coefficient of innovations by states represents the measure of innovation concentration in the paper. A positive and significant university impact on the concentration of innovations evidences the presence of knowledge transfers.

[5] See Acs at al. (1994/A) p. 339. Their findings are in accordance with the result by Link and Rees (1990): small firms are able to utilize university research much more efficiently than their large counterparts.

Jaffe (1989) admits that most of the US states are too large spatial units to capture micro level interactions between universities and high technology facilities. Despite the strong state level university effects on the production of new knowledge found in Jaffe (1989), Acs et al. (1991, 1994/A,C), Feldman (1994/A), and Feldman and Florida (1994), the inappropriate spatial data aggregation in the studies precludes us to consider these findings as real evidence of local academic knowledge transfers. Anselin et al. (1997/A,B) represent the first studies in the knowledge production function literature that apply a data set which is aggregated at a relevant spatial scale, at the level of US metropolitan areas. The specially collected MSA level data on innovations and private research lab professional employment provided the technical basis for the studies. As a first instance in this research area, Anselin et al. (1997/ A, B) employ the methodology of spatial econometrics to find the correctly specified final estimated form of the knowledge production function. They found a very strong and positive relationship between MSA innovations and university research. Additionally, they were able to determine the spatial extent of academic knowledge transfers: although its intensity is smaller, the impact of university research is still in effect within a 75 mile distance range around the innovating MSA.

Increasing understanding of the spatial extent of academic knowledge transfers provides an important empirical support for both the theory of endogenous economic growth (e.g., Romer, 1986, 1990 and Lucas, 1988) and regional economic policy makers. However, it is very likely that, without a certain spatial concentration of economic activities, a simple geographic proximity is not a sufficient condition of meaningful university technology transfers. The case study by Feldman (1994/B) provides a good example in this respect. She points out that, though Johns Hopkins University is the largest recipient of federal research funds, no significant high technology concentration has emerged in the Baltimore area. She argues that a missing “critical mass” of high technology enterprises, the lack of producer services, venture capital and entrepreneurial culture explain this apparently insufficient local spillover effect.

Still within the Griliches-Jaffe knowledge production framework, the first formal evidence of the positive effect of agglomeration on local academic knowledge spillovers was provided in Varga et al. (1997). Based on a data set of 125 US metropolitan areas, they found that spatial concentration of high technology production and business services are in a definite positive relationship with the intensity of local academic knowledge transfers. Increasing returns resulted from the spatial concentration of economic activities was clearly demonstrated in the study. It was shown that the same amount of local expenditure on university research yields dramatically different levels of innovation output depending on the concentration of economic activities in the metropolitan area. It was found that a critical mass of agglomeration should be reached to expect substantial local economic effects of academic research spending. This critical mass was characterized with city population around 3 millions, employment in high technology production facilities and business service firms about 160,000 and 4,000, respectively.

VII. Summary and conclusions

A sizable literature of descriptive studies has documented the important role of universities in the development of the world's largest high technology concentrations. Silicon Valley in California, Route 128 around Boston, Massachusetts, and the Cambridge Phenomenon in England are the most recognized agglomerations of such high technology activities. University knowledge effects on these regions' economic growth are transmitted via technology transfers: many high technology innovations were originated in research findings at local universities, and the expectation of potential future knowledge transfers from academic institutions has attracted a large number of new companies into these areas. It is the fundamental research question of the surveyed literature whether local university knowledge impacts are unique, non-repeatable phenomena, or whether they can be experienced in other regions as well.

Case studies, surveys, and descriptive studies of several high technology concentrations evidence that the location impact of universities varies by industries, ownership status of the firms, firm size, and city size. Regarding the effect of technology transfer on local economic development, the evidence is still vague. Its main reason is that no appropriate model of local university knowledge effects has been developed in the literature. Studies either test for a direct university effect on economic conditions or focus only on academic technology transfer, but none of them provides an integrated approach. A major problem with the studies of direct university impact on local economic variables (such as total high technology production or employment) is that they do not consider that academic knowledge may not be equally important for each production activity. Non-routine functions (e.g., research and development, prototype manufacturing) might draw heavily upon scientific knowledge generated at local universities, but it is unlikely that mass production of even the most sophisticated high technology products needs substantial academic assistance. Applied data in these studies mix information on routine and non-routine activities and, consequently, provide only vague evidence of university effects.

It is an important lesson from the reviewed econometric studies that non - routine functions of high technology firms are the ones where strong university impacts are detected. The Griliches-Jaffe knowledge production approach is considered a major framework of modeling technology transfers from academic institutions. In Anselin et al. (1997/A,B), strong evidence of MSA-level academic technology transfers have been found. It is evidenced in these studies that academic knowledge spillovers follow a definite distance decay pattern.

The other important finding in the recent literature is that the intensity of local academic knowledge transfers is strongly and positively correlated with spatial concentration of economic activities (Varga et al., 1997). A major policy consequence of this finding is that strengthening universities in order to advance local economies can be a good option for a relatively well developed metropolitan area but not necessarily for a lagging high technology region. For the latter, a more comprehensive approach is needed, including a complex regional economic development plan that targets not only local academic institutions, but also high technology employment, business services, and small firms.

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TABLE 1: THE LITERATURE ON HIGH TECH PLANTS AND UNIVERSITIES

	MARKUSEN ET AL(1986)	**GLASMEIER(1991)**	**GLASMEIER(1991)**	**FLORAX AND FOLMER (1992)**	**BANIA ET AL (1993)**	**AUDRETSCH AND STEPHAN (1996)**
NUMBER OF OBSERVATIONS	264	247	247	320	75	312
YEAR	1977	1982	1982	1977-1984	1976-1978	1990-1992
ADJ. R-SQUARE	0.71		0.65	0.89	0.32	
DEPENDENT VARIABLE	HIGH TECH PLANTS	HIGH TECH PLANTS	HIGH TECH PLANTS	MANUFACTURING INVESTMENT	FIRMS OPENING RATE	PROBABILITY THAT THE UNIVERSITY SCIENTIST AND THE FIRM ARE LOCATED N THE SAME REGION
AGGREGATION	SMSA	SMSA ADJACENT RURAL AREAS	SMSA	40 REGIONS IN THE NETHERLANDS	25 SMSA	312 UNIVERSITY SCIENTISTS
METHOD	OLS	TOBIT	OLS	EGLS - SPACE AND TIME	OLS	PROBIT
UNIVERSITY VARIABLE	**UNIVERSITY R&D (NEGATIVE SIGN)**	**NUMBER OF COLLEGES IN SMSA**	**NUMBER OF COLLEGES IN SMSA***	**CONTAGIOUS KNOWLEDGE DISTRIBUTION** **HIERARCHICAL KNOWLEDGE DISTRIBUTION***	**R&D EXPENDITURES*** **NUMBER OF UNIVERSITIES**	
OTHER INDEPENDENT VARIABLES	*LABOR:* WAGE RATE UNIONIZATION RATE* UNEMPLOYMENT RATE *AMENITIES:* CLIMATE INDEX* HOUSING PRICE EDUCATTIONAL OPTIONS* *ACCESS FEATURES* FREEWAY DENSITY* AIRPORT ACCESS* *AGGLOMERATION* FORTUNE 500* BUSINESS SERVICES* (UNIV R&D) *SOCIO -POLITICAL* DEFENSE SPENDING PER CAPITA PERCENTAGE BLACK*	*SMSA VARIABLES:* CLIMATE* HOUSING PRICES PROPERTY TAX AIR SERVICE* SIXTEEN YEARS EDUCATION POVERTY LEVEL UNEMPLOYMENT PROCUREMENT CONTRACTS PER CAPITA* MIGRATION % UNIONIZATION IN MANUFACTURING* EMPLOYMENT IN 1982*	*SMSA VARIABLES:* CLIMATE HOUSING PRICES PROPERTY TAX AIR SERVICE* SIXTEEN YEARS EDUCATION POVERTY LEVEL* UNEMPLOYMENT PROCUREMENT CONTRACTS PER CAPITA* WAGE RATE MIGRATION* % UNIONIZATION IN MANUFACTURING*	MANUFACTURING OUTPUT CHANGE IN MANUF OUTPUT REAL USER COST OF CAPITAL* REAL WAGE	LABOR COST* % UNIONIZED WORKERS* MANUF. CAPITAL COST* BUSINESS TAXES ENERGY PRICE* SMSA POPULATION* % EMPLOYED SCIENTIST AND ENGINEERS	AGE OF THE SCIENTIST* NUMBER OF CITATIONS NOBEL PRIZE* FOUNDER/CHAIR IN THE COMPANY* FIRM DENSITY AT THE LOCATION OF THE SCIENTIST* CALIFORNIA (DUMMY) NORTH EAST (DUMMY)*

NOTES:

***SIGNIFICANCE OF AT LEAST 0.90**

VARIABLES IN MARKUSEN ET AL. (1986):

EDUCATION OPTIONS=INDEX OF OPTIONS AT 2 AND 4-YEAR POST-SECONDARY EDUCATONAL INSTITUTIONS AND PROFESIONAL PROGRAMS

BUSINESS SERVICES=% OF EMPLOYMENT IN ACCOUNTING, CONSULTING, R&D DATA PROCESSING AND COMPUTER SERVICES

TABLE 2: THE LITERATURE ON HIGH TECH LABOR AND UNIVERSITIES

	MARKUSEN ET AL (1986)	HERZOG ET AL(1986)	GLASMEIER(1991)	GLASMEIER(1991)	BEESON & MONTGOMERY(1993)	ACS ET AL(1994/B)
NUMBER OF OBSERVATIONS	264	4813	247	247	218 SMSA	888
YEAR	1977	1975-1980	1982	1982	1980	1988-1991
ADJ. R-SQUARE	0.71			0.50	0.17	0.62
DEPENDENT VARIABLE	HIGH TECH JOBS	LIKELIHOOD OF HIGH TECH WORKERS MIGRATION	HIGH TECH EMPLOYMENT	HIGH TECH EMPLOYMENT	% SCIENTISTS AND ENGINEERS OF LABOR FORCE	HIGH TECH EMPLOYMENT
AGGREGATION	SMSA	INDIV. DATA ANALYZED BY SMSA`S	SMSA ADJACENT RURAL AREAS	SMSA	SMSA	37 SMSAs
METHOD	OLS	BINARY LOGIT	TOBIT	OLS	OLS	2SLS
UNIVERSITY VARIABLE	**UNIVERSITY R&D (NEGATIVE SIGN)**	**PRESENCE OF RANKED HIGHER EDUCATION OPTIONS**	**NUMBER OF COLLEGES IN SMSA**	**NUMBER OF COLLEGES IN SMSA***	**UNIV R&D*** **PROGRAM RATING** **BACHELOR`S DEGREES** **DEGREES IN S & E***	**UNIV R&D***
OTHER INDEPENDENT VARIABLES	*LABOR:* WAGE RATE UNIONIZATION RATE* UNEMPLOYMENT RATE *AMENITIES:* CLIMATE INDEX* HOUSING PRICE* EDUCATTIONAL OPTIONS* *ACCESS FEATURES* FREEWAY DENSITY* AIRPORT ACCESS *AGGLOMERATION* FORTUNE 500 BUSINESS SERVICES* (UNIV R&D) *SOCIO -POLITICAL* DEFENSE SPENDING PER CAPITA* PERCENTAGE BLACK	AGE* EDUCATION* MARRIED SCHOOL-AGE CHILDREN* PRIOR GEOGRAPHIC MOBILITY* CLIMATE HOME PRICES* LOCAL PROPERTY TAX* LOCAL SALES, INCOME TAXES *EDUCATIONAL QUALITY* EXPENDITURE PER STUDENT* STUDENT/TEACHER RATIO (HIGHER EDUC OPTIONS) *ACCESSIBILITY TO* CULTURAL AMENITIES RECREATION* TRANSPORTATION* PER CAPITA INCOME* EMPLOYMENT GROWTH(1975-79) CENTRAL CITY RESIDENCE POPULATION* POPULATION SQUARED*	*SMSA VARIABLES:* CLIMATE* HOUSING PRICES PROPERTY TAX AIR SERVICE* SIXTEEN YEARS EDUCATION POVERTY LEVEL UNEMPLOYMENT RATE PROCUREMENT CONTRACTS PER CAP WAGE RATE MIGRATION % UNIONIZATION IN MANUFACTURING* EMPLOYMENT IN 1982*	*SMSA VARIABLES:* CLIMATE* HOUSING PRICES* PROPERTY TAX AIR SERVICE* SIXTEEN YEARS EDUCATION POVERTY LEVEL* UNEMPLOYMENT RATE PROCUREMENT CONTRACTS PER CAP* WAGE RATE MIGRATION* % UNIONIZATION IN MANUFACTURING	POPULATION POP SQUARED HEATING DEGREE DAYS CRIME RATE STUDENT-TEACHER RATIO HOUSING COSTS BUSINESS TAXES SALES & INCOME TAXES MANUFACT EMPL SHARE	WAGES* POPULATION* HUMAN CAPITAL NUMBER OF INNOVATIONS*

NOTE:
SIGNIFICANCE OF AT LEAST 0.90

TABLE 3: THE LITERATURE ON INDUSTRY R&D AND UNIVERSITIES

	JAFFE(1989)	BANIA ET AL (1992)	FELDMAN-FLORIDA (1994)	SIVITANIDOU AND SIVITANIDES (1995)	ANSELIN ET AL. (1997)
NUMBER OF OBSERVATIONS	196	194	397	231	125
YEAR	1972-77, 1979, 1981	1986	1982	1990	1982
ADJ. R-SQUARE		0.59		0.38	0.651
DEPENDENT VARIABLE	LOG OF INDUSTRY R&D	LOG(1980 R&D EMPLOYMENT)	LOG OF INDUSTRY R&D	LOG(R&D PROPERTY RENTS)	LOG(R&D EMPLOYMENT
AGGREGATION	29 STATES	SMSA	29 STATES	231 R&D PROPERTIES	125 MSAs
METHOD	3SLS	OLS	3SLS	OLS	2SLS-ROBUST
UNIVERSITY VARIABLE	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***	**URESEARCH*** **USTATE***	**LOG OF UNIVERSITY R&D***
OTHER INDEPENDENT VARIABLES	LOG OF MANUF VALUE ADDED* LOG OF POPULATION	LOG(LAND AREA)* LOG(POP)* LOG(EMP PCT) LO(GOV EXP)* LOG(WELFARE) LOG(BUS TAX) LOG(COLLEGE ED)* LOG(CORP HDQRTS)	LOG (HEADQUARTERS)* LOG (POPULATION)* LOG(RELATED IND. PRESENCE)*	AIRPORT FRREWAY* EDUCATION * URBAN* CRIME* POLLUTION* GROWTH* ZONING* NET* SINGLE* SIZE* AGE*	LOG(RD50)* LOG(URD75) LOG(HIGH TECHNOLOGY EMPLOYMENT)* FORTU* RANK

NOTES:

***SIGNIFICANCE OF AT LEAST 0.90**

VARIABLES IN BANIA ET AL. (1992)

EMP PCT= 1986 SMSA employment / population

GOV EXP=1982 per capita SMSA gov spending on education, highways, fire and police
WELFARE=1982 per capita gov spending on welfare, health and hospitals
BUS TAX=1986 estimated effective business tax rate
COLLEGE EDUCATED=percent of 1980 SMSA population with 4 or more years of college education
CRP HDQTRS=number of Fortune 500 headquarters in the SMSA

VARIABLES IN SIVITANIDU AND SIVITANIDES (1995)

URESEARCH=gravity index to capture ranked university research and distance
USTATE=distance to closest California state campus
AIRPORT=distance from closest airports
FREEWAY=freeway density
EDUCATION=teacher-to-student ratio*100 in 1990
URBAN=employment in cultural, recreation,entertainment, and retail activities per resident population in 1990
CRIME=total crimes per 1000 residents, 1990
POLLUTION=suspended particulate concentration

VARIABLES IN ANSELIN ET AL.(1997)

RD50=number of R&D professional employment within a 50 mile range around the MSA
URD50=university research expenditures within a 75 mile range around the MSA
FORTU=1 if at least 10 Fortune 500 companies in the MSA, 0 otherwise
RANK= 1if at least one high technology university department ranks among the top ten of the nation, zero otherwise

TABLE 4: THE LITERATURE ON KNOWLEDGE TRANSFER FROM UNIVERSITIES

	JAFFE(1989)	**ACS ET AL(1991)**	**ACS ET AL(1994/A)**	**FELDMAN-FLORIDA (1994)**	**ANSELIN ET AL. (1997)**
NUMBER OF OBSERVATIONS	196	125	145	397	125
YEAR	1972-77, 1979, 1981	1982	1982	1982	1982
DEPENDENT VARIABLE	LOG OF CORPORATE PATENTS BY AREA	LOG OF INNOVATIONS	LOG OF INNOVATIONS	LOG OF INNOVATIONS	LOG OF INNOVATIONS
AGGREGATION	29 STATES	29 STATES	29 STATES	29 STATES	125 MSAs
METHOD	POOLED OLS, 3SLS	POOLED OLS	TOBIT	3SLS	OLS
SPATIAL DIAGNOSTICS	NO	NO	NO	Durbin-Watson	ML SPATIAL LAG ML SPATIAL ERROR
ZEROS	log(K) = -1	DROPPED	log(K) = -1	log(K)=log(10(K+1))	DROPPED
LOCAL UNIVERSITY KNOWLEDGE TRANSFERS	**[GEOGRAPHIC COINCIDENCE INDEX*LOG OF UNIVERSITY R&D]**	**[GEOGRAPHIC COINCIDENCE INDEX*LOG OF UNIVERSITY R&D]**	**[GEOGRAPHIC COINCIDENCE INDEX*LOG OF UNIVERSITY R&D]**		**DIRECT ANALYSIS**
UNIVERSITY VARIABLE	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***	**LOG OF UNIVERSITY R&D***
OTHER INDEPENDENT VARIABLES	LOG OF INDUSTRY R&D* (TOTAL) LOG(POPULATION)	LOG OF INDUSTRY R&D* (TOTAL) LOG(POPULATION)	LOG OF INDUSTRY R&D*(TOTAL) LOG(POPULATION)*	LOG OF INDUSTRY R&D*(TOTAL) LOG(RELATED IND. PRESENCE)* LOG(BUSINESS SERVICES)* LOG(POPULATION)* LOG(INDUSTRY SALES)* CONC* [SHARE OF THE STATE`S VALUE OF MANUF. SHIPMENTS HELD BY THE STATE`S LARGEST SMSA]	LOG(INDUSTRY R&D EMPLOYMENT - SECTORAL)* LOG(INDUSTRY R&D EMPLOYMENT WITHIN A 75 MILE DISTANCE RANGE) LOG(UNIVERSITYY R&D WITHIN A 50 MILE DISTANCE RANGE)* LOG(BUSINESS SERVICES)* LOG(LOCATION QUOTIENT)* LOG(PERCENTAGE OF LARGE FIRMS)* LOG(RANK OF UNIVERSITIES)*

NOTES:
***SIGNIFICANCE OF AT LEAST 0.90**