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**URBANIZATION, PRODUCTIVITY AND INNOVATION:
EVIDENCE FROM INVESTMENT IN HIGHER EDUCATION**

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Urbanization, Productivity and Innovation:
Evidence from Investment in Higher Education*

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Abstract

During the past fifteen years, Swedish government policy has decentralized post-secondary education throughout the country. We investigate the economic effects of this decentralization policy on the level of productivity and innovation and their spatial distribution in the Swedish economy. We find important and significant effects of this policy upon economic output and the locus of knowledge production, suggesting that the decentralization has affected regional development through local innovation and increased creativity. Our evidence also suggests that aggregate productivity was increased by the deliberate policy of decentralization. Finally, we estimate the spillovers of university investment over space, finding that they are greatly attenuated. Agglomerative effects decline rapidly; roughly half of the productivity gains from these investments are manifest within five to eight kilometers of the community in which they are made.

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1. Introduction

Sweden undertook a conscious spatial decentralization of its system of higher education beginning in 1987. This decentralization was motivated by a complex variety of political, social, and economic factors. In this paper, we analyze the effects of this policy on economic productivity and upon the level and distribution of innovative activity in the economy. We provide quantitative evidence on the effects of the decentralization policy upon output per worker and upon the award of commercial patents for innovations and discoveries. We also provide new evidence that the policy has increased aggregate productivity and economic output.

From a broader perspective, there has been intense debate in the US and in other developed countries about the role of university research, and the spin-offs of that research, in stimulating regional development. The popular press in Sweden has documented—endlessly it seems—the role of Stanford and Berkeley in fostering the growth of the Silicon Valley in Northern California. One implication seems to be that investment in post-secondary education affects the aggregate level of economic activity as well as its geographical distribution.

A related line of research has sought to understand more generally the economic role of space in affecting economic growth and increased productivity. Recent theories have stressed the role of knowledge spillovers in cities in generating growth, distinguishing between spillovers among firms within an industry (Marshall-Arrow-Romer externalities) and spillovers across industries arising from the colocation of economic activity in cities (Jacobs externalities). Work by Glaeser *et al*, (1992) is consistent with the importance of industrial diversity (rather than concentration) in fostering economic growth in the U.S. In contrast, Henderson, *et al*, (1995) find that concentration facilitates growth in mature capital-intensive industries.

The precise linkages among educational investments, knowledge, spillovers and regional output remain unclear, and, in the words of Jaffe (1989), the "transport mechanism" is not well understood. The work of Romer (1986, 1990), Lucas (1988), and especially Fujita (1988) suggests that these external economies from concentration are endogenous outcomes caused by the colocation of firms and workers. In any case, it is now quite natural to recognize "productivity gains from the geographical concentration of human capital" (Rauch, 1993).

One specific mechanism linking educational investment to regional output is innovation itself. If educational investment stimulates local innovation and creativity, productivity gains may arise from the new knowledge whose production is facilitated by the pattern of spatial investment (Jaffe, *et al*, 1993). We analyze this mechanism using the natural experiment of decentralization of higher education in Sweden. We trace the implications of this exogenous change in policy upon productivity and upon the level and distribution of innovative activity in the Swedish economy. In conducting this analysis, we rely upon unique bodies of data -- annual estimates of output per worker for each of 284 local civil divisions in Sweden and comprehensive records on patent awards, which include the home address of the inventor.

Our results document the surprisingly large effects of these specific university investments in stimulating creativity and increased regional productivity. We quantify the importance of university research in the production of patents, although we cannot distinguish between the direct activities of a university and its ancillary role in inducing the nearby location of research-intensive industry. Our results also document the effects of university investments on local economic activity, especially increases in output and worker productivity.

Most surprising, to us, is the net effect of the spatial rearrangement of economic activity upon aggregate output. When our statistical results are used to compare the economic effects of increased university investment in the pre-existing institutions (in older, denser, urban regions)

with equivalent investments in new institutions (in less dense, less urbanized regions), the results suggest that the decentralization policy has led to an increase in aggregate output and aggregate creativity. The estimated effects are not large, but they persist across specifications and statistical models. These results are consistent with recent work by Rosenthal and Strange (2003, 2005a, 2005b) which suggests that external economies of agglomeration are sharply attenuated with distance and that the marginal effects of additional employees at small new establishments are larger than the economic effects of equivalent investments at larger traditional locations.

Section 2 provides a brief review of Swedish university policies and innovation during the last few decades. Section 3 surveys the literature on university research, knowledge spillovers, and innovation as they affect economic growth. Section 4 presents the data and the models used in our statistical analysis. Section 5 summarizes our results and conclusions.

2.   Swedish University Policy

As recently as 1977, only six universities operated in Sweden, a country of nine million people about the size of California. Universities were located in Stockholm, Göteborg, Lund, Uppsala, Linköping and Umeå. In addition, there were three large technical institutes in Stockholm,[1] as well as two others.[2] The locations of these eleven institutions, the old established universities, are depicted in Figure 1. In addition, fourteen small colleges existed; each was affiliated with a university. In 1977, the university structure was changed, establishing eleven

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[1] The Royal Institute of Technology; the Karolinska Institute of Medicine; and the Stockholm School of Economics.

[2] The Chalmers Institute of Technology in Göteborg; and the Institute of Agriculture near Uppsala.

new institutions, raising the status of the fourteen colleges and placing all 36 universities, institutes and colleges (located in 26 different municipalities) under one administration. The "new" university structure is also indicated in Figure 1.

Figure 1. Location of "Old" and "New" Universities in Sweden
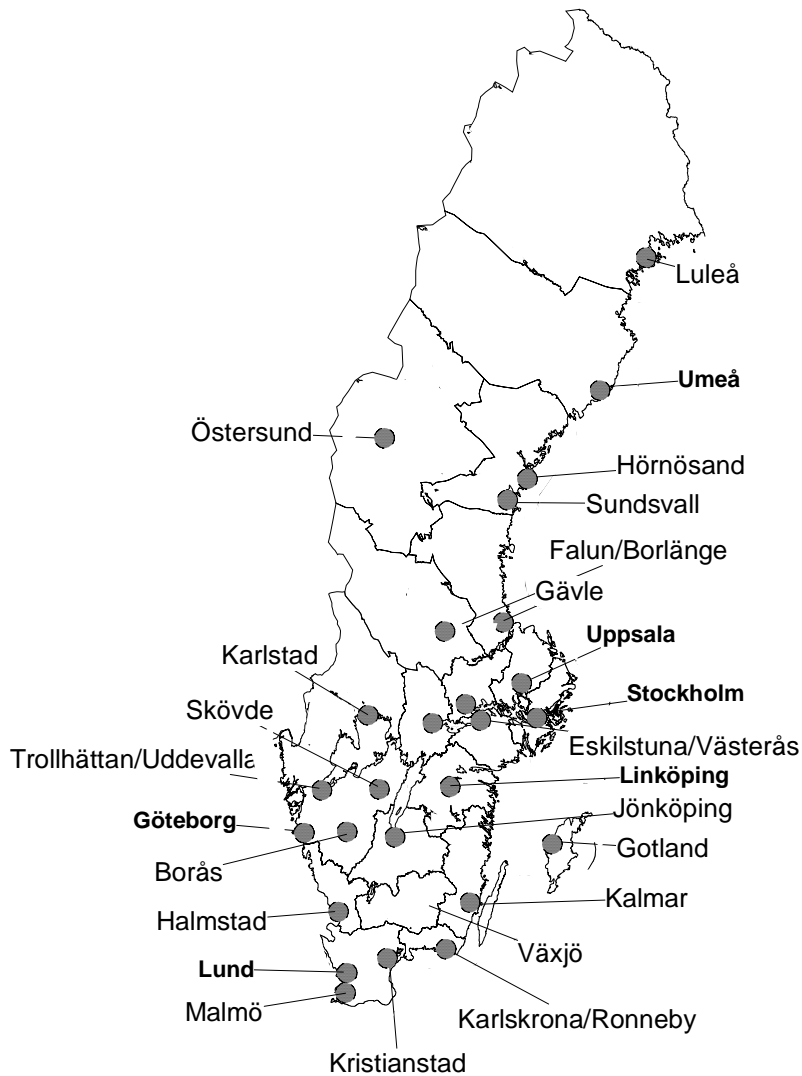
Note: Locations of "old" institutions are in boldface.

In almost all cases, the sites chosen for the new institutions of higher education were formerly occupied by teacher training schools, engineering academies, or by military training facilities.[3] In only one instance is there any indication that regional economic considerations affected the location chosen for a new institution.[4]

Despite the change in status, the new institutions of higher education developed relatively slowly during the first decade after reorganization. Thus, the number and distribution of students between the older institutions and the newly established colleges of higher education was about the same in 1987 as it had been in 1977. However, beginning in 1987, there was a substantial expansion. During the subsequent period, the number of students at the newer colleges more than doubled while the number of students at the older universities increased half again. Moreover, the resources for research at the newer institutions were increased substantially, particularly during decade of the 1990s. By 1998, the newly established institutions had grown to a total of 84,000 students, and more than a third of all the students enrolled in higher education attended one of these institutions.

The motives for rapid decentralization were political and social as much as economic. One important motivation for the establishment of these new colleges was the desire to make undergraduate education geographically more accessible in all parts of Sweden. A related motivation was to increase the representation in higher education of students from areas geographically more remote from the established universities. The policy also sought to increase

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[3] Five sites of university expansion formerly housed institutions of preschool education; eight formerly housed affiliates of Sweden's Institute of Education; two had been schools of naval science (several sites had housed more than one of these facilities).

[4] The college established in Karlskrona-Ronneby was in an area of high unemployment caused by the closing of a major shipyard. In all other cases, the new colleges were located to replace or upgrade existing post secondary school and teacher training activities. See *De första 20 åren,* 1998, for an extensive discussion.

the access to higher education of different social classes, especially those for which higher education has not been a tradition. Proponents of this decentralization also claim that the policy favors those who would like to stay, to live, and to work locally. A premise of this regional policy is that the allocation of resources to the newer regional colleges would increase not only the local educational level, but also the number of jobs in these regions (Andersson, 2005). Many of these same arguments are familiar in other contents, for example, California's decision to establish a new university campus inland in Merced and British Columbia's decision to establish new university campuses at Prince George, 490 miles north of Vancouver, and at Kelowna, 250 miles inland.

The university decentralization can be interpreted simply as Keynesian fiscal policy at the regional level.[5] Two other potential effects of this policy can be identified. The first is the expectation that the enhanced institutions provide spillovers or local externalities that could improve productivity and lead to regional expansion by existing companies or by start-up firms. Alternatively, research at a regional college or university could foster directly innovation and increased entrepreneurial activity -- the "Silicon Valley model."

Of course, these two effects are not mutually exclusive. Exogenous changes in the distribution of university resources may induce spillovers among firms, leading to increased productivity and economic output directly. Increased innovative activity represents one way in which regional output and creativity could have been increased.

In Section 4, below, we investigate these connections, analyzing the changes in productivity induced by these investments and the subsequent changes in the spatial distribution

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[5] Direct expenditures will increase employment and economic output, and the construction and operation of new facilities will induce more economic activity through the local multiplier (See Florax, 1992)

of innovative activity and the level of creativity in the economy. It is surely true that there are lags between investments in research staff, facilities, and resulting levels of innovation. There are further lags between creative output, its embodiment in a patent granted after review, and its effects on productivity and economic output. Even beyond any lags in observing responses, the complementarity between the specialties chosen for education and research by the various regional colleges (science, technology, social science, etc.) and the economic activities in the region probably matters in generating innovative activity. We investigate these issues.

3. University Research, Production, and Innovation

Alfred Marshall (1890) first drew attention to the economic effects of agglomeration and scale economics external to an individual firm but internal to an industrial district or cluster. He argued that the colocation of firms increased output and the productivity of inputs. Externalities flowing from human capital in regional development had a scientific revival with the endogenous growth models of Romer (1986, 1990), Lucas (1988) and Grossman and Helpman (1991). Griliches (1979, 1998) and Jaffe (1986, 1989) have modeled this effect in a simple production function framework using industry and university research as inputs.

As Marshall and later Krugman (1991), Feldman (1994), Jaffe, *et al*, (1993), Audretsch and Feldman (1996), and others have emphasized, space itself forms a barrier to the diffusion of knowledge. Daily face-to-face contact may be quite important in the diffusion of results from scientific research and development (R&D). It is thus beneficial for commercial developers to locate close to universities and other centers of basic research. However, geographic proximity to other firms in the same industry may be of even greater importance in stimulating applied research and innovations which improve practice.

Florax (1992) found that proximity to a college or university is not a significant factor in explaining regional variations in the incidence and location of new start-up companies. Our own work (Andersson, *et al*, 2004) questions these conclusions, at least for Sweden.

During the last two decades, data on patents have been relied upon increasingly in investigating the production of knowledge (See Griliches, 1984).[6] Using patent counts, Acs, *et al*, (2002) found that both university research and private R&D exerted substantial effects on innovative activity and patents across US metropolitan areas, with a clear dominance of private R&D over university research.

Jaffe (1986) investigated the link between patents and the R&D activities of firms. His research suggests that knowledge transfers occur more easily among companies in regions with a high output of patents. Companies performing research in areas where a considerable amount of research is carried out by *other* companies also appear to generate more patents per dollar spent on R&D than companies located in areas where relatively little research is carried out by *other* companies. Thus, clusters of research companies facilitate the diffusion of new knowledge. Jaffe (1989) analyzed time series data on corporate patents for US states, corporate R&D, and university research, investigating spillovers from academic research. He found a significant effect of university research on corporate patents. His results also suggested that university

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[6] In his 1990 survey paper, Griliches observed that a patent represents "a minimal quantum of invention that has passed both the scrutiny of the patent office as to its novelty and the test of the investment of effort and resources by the inventor (p 1669)." He emphasized that patents comprise only a subset of all inventions, since a great many valuable inventions are not patented. More recently, Jaffe and Trajtenberg (2002) caution that citation-weighted patent counts are a better measure of the value of patents than unweighted counts of patents.

research may have an indirect effect on local innovation by inducing R&D spending by private firms.[7]

Attila Varga (1998) related the output of R&D (measured by regional registrations of more than four thousand product innovations) to annual expenditures on university research as well as the number of employees in laboratories and research institutes within private companies. Using aggregate data for US states, he found important returns to scale and scope. Varga concluded that there is a critical mass relating the density and size of a region to the output of innovative activity. In this process, university inputs "matter."

Fischer and Varga (2003) related patent applications in 99 political districts in Austria to aggregate research expenditures by private firms in those districts and to estimates of university research expenditures in those districts, finding significant effects of inputs on patent applications. The interpretation of the results of this investigation is somewhat problematic,[8] but they are suggestive of a linkage.

4.   Hypotheses and Data

Our models estimate the effects of university-based researchers on the productivity and innovations of local areas, and they compare the effects for the older established (pre-1977) universities with those for the newer, smaller, and less centralized institutions established since

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[7] Jaffe also points out that he would have preferred to carry out his regional analysis on a finer spatial scale using economically more meaningful units than US states.

[8] For example direct university research expenditures were made in only 7 districts, and 27 districts which reported no patents were simply excluded from the analysis. More importantly, patent applications were linked to the geographical location of the assignee rather than the location of the inventor. Thus, the locations of firm headquarters rather than the locations of research establishments or individual inventors were used to allocate the distribution of patents over space.

then. Decentralization is measured by the spatial distribution of the post graduate university research staffs, productivity is measured by output per worker, and innovative activity is measured by the award of patents by the Swedish Patent and Registration Office.

As reported in Figure 2, the number of post graduate researchers employed in Swedish universities tripled from 6,091 in 1985 to 19,657 in 2001. The fifteen percent per year increase in the post graduate research staff includes much larger percentage increases in those employed at the smaller and newer institutions. Currently about one eighth of research staff positions are located at these new colleges, and the scale of these positions is expected to grow.[9]

During this same period, university enrollment increased by almost 90 percent, from 160 thousand students to 306 thousand. There was an increase of roughly 63 thousand students in the older established universities and 83 thousand students in the newer universities. The capacity of the newer colleges and universities more than tripled to 114 thousand students.

During the period beginning in 1985, annual increases in real output per worker averaged about 2.3 percent per year in Sweden, with productivity increases as large as 5.5 percent (in 1993) and as low as minus 2.5 percent (in 1990). Figure 3A reports aggregate annual productivity increases during the 1985-1998 period. Annual increases in new knowledge (at least, as measured by commercial patents) also varied significantly. Between 1994 and 2001, about 16,000 commercial patents were approved. Annual approvals ranged from a low of about 1,500

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[9] It should be noted that the allocation of staff positions is made centrally by the Ministry of Education, not by the institutions themselves using "soft money."

Figure 2
Post Graduate Research Staff
at Swedish Universities, 1985-2001
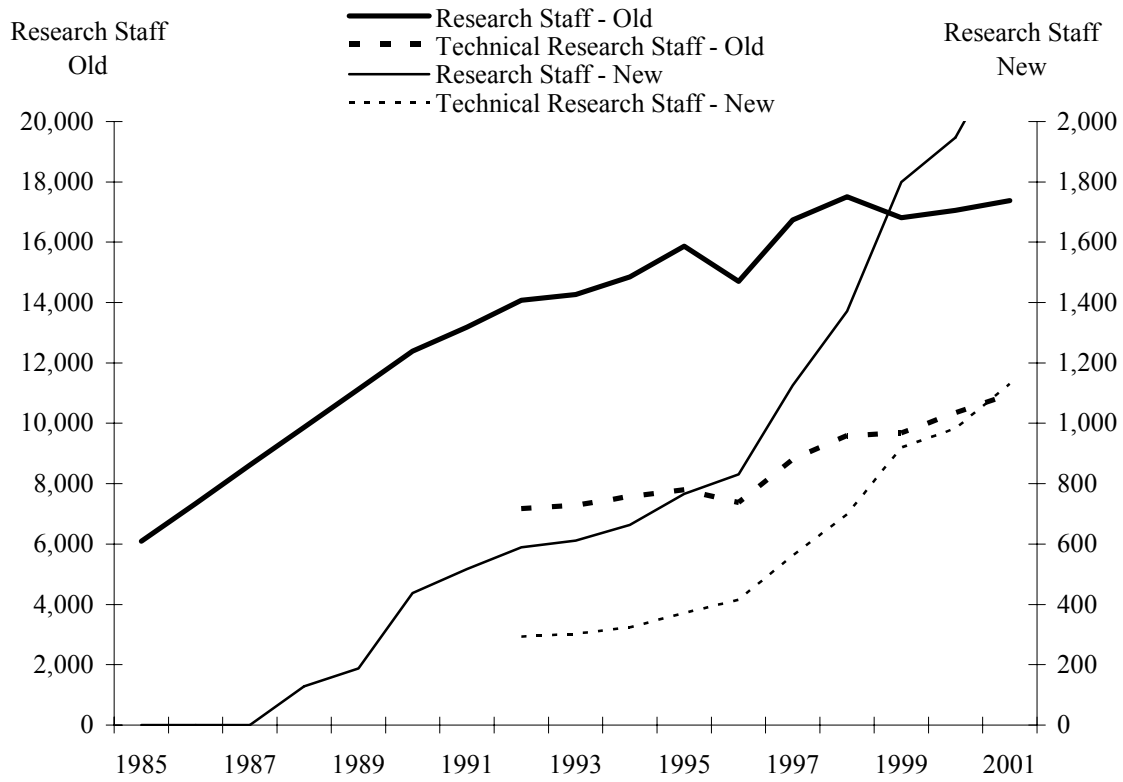
Note: Technical research staff (our calculations) is not available separately before 1992.

patents granted in 1995, to a high of almost 2,500 patents granted in 2001. Figure 3B reports the

trends in patent awards per 10,000 workers.

The record for each patent award includes both the date of the award and the date of the

application. It generally takes about three years for a successful application to be approved. In

1994, for example the average time interval from application and award was 2.5 years, and 80

percent of approvals were made within four years of the initial application. In 2001, the average

time interval increased to 2.9 years, and three quarters of approvals were made within four years

of application.

As noted above, output per worker is recorded annually for each of 284 municipalities.[10]

Patent data record the home address of the innovator(s). Because inventors may live in one

municipality and work in another, we allocate each patent to the (geographically larger) labor

market area in which the inventor lives.[11] Figure 4 provides a summary of this allocation process.

For each of the 100 labor market areas in Sweden, the map indicates the aggregate number of

patents per capita awarded during 1994-2001.

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[10]   Gross regional product is estimated by the value-added approach for 45 different business sectors at the
municipal level. For a few sectors (for example, the agricultural sector), the income approach is utilized at
the national level and is then imputed to the regional level (for example, using acreage in various crops).

[11]   Labor market areas are defined in terms of commuting patterns much the same as metropolitan
statistical areas are defined in the U.S. (except that the basic building block is the municipality rather than
the county). In the case of multiple inventors in different labor markets, the allocation of invention to labor
market areas can be made proportionately.

Figure 3A. Annual Changes in Output Per Worker in Sweden, 1985-1997
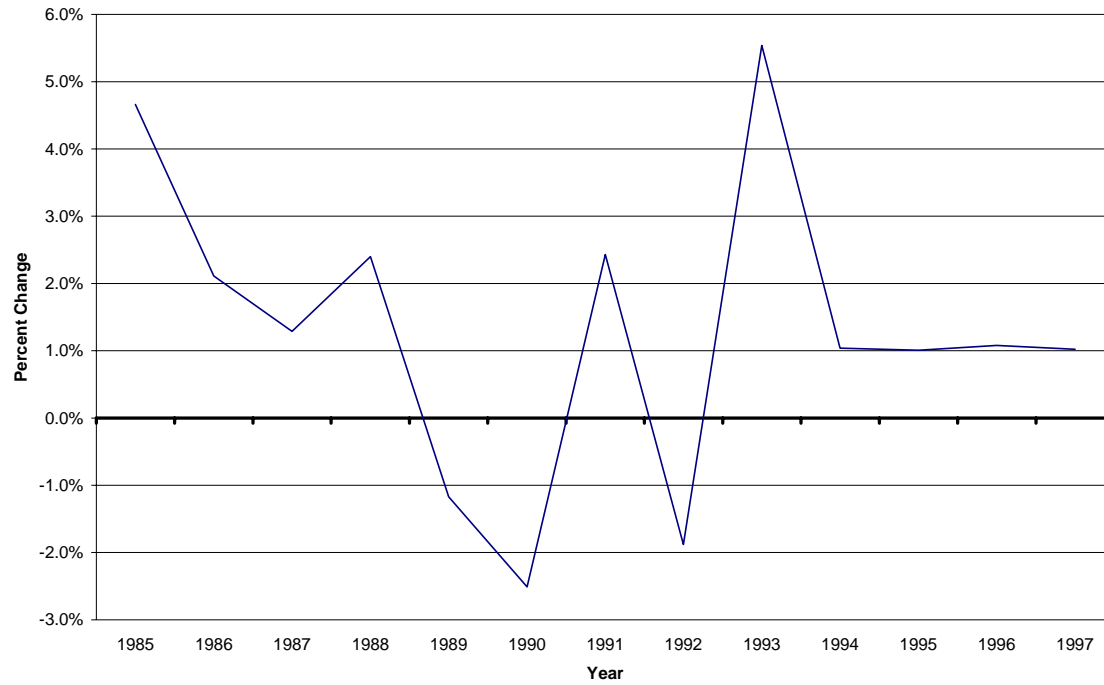
Figure 3B. Annual Awards of Commercial Patents per 10,000 workers in Sweden, 1994-2001
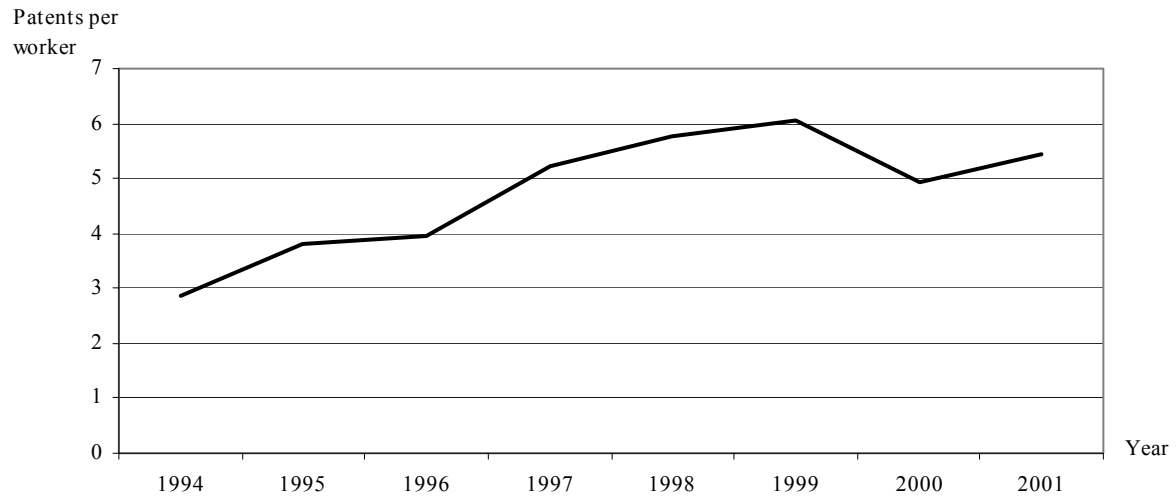
Table 1A provides a summary of the average productivity in municipalities containing the old universities, in municipalities containing the new universities and in municipalities which do not contain universities or colleges. For each of the comparison years, average productivity is higher in municipalities containing the old institutions than in those containing the new institutions. Analogously, Table 1B provides a summary of the patents awarded to inventors residing in labor market areas containing the old universities, those awarded to inventors in labor market areas containing the new universities, and those awarded in labor market areas which do not contain universities or colleges. In 1995, there were about 3.8 patents awarded per ten thousand workers in Sweden -- 4.5 patents per ten thousand workers in labor market areas containing the old universities, 3.4 in labor market areas containing the newly established universities, and 3.1 in labor market areas which do not contain universities or colleges. In 2001, the number of patents increased. However, the same pattern of patents per worker persists in the three types of regions, even though the patents per worker in regions with older institutions increased rapidly.

Of course, many other factors have much larger effects upon productivity and patent activity than the factors identified in the comparisons in Tables 1A and 1B. For one thing, the largest and most heavily developed metropolitan regions in Sweden are all labor market areas that contain the old established universities. For another thing, the distribution of firms with different patterns of productivity per worker (particularly large chemical and pharmaceutical firms with a great deal of patent activity) is heavily concentrated by city and region.

Figure 4. Patents approved (PA) per thousand inhabitants 1994–2001. Sites of the old universities are indicated by a black dot.
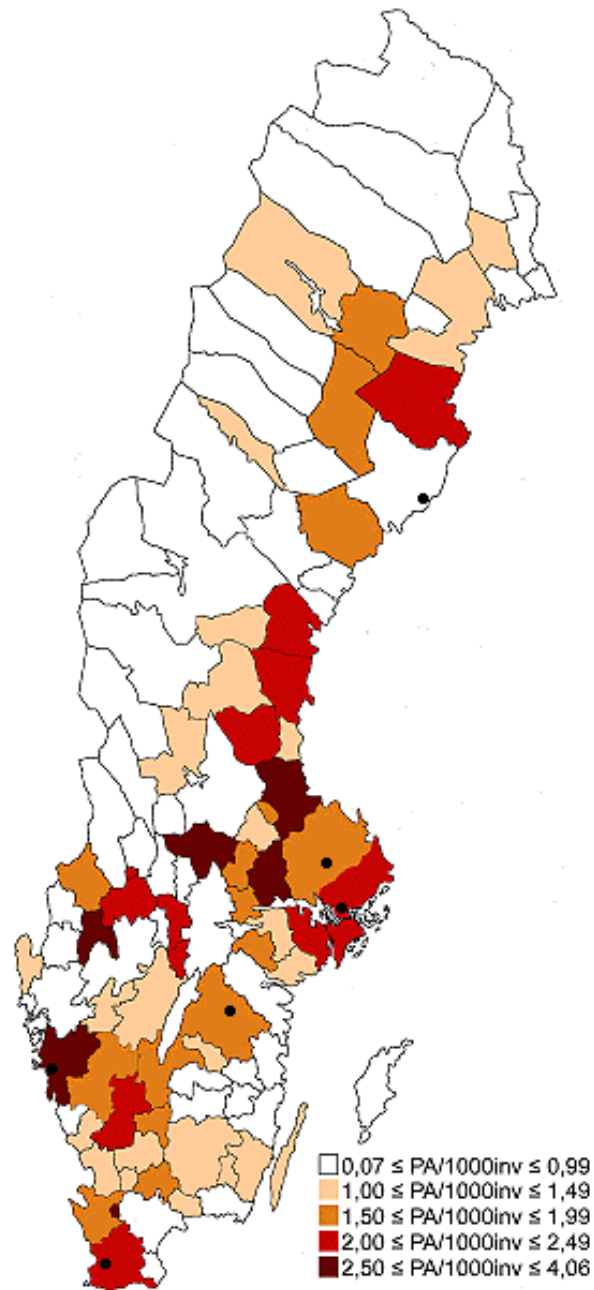
Table 1A

Average Productivity in Municipalities
Containing "New" and "Old"
Institutions of Higher Education
(Output per worker, thousands of SEK)

Year	1985		1990		1995	
Measure	Productivity	Change in Productivity	Productivity	Change in Productivity	Productivity	Change in Productivity
Average	200	19	299	19	405	9
In labor market with						
New Institutions	194	9	284	14	393	20
Old Institutions	201	19	310	24	425	22
Neither New nor Old	202	19	299	18	399	17

Table 1B

Patents Awarded in Labor
Market Areas Containing "New" and "Old"
Institutions of Higher Education
(Number of Patents)

Year	1995		2001		total 1995-2001	
Patents	Number of Patents	Patents Per Worker (0000)	Number of Patents	Patents Per Worker (0000)	Number of Patents	Patents Per Worker (0000)
Total	1,465	3.80	2,231	5.43	13,934	5.03
In labor market with						
New Institutions	303	3.42	488	4.13	3,770	4.48
Old Institutions	786	4.49	1,387	7.01	7,805	6.03
Neither New nor Old	376	3.00	356	3.75	2,359	3.72

5. Statistical Models of Productivity

We analyze productivity and patent activity over time and space using a model with fixed effects, that is, indicator variables for each of the municipalities and labor market areas and for each year. In this formulation, the distinctive characteristics of each municipality or labor market area are held constant, as are the distinctive characteristics of each time period. Identification is achieved through changes in productivity and patent activity within geographical areas and years.

First, we analyze the link between university inputs and productivity. In the next section we consider the relationship with patents. Our models estimate the effects of university-based researchers on the productivity of local areas, and they compare the effects for the older established (pre-1977) universities with those for the newer, smaller, and less centralized institutions established since then. The geographical areas are generally quite small, and our research design attempts to control for potential spillovers across geographical boundaries in a variety of ways. The general form of the model is:

$$(1) \qquad \log P_{it} = \alpha\, E_{it} + \sum_{j} \beta_{j} M_{j} + \sum_{k} \gamma_{k} T_{k} + \varepsilon_{it}$$

The dependent variable is worker productivity, output per worker, P_{it}, in community i in year t. E_{it} characterizes post secondary education in community i in year t. M_j and T_j are fixed effects; M_j is a dummy variable with a value of one for municipality $i=j$ and zero otherwise ($i{\neq}j$), and T_k is a dummy variable with a value of one for year $t=k$ and zero otherwise ($t{\neq}k$). α, β, and γ are estimated parameters, and ε is an error term.

In our regressions, we measure E by the number of university-based researchers (R) employed in the community. In other regressions, we distinguish between university-based

researchers employed at the 'old' and the 'new' institutions (R^o and R^N, respectively). In still other models we distinguish those university-based researchers trained in technical specialties.

We estimate several models and variants to account for intercommunity spillovers arising from the economic activity stimulated by investment in post secondary institutions. In the most straightforward of these extensions, we include a gravity variable summarizing the distance of each community to the universities and university researchers employed in all other communities. In linear models, we include an additional variable, $\sum_{j \neq i} R_{jt} / d_{ij}^2$, where d_{ij} is the distance between community i and community j. The gravity measure weights the university research activity in each of the other communities inversely proportional to the square of its distance to that jurisdiction.

We also recognize that the decentralization "experiment" did not employ random assignment in the geographical distribution of new institutions of higher education. The 278 communities and 83 labor market areas without a university at the time of the adoption of the policy were not equally likely to have established a university subsequently.

Although the historical record clearly specifies that the location of only one of the new facilities was chosen for economic considerations, there may be systematic determinants of the choices of locations for these new facilities. For our purposes, the most important issue is whether the sites chosen were those which were poised for economic development and increased patent activity anyway.

To address this issue, we also present instrumental variables estimates of equation 1. As instruments for the presence of a university and for the number of researchers, we employ a vector of variables indicating the number of students enrolled in each of the following facilities in each community in each year: military facilities; nursing schools; secondary engineering schools;

and preschool teacher training facilities. Students at these facilities have a negligible effect upon current productivity, but the presence and scale of these facilities do affect the ease of expanding university presence into any community (See note 3 above).

Table 2 reports the coefficients of these models, ordinary least squares regressions and instrumental variables estimates. Panel A reports estimates of the log linear specification in Equation (1). Panel B reports the results using a logarithmic specification (and incrementing the number of researchers by one, e.g, log [R+1], etc.). The OLS models clearly indicate a link between the number of university researchers in a community and the output per worker in that community. This productivity link is highly significant for post graduate researchers employed at both the old and the new educational institutions. However, the coefficient indicating the importance of post graduate researchers is almost ten times as large for the new institutions as for the older institutions. The pattern is unchanged when the distances among municipalities are controlled for in a gravity representation. But these latter models suggest that there are spillovers across communities in the productivity linkages; university post graduate researchers in a community also increase productivity in neighboring communities.

The results from the IV estimates are essentially the same. These latter estimates utilize only pre-determined data on utilization of other educational facilities -- data on the location of infrastructure suitable for conversion to facilities for higher education. Thus the results provide no evidence that the locations chosen for university expansion were those which were otherwise poised for economic development and, presumably, for increased patent activity as well. The qualitative results are quite consistent across specifications.

Table 2

Estimates
of the Effects of Universities on
Productivity, by Municipality
1986-1998
(t ratios in parentheses)

	OLS Estimates				IV Estimates			
A. Log linear Models								
	L1	L2	L3	L4	L5	L6	L7	L8
$R \times 10^4$	0.613	0.649			0.530	0.560		
	(3.67)	(3.89)			(3.59)	(3.81)		
$R_n \times 10^4$			4.580	4.955			4.113	4.450
			(2.99)	(3.24)			(2.81)	(3.05)
$R_o \times 10^4$			0.575	0.608			0.500	0.528
			(3.43)	(3.64)			(3.38)	(3.58)
$Gr \times 10^4$		2.296		2.351		1.910		1.954
		(5.07)		(5.19)		(4.85)		(4.96)
B. Log Log Models								
	L9	L10	L11	L12	L13	L14	L15	L16
ln R	0.016	0.017			0.018	0.019		
	(4.86)	(5.15)			(5.19)	(5.44)		
ln R_n			0.016	0.017			0.017	0.018
			(4.67)	(4.97)			(4.93)	(5.19)
ln R_o			0.109	0.116			0.090	0.097
			(3.30)	(3.52)			(3.36)	(3.61)
ln Gr		0.217		0.230		0.156		0.171
		(3.09)		(3.27)		(2.50)		(2.74)

Note: Gr represents the coefficient for $\sum_{j \neq i} R_{jt} / d_{ij}^2$ where d_{ij} is the distance between communities i and j. All models include fixed effects for 284 municipalities and 13 years.
The sample consists of a panel of 3692 observations on output per worker by municipality and year.

Figures 5A and 5B provide a non-statistical summary of these results. Figure 5A plots the average productivity in those communities which received a new university and a post graduate research staff ("treatment") with those communities which did not receive a university ("control"). Productivity in each community is measured relative to its value in 1986. Figure 5B compares the productivity of three groups of communities: those in which a new university was established; those in which a university had previously been established; those without a university. From either figure, it seems clear that output per worker in a community increased after the establishment of the university in that community. Trends in productivity in the communities with newly established universities are quite similar to those with the older established universities. Productivity trends in communities without a university are lower.

The IV results in Table 2 give this a more precise interpretation. The coefficients of model L8 suggest that the introduction of 100 additional post graduate researchers in a newly established university augments local productivity by 5.1 percent while the introduction of the same number of researchers in communities containing older established universities augments productivity by 0.6 percent. The introduction of 100 additional researchers in a community ten kilometers away increases local productivity by 2.4 percent. These effects are precisely estimated.

The differential effects of additional university researchers at "new" and "old" institutions on productivity are consistent across models, and they do not arise simply as an artifact of the log linear specification of equation (1). For example, according to the simplest OLS model, L3, with a log linear specification, an augmentation of 100 post graduate researchers at an older established university increases productivity by 0.6 percent while the equivalent investment at a newer institution increases productivity by 4.6 percent. Using the analogous logarithmic specification, L11, we estimate an augmentation of 100 post graduate researchers at an older

Figure 5A. Relative Productivity Before and After Establishment of Research Staff
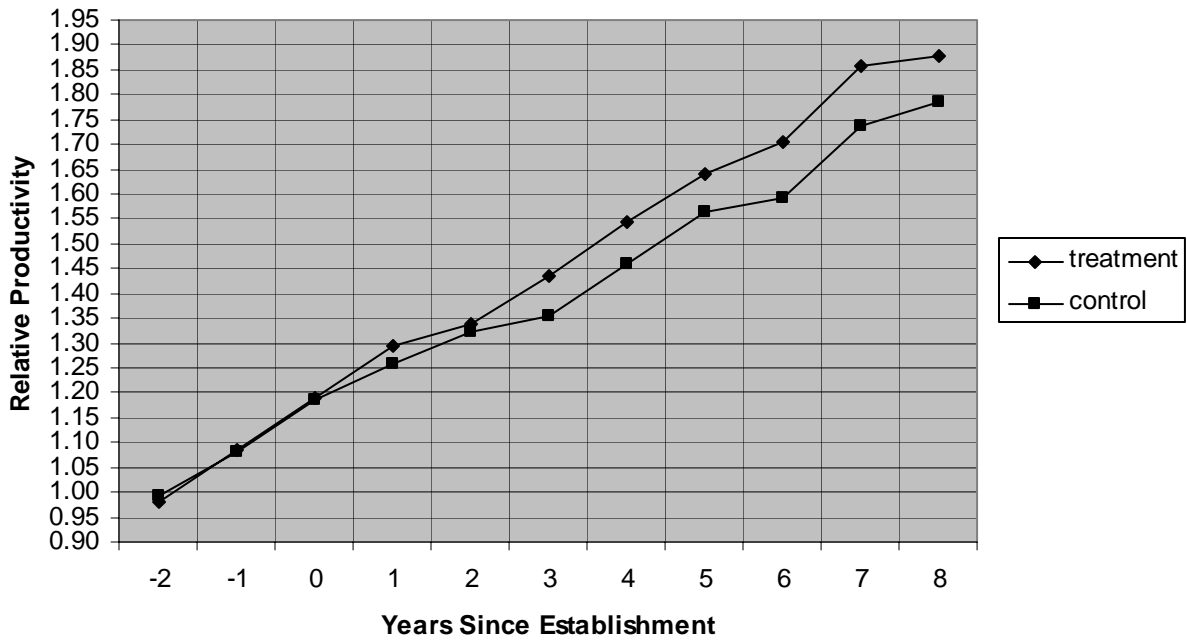
Figure 5B. Relative Productivity Before and After Establishment of Research Staff
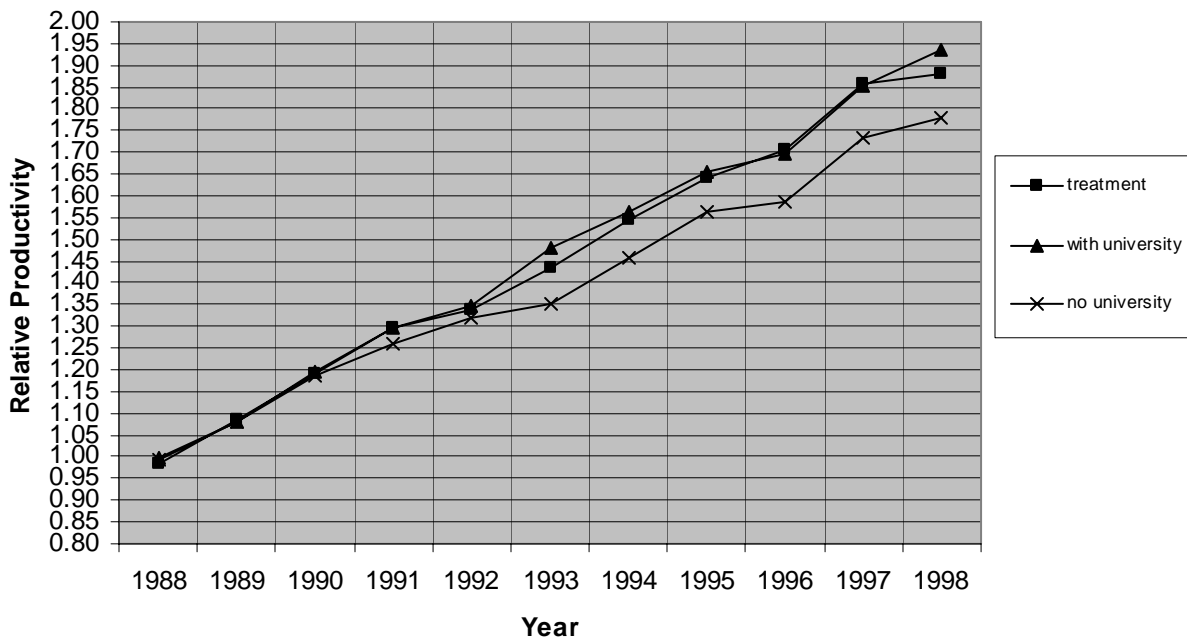
established University increases productivity by 0.4 percent while the equivalent investment at a newer institution increases productivity by 2.5 percent.[12]

6.   Statistical Models of Creativity

We analyze the effects of university decentralization on creativity in a parallel manner, using methods appropriate to the analysis of patent count variables.

We assume that the number of patents, η_{it}, awarded in labor market area i in year t is distributed as,

$$(2) \ \operatorname{prob}\left(\eta_{\text{it}} = y_{it}\right) = \frac{e^{-\mu_{it}\lambda_{it}}\left(\mu_{it}\lambda_{it}\right)^{y_{it}}}{y_{it}!} \, ,$$

for $y_{it} = 0, 1, 2, ...$

In this formulation, the left hand side represents the probability that the number of patents in labor market i and year t, η_{it}, equals the number y_{it}.

We further assume that

$$(3) \ \log \lambda_{it} + \log \mu_{it} = X_{\text{it}} \, ,$$

that is, the parameter λ_{it} is log linear in a vector, X, of regressors describing the labor market area i and the time period t. If $\mu_{it} = 1$, the mean and the variance of the count distribution are equal,

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[12]   These conclusions are also robust to estimation by instrumental variables and to the recognition of spatial factors in the model. Using the coefficients of model L7, it is estimated that an augmentation of 100 researchers increases productivity by 0.5 percent at old universities and 4.1 percent at new universities. Using model L15, the estimated productivity increases are 0.3 percent and 2.7 percent respectively. Finally, using model L8 (model L16) the estimated productivity increases are 0.5 percent (0.3 percent) at old institutions and 4.4 percent (2.9 percent) at new institutions.

and equation (2) is a straightforward poisson model. If the mean and variance of the count distribution are unequal, the parameters of the model may be represented as an equally straightforward negative binomial count model.[13] We define a set of regressors,

$$(4) \quad X_{it} = \delta E_{it} + \sum_{j} \beta_j L_j + \sum_{k} \gamma_k T_k$$

where E_{it} characterizes post secondary educational institutions in labor market area i in year t. L_j is an indicator variable with a value of one for labor market area $j=i$ and zero otherwise; T_k is an indicator variable with a value of one for year $t=k$ and zero otherwise. As before, δ, β, and γ are parameters.

The effects of university decentralization upon innovative activity are identified by changes in measures of university activity within each labor market area over time. To estimate the model, we include a complete set of fixed effects for each time period and labor market area using a maximum likelihood estimator. As shown by Blundell, Griffith and Windmeijer (2002), this is equivalent to the conditional maximum likelihood estimator proposed by Hausman, Hall, and Griliches, HHG (1984). We test whether the constant variance is equal to the mean (See Cameron and Trivedi, 1998, pp 282-284) by estimating the parameters of the negative binomial model.

We relate the decentralization in educational policy to the level of innovative activity, as measured by patents granted three years after the educational investments (See also Fischer and

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[13] This follows directly, if it is assumed that μ_{it} follows a gamma distribution, $\mu_{it} \sim Gamma\left(1/\alpha, \alpha\right)$. If $\alpha=0$, the model is poisson. If $\alpha > 0$, the model is negative binomial.

Varga, 2003, and Verspagen and De Loo, 1999). In particular, for each labor market area and year, we record the number of university-employed post-graduate researchers R_{it}. We also record the number of research staff at each university employed in technical research specialties.

Table 3 presents the basic results. The table relates the number of patents in any labor market area and year to the number of post graduate researchers employed at universities in that labor market (L). Research staffs are further disaggregated between those employed at new (R_n) and old (R_o) universities for all staff and for those in technical occupations.

Columns 1, 2, and 3 suggest that the number of post graduate researchers is associated with higher levels of innovative activity, holding constant the important unmeasured characteristics of these differing labor market areas. The total number of patents in any of these regions is 15,805 during the 1994-2001 period or about 200 per year in a given labor market area. From column 1, the addition of a single post graduate researcher increases the number of patents in any labor market area by a factor of exp(.000113) or by almost 0.01 percent in any year.

In column 2 (model M2), we disaggregate the research staff by those employed at the old universities and those employed at the new institutions. Both measures are highly significant, but the coefficient estimated for researchers at the new universities (.00244) is larger by an order of magnitude than the coefficient estimated for researchers at the old established universities (.0000953). When researchers in scientific and technical occupations are considered separately, the significance of the coefficient measuring post graduate staff is reduced (to the five to ten percent level for a one-tailed test) at new universities. However, the magnitude of the coefficient for researchers at new universities is again larger by an order of magnitude than is the estimated coefficient for researchers employed at the older institutions.

Table 3 also presents the results from the more general negative binomial model, reported as models N1 through N3. We relax the maintained hypothesis in the poisson model that the mean and the variance of the count distribution are equal, but, we follow HHG in estimating separately a common mean and common variance for the count distribution.

The more general negative binomial model clearly fits the data better; alpha is significantly different from zero, rejecting the poisson specification. The estimated mean of the distribution is significantly smaller than the variance, as indicated by a comparison of the values of the log likelihood function in Table 3. The qualitative results of the model are similar, but the magnitudes of the coefficients measuring the importance of post graduate research staffs in affecting patents activity are uniformly larger in these more general models.

Conditional upon the establishment of an educational institution in a region, the marginal effect of an increase in the research staff upon patent activity is not trivial. And the marginal effects on creativity of adding research staff at the new institutions is estimated to be consistently larger than the effects of adding staff at the older, more established institutions.

For example, from model M2 it is estimated that an additional research complement of ten individuals at a new institution leads to an increase in patents of about 2.4 percent while a similar increase in research staff at an older institution leads to an increase in patents of about 0.1 percent.[14] This difference does not appear to arise from a different mix of technical and non-

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[14]   Specifically, at the point of means, from equation M3 ten additional post graduate researchers yield 2.05 patents in the new institutions and 0.16 patents in the old institutions.

Table 3

Estimated Parameters of Poisson (M1 to M3) and Negative Binomial (N1 to N3) Models of Patent Counts

(t ratios in parentheses)

	Poisson Estimates			Negative Binomial Estimates		
	M1	M2	M3	N1	N2	N3
R x 10^4	1.130	-	-	2.293	-	-
	(4.41)			(3.71)		
Rn x 10^4	-	24.411	-	-	25.635	-
		(3.08)			(2.52)	
Ro x 10^4	-	0.954	-	-	1.739	-
		(3.70)			(2.91)	
Rn-technical x 10^4	-	-	37.462	-	-	49.078
			(2.03)			(2.21)
Ro-technical x 10^4	-	-	2.345	-	-	3.267
			(6.33)			(3.76)
alpha	-	-	-	0.014	0.013	0.012
				(5.32)	(3.98)	(3.72)
Pseudo R2	0.934	0.934	0.935	0.400	0.400	0.400
Log L	-1771.147	-1768.430	-1760.254	-1731.768	-1731.698	-1730.535

Note: alpha provides a test of hypothesis that the count distribution is poisson. All models include fixed effects for 100 labor market areas and 8 years. The sample consists of a panel of 800 observations on patent counts by labor market area and year.

technical research staffs at the two institutions. For example, from model M3 which considers only post graduate researchers in technical specialties, an increase of ten technicians yields an increase in patents of 3.8 percent in the newer institutions and about 0.2 percent in the older institutions.[15] Of course all these comparisons abstract from the many other, and presumably more important, aspects of these different labor market regions which affect creativity and innovation. The fixed effects distinguishing these one hundred labor market areas are large and highly significant in all specifications.

7. Spillovers, Externalities, and Interactions

How localized are the productivity and creativity increases attributable to these public investments? The spatially disaggregated data on individual municipalities and labor market areas provides some opportunity to explore the extent of spatial agglomeration and externalities.

Table 2 hints at the importance of spillovers in productivity gains over space. In both of the statistical models reported, the gravity measure is statistically significant, suggesting the presence of spatial agglomeration. However, the values of Moran's I Statistics are also quite large, suggesting that the simple gravity model does not capture the underlying spatial relationship very well.[16]

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[15] Note again that we cannot distinguish, in these models, between the direct effects of university resources in stimulating innovation and the indirect effects arising from the location of other facilities in response to the investments in university facilities.

[16] For example, for model L1 Table 3, the value of Moran's I is 8.741. When the model is extended to include the gravity representation of space, in L2, the value of Moran's I is smaller, 7.823. However this latter value is still highly significant statistically, suggesting the presence of spatial autocorrelation in the data.

As an alternative, we consider a general spatial lag model, incorporating spatial structure explicitly into the model:[17]

(5) $\log P_{it} = \rho \sum_{j \neq i} W_{ij}^1 \log P_{jt} + E_{it} + ... + \varepsilon_{it}$

$\varepsilon_{it} = \lambda \sum_{j \neq i} W_{ij}^2 \varepsilon_{it} + \upsilon_{it}$.

In this formulation, the productivity of labor in any municipality also depends upon the productivity of labor in neighboring towns. In response to an exogenous change in university investment in one municipality, productivity in neighboring municipalities may be enhanced as well. In the spatial error formulation, ρ indicates that productivity depends directly upon the productivity other municipalities, where W_{ij}^1 are the weights. Analogously, the parameter λ is the coefficient in the spatial autoregressive structure, and W_{ij}^2 are the weights for the errors in other municipalities. If there are no priori reasons to suppose that the spatial interaction patterns are different, then $W_{ij}^1 = W_{ij}^2$, and ρ and λ are not separately identified.

In this spatial application, we assume $W_{ij}^1 = W_{ij}^2 = 1/d_{ij}^2$ that is, we assume that the weight matrix is of the form of the gravity model. If ρ defines the autoregressive spatial structure in equation (5), $\lambda = 0$, we can estimate the Spatial Autoregressive Model (SAR):

(6) $\log P_{it} = \rho \sum_{j \neq i} \left(1/d_{ij}^2\right) \log P_{jt} + E_{it} + ... + \varepsilon_{it}$

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[17] Anselin (1998) is the standard reference documenting these spatial models.

Table 4

Spatial Autoregressive Models of the Effects of Universities on Productivity, by Municipality
1985-1998
(asymptotic t ratios in parentheses)

	SAR Estimates		SEM Estimates	
	S1	S2	S3	S4
Rn x 10^4	2.808	3.064	2.888	3.043
	(1.97)	(2.16)	(2.04)	(2.15)
Ro x 10^4	0.082	0.098	0.061	0.119
	(1.20)	(1.44)	(0.91)	(1.75)
Gr x 10^4	-	0.944	-	0.984
		(4.41)		(4.14)
λ	-	-	0.239	0.182
			(39.03)	(25.96)
ρ	0.238	0.196	-	-
	(128.36)	(109.80)		

Note: Gr represents the coefficient for $\sum_{i \neq i} R_{jt} / d_{ij}^2$ where d_{ij} is the distance between communities i and j. The sample consists of a panel of 3976 observations on output per worker by municipality and year.

Alternatively, if λ defines the autoregressive spatial structure, $\rho=0,$ we can estimate the Spatial Error Model (SEM):

(7) $\log P_{it} = E_{it} + ... + \varepsilon_{it}$

$$\varepsilon_{it} = \lambda \sum_{j \neq i} \varepsilon_{jt} / d_{ij}^2 + \upsilon_{it}$$

Table 4 reports the coefficients of the SAR and SEM models, estimated by maximum likelihood methods, assuming normality of the error terms.   As reported in the table, when spatial autocorrelation is recognized in the models, the coefficients of the other variables are reduced in magnitude and statistical significance. But the basic pattern of coefficients is unchanged. The alternate models of spatial autocorrelation yield quite similar results in terms of magnitude and significance. Either measure of spatial dependence, ρ or λ, is highly significant.

In models relating productivity to the number post graduate researchers, the coefficient on the number of researchers in the same community is highly significant. The magnitudes of the coefficients on university researchers are smaller in these models which incorporate spatial auto-correlation and the broader productivity linkages among municipalities.   In all cases, the coefficients indicate that productivity is higher in communities in which more university-based researchers are employed. These results are significant at the 0.15 level. We also find clear evidence that this effect is substantially larger for those researchers employed at the newer institutions than for those employed at the older institutions. Finally, we find that productivity is greater in communities in closer proximity to pools of university-based researchers. This latter finding is consistent with results reported by Adams (2002) for U.S. academic institutions.

Spillovers in creativity are less likely to be uncovered, in part due to the more aggregate representation of space. As noted above, we measure patent counts annually at the level of the labor market area.   There the only 100 labor market areas in Sweden (as compared to 284

municipalities), and their boundaries are chosen to maximize the within-area economic relationships relative to the between-area relationships. Nevertheless, it is possible to conduct a parallel effort to test for spatial linkages.

Consider the spatial poisson model, equations (2)-(4) but in which equation (4) is replaced by

$$(4') \quad X_{it} = \xi \sum_{i \neq j} W_{ij}^3 \eta_{jt} + \delta \, \mathrm{E}_{it} + \sum_j \beta_j L_j + \sum_k \gamma_k T_k \, .$$

In this model, the patent count in any one labor market is related to the patent count in all other labor market areas. As before, W_{ij}^3 is a weight matrix involving the distances between labor market areas, and ξ is a parameter. A variant of this model, the class of spatial poisson regression models, is described in Best, *et al* (2000).[18] Related models, with epidemiological applications, are discussed in Elliot, *et al* (2001). The model can be estimated iteratively using Bayesian methods.

Table 5 reports the results of this investigation of potential spillovers in patent activity. We use the nearest neighbor technique[19] to define the weight matrix, W^3, again using $1/d_{ij}^2$ as elements of W_{ij}^3. We investigate the same models analyzed in Table 4. Parameters of the spatial poisson model are estimated using Geobugs.[20] The magnitudes of the estimated coefficients are

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[18] In the application by Best *et al* (2000), a slightly different specification of the spatial relationship in (4') is used to analyze spatial correlation in the distribution of counts measuring the incidence of respiratory ailments across geographical areas. In a related application, Ickstadt and Wolpert (1997) analyzed the spatial distribution of hickory trees in different plots situated in a forest.

[19] See Anselin (1998) for a through discussion.

[20] We are grateful to Nicky Best for making an advance version of release 4.1 available to us for this purpose. In our applications, we use 1000 "burn in" iterations to derive starting values for the coefficients, and we use another 1,000 iterations to produce coefficient estimates. Results are insensitive to these choices. These results are also insensitive to the inclusion or exclusion of fixed effects.

larger in these estimates, but the pattern of the coefficients is identical to those reported previously. The coefficient of the variable measuring the number of university-affiliated post graduate researchers is significant, as is the number at new institutions, and the number of technical researchers at new institutions. The coefficient on the number of researchers is consistently higher for the new universities than for the old institutions.

There is no evidence in these results of spatial autocorrelation in the patent counts across labor market areas. The coefficient ξ is not precisely estimated to be zero, but its standard error is quite large in all specifications. This contrasts with our finding of spatially correlated productivity effects. Of course, the productivity effects are measured for much smaller geographical units of observation. The regions used for the analysis of patents are both larger [21] and are constructed to maximize the intra-regional economic linkages relative to the inter-regional linkages. Thus, it should not be surprising that, at this level of detail, spatial autocorrelation cannot be detected.

Finally, our spatially disaggregated data supports some investigation of the importance of human capital externalities and the absorptive capacity of regions in affecting productivity and creativity. In particular, for each of the labor market areas and municipalities, we can measure the fraction of the labor force with Ph.D. degrees in each year. Table 6 summarizes the importance of this factor in conditioning the effects of post graduate university researchers on output per worker and patent activity.

The table reports the results of including a variable measuring the fraction of PhD's in the labor force and its interaction with the number of researchers at old universities. In models of patent counts this measure of labor force quality is generally significant (even in models that

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[21] For example, the Stockholm labor market area includes some 27 municipalities.

include fixed effects for 100 labor market areas). In models of productivity, the coefficient exceeds its standard error but is insignificant (in models that include fixed effects for each of the 284 municipalities). The interpretation of this result is problematic since, as emphasized by Moretti (2004), regional variation in human capital may simply be endogeneous.

However, the results also suggest that the importance of researchers at the new universities in increasing local productivity and creativity is larger in regions with a more highly educated labor force. Regions with higher fractions of educated labor are those where the effects of new universities on productivity and patents is larger.

8.   Conclusion

During the past fifteen years, Swedish higher education policy encouraged the decentralization on of post secondary education. We investigate the spatial and economic effects of this decentralization on productivity and creativity. We provide several tests of the hypothesis that the establishment or expansion of university research in a region improves productivity and enhances creativity. We find systematic evidence that output per worker is higher and the award of patents is greater in regions that have received larger university-based investments as measured by the number of researchers employed on staff. We also find that changes in productivity are higher and new patent awards are more frequent in regions in which the "new" universities and institutions are located than in regions in which the "old" universities are located.

Our analysis permits us to hold constant the important factors affecting economic activity by municipality, labor market area and time, thereby improving the precision of estimates. The

Table 5
Estimated Parameters of Spatial Poisson Models of Patent Counts
(asymptotic t ratios in parentheses)

	M1	M2	M3
R x 10^3	5.665	-	-
	(1.95)		
Rn x 10^3	-	5.994	-
		(3.96)	
Ro x 10^3	-	3.826	-
		(1.42)	
Rn-technical x 10^3	-	-	10.470
			(3.39)
Ro-technical x 10^3	-	-	1.037
			(1.52)
ξ	4.588	0.247	1.270
	(0.00)	(0.00)	(0.000)
Log L	-6240	-4312	-6280

Note: ξ represents the coefficient for $\sum_{j \neq i} W_{ij}^3 \eta_{jt}$ where η_{it} is the patent count in labor market j in year t and the weight matrix $W_{ij}^3 = (1/d_{ij}^2)$ is based upon the nearest neighbor method. All models include fixed ef

Table 6

Estimated Interactions Between University Researchers and the Education of the Workforce on Productivity and Creativity

	Creativity				Productivy	
	Poisson	Poisson*	Neg Bin	Neg Bin*	SAR	SEM
Rn x Phd_ratio x 10^4	4713.12	8321.40	4621.71	8918.23	458.842	456.223
	(4.20)	(3.06)	(2.89)	(2.61)	(1.93)	(1.93)
Ro x Phd_ratio x 10^4	-29.16	29.56	10.15	69.39	-4.320	-4.182
	(1.62)	(1.19)	(0.29)	(1.34)	(-1.11)	(-1.06)
Phd_ratio	133.70	95.50	78.38	64.15	0.954	1.053
	(4.48)	(3.38)	(1.82)	(1.57)	(1.19)	(1.27)
Gr					0.793	0.779
					(3.29)	(3.03)
ρ					0.196	-
					(107.23)	
λ					-	0.180
						(25.50)
Pseudo R2	0.9350	0.9350	0.4008	0.4007	0.2154	0.2142
Log L	-1749.80	-1752.98	-1728.30	-1728.56	-11228.34	-11230.57

Note: All models include fixed effects for 100 labor market areas and 284 municipalities. Productivity Models are estimated for 1986-1998. Creativity Models are estimated for 19XX-19XX.

*These models use the number of post doctoral university researchers in technical specialties and are estimated for 19XX-19XX.

results are broadly consistent across theoretical models and statistical results. There is strong evidence that an expansion of university presence in a region, measured by the number of university-based researchers, is associated with increased output per worker and with increases in the patents awarded to inventors in that community.

The importance of the university in affecting productivity and creativity is consistently larger at the margin for the new institutions. For patents, at least, this could arise if the new institutions specialize more narrowly in technical specialties than do the more traditional institutions of higher education. Of course, some of the new institutions are, in fact, expansions of institutions that formerly provided some technical training (e.g. military facilities). This may explain some of the differences.[22]

Our findings also suggest that there are substantial, but highly localized, spillovers in productivity gains over space. For example, the coefficients reported in Table 4 suggest that more than half of the productivity gains from new universities are manifest within about 5 kilometers of the institution; about a third of the productivity gains from the older established universities are manifest within 5 kilometers of the institution. Table 7 reports these calculations.

These findings are consistent with a growing body of empirical research in other countries on the agglomerative tendencies of so-called "knowledge industries." Saxenian (1994), for example, suggested that knowledge generated at a firm in the U.S. is more likely to spill out locally if it originates in a small firm. Conversely, Henderson's analysis (2003) of U.S. high tech

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[22] Without conducting a more anthropological investigation, it is not possible to resolve this. But some collateral information is suggestive of a more commercial and industrial orientation among (some) of the new institutions. Thus, Karlstad University in the heart of the Swedish pulp and paper region boasts a substantial research program in "Forests, environment, and materials,"(at http:www.kau.se/eng/research/forests.lasso) and Luleå University has an institute of "Applied Physics…" and another of "Applied Chemistry…" (at http:www.ltu.se/pub/jsp/plopony.jsp?d=10da=159).

Table 7. Cumulative Productivity Gains at Various Distances from the University (as a percentage of the total gains).

Distance in Kilometers	SAR Model		SEM Model	
	New institution	Old institution	New institution	Old institution
1	40%	15%	40%	15%
5	53	32	52	33
10	59	41	58	41
15	63	47	62	47
20	65	50	65	50
30	69	56	69	56

Note: Computed from results reported in Table 4, columns 2 and 4.

industry at the plant level suggests that smaller firms are more likely to benefit from local agglomeration. Rosenthal and Strange (2003) found that small establishments in the knowledge industry have larger effects on locational attractiveness than larger ones. In an earlier paper using micro data from Dunn and Bradstreet, they also found (Rosenthal and Strange, 2001) that proxies for knowledge spillovers in the U.S. affect firm agglomeration only at the very local (postal code) level. Two other analyses of U.S. industry suggest that local externalities and agglomerative economies greatly attenuate with distance. Rosenthal and Strange (2005a) analyzed manufacturing, trade and services in New York, finding that agglomerative effects on firm births and employment decline rapidly over space. (They attribute this attenuation to the "high costs of moving ideas" over space.) They also analyzed nationally representative data for the U.S. (Rosenthal and Strange, 2005b), finding that the effects of urbanization economies on worker productivity may be only one fourth as large at distances over 8 kilometers as it is at closer distances.

The results of our analysis of Swedish productivity are consistent with these findings. We find highly significant, but highly localized, external effects arising from the geographical locations chosen for these new institutions of higher education.

Finally, it is also possible, at least in principle, to estimate the net change in output and patent activity arising from the spatial rearrangement of researchers. Using the results presented in Table 3, for example, the level of innovation in each region can be computed under the counterfactual of no decentralization of Swedish universities. To do this, we reallocate the researchers, employed in the 25 newly established institutions during the period 1995-2001, back to the 11 institutions which had been in existence in 1987. We reallocate researchers to the pre-existing institutions in proportion to their distribution in 1987. A comparison of this counterfactual with actual inventive activity yields the net change in patents arising from the decentralization of higher education. Using the coefficients in Model N3 in Table 3, we estimate that the net effect of this spatial rearrangement to be about zero. Similarly, we can use the results presented in Table 2 to estimate the level of productivity under the counterfactual of no decentralization of Swedish universities. (We use the same counterfactual, and again, we reallocate researchers to the pre-existing institutions in proportion to their distribution in 1987.) Data on the number of workers in each municipality allow us to compare the value of total output with output under the counterfactual. A comparison of this counterfactual with realized output yields the net change in GDP arising from the policy of decentralizing higher education. Using the coefficients of the log linear Models L7 and L8 in Table 2, we estimate the net effect of this spatial arrangement to be an increase in GDP of between 0.01 percent and 0.07 percent.[23] These

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[23] Using the analogous logarithmic models, L15 and L16, the increase in GDP is estimated to be 0.13 to 0.18 percent.

calculations suggest that the increment to GDP is quite large. Indeed, it is roughly as large as the initial contribution to GDP of these workers.

Our findings are consistent with a substantial effect of investment in higher education, augmenting the productivity of local areas and the local economies in which they are situated.

References

Acs, Zoltan, Anselin, Luc and Varga, Attila (2002), "Patents and innovation counts as measures of regional production of new knowledge," *Research Policy 31*(7): 1069-1085.

Adams, James D. (2002), "Comparative Localization of Academic and Industrial Spillovers," *Journal of Economic Geography*, 2(3): 253-278.

Anselin, Luc. (1988), *Spatial Econometrics: Methods and Models.* Dordecht: Kluwer Academic Publishers.

Andersson, Roland (2005), "The Efficiency of Swedish Regional Policy," *Annals of Regional Science*, forthcoming.

Andersson, Roland, John M. Quigley, and Mats Wilhelmsson, (2004), "University Decentralization as Regional Policy: The Swedish Experiment," *Journal of Economic Geography*, 4(4): 371-388.

Anselin, L., Varga, A. and Acs, Z. (1997), "Local Geographic Spillovers between University Research and High Technology Innovations," *Journal of Urban Economics*, 42(3): 422-448.

Audretsch, D. and Feldman, M. (1996), "R&D Spillovers and the Geography of Innovation and Production," *American Economic Review*, 86(3): 630-640.

Best, Nicola G., Katja Ickstadt, and Robert L. Wolpert (2000), "Spatial Poisson Regression for Health and Exposure Data Measured at Disparate Resolutions," *Journal of the American Statistical Association*, 95(452): 1076-1088.

Blundell, Richard, Rachel Griffith, and Frank Windmeijer (2002), "Individual Effects and Dynamics in Count Data Models," *Journal of Econometrics* 108:113-131.

Cameron, A. Colin and Pravin K. Trivedi. (1998), *Regression Analysis of Count Data*, Cambridge, UK: Cambridge University Press.

De första 20 åren. Utvecklingen vid de mindre och medelstora högskolorna sedan 1977 (1998), Stockholm: Högskoleverket (National Agency for Higher Education).

Elliott, *et al* (2001), *Spatial Epidemiology: Methods and Applications,* Oxford: Oxford University Press.

Fischer, Mafred M. and Attila Varga (2003), "Spatial Knowledge Spillovers and University Research: Evidence from Austria," *Annals of Regional Science*, 37:303-322.

Feldman, Maryann (1994), *The Geography of Innovation*, Boston, MA: Kluwer Academic Publishers.

Florax, R. (1992), *The University: A Regional Booster?* Aldershot, Avebury.

Fujita, Masahisa, "A Monopolistic Competition Model of Spatial Agglomeration: A Differentiated Product Approach," *Regional Science and Urban Economics*, 18(1), 1988: 87-124.

Glaeser, Edward L., Heidi D. Kallal, Jose A. Scheinkman, and Andrei Shleifer (1992), "Growth in Cities," *Journal of Political Economy*, 100(6): 1126-1152.

Griliches, Zvi (1979), "Issues in Assessing the Contribution of R&D to Productivity Growth," *Bell Journal of Economics*, 10(1): 92-116.

Griliches, Zvi, ed. (1984), *R&D, Patents and Productivity*. University of Chicago Press, Chicago.

Griliches, Zvi (1990), "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature,* XXVIII: 1661-1707.

Griliches, Zvi (1998), *R&D and Productivity*, Chicago, IL: The University of Chicago Press, Chicago.

Grossman, G. M. and E. Helpman (1991), *Innovation and Growth in the Global Economy,* Cambridge, MA: The MIT Press.

Hausman, Jerry A., Bronwyn H. Hall, and Zvi Griliches (1984), "Econometric Models for Count Data with Applications to the Patents- R and D Relationship," *Econometrica*, 52: 909-938.

Henderson, Vernon (2003) "Marshall's Scale Economies," *Journal of Urban Economics*, 53(1): 1-28.

Henderson, Vernon, Ali Kuncoro, and Matt Turner (1995), "Industrial Development in Cities," *Journal of Political Economy*, 103(5): 1067-1090.

Ickstadt Katja and Robert L. Wolpert (1997), "Multiresolution Assesment of Forest Inhomogeneity," *Case Studies in Bayesian Statistics*, Volume III, edited by Gatsonis, *et al*, Berlin, Springer-Verlag: 371-386.

Jaffe, A. (1986), "Technological Opportunity and Spillovers of R&D: Evidence from Firms Patents, Profits and Market Value," *American Economic Review,* 76: 984-1001.

Jaffe, A. (1989), "Real Effects of Academic Research," *American Economic Review,* 79:957-970.

Jaffe, A., Trajtenberg, M. and Henderson, R. (1993), "Geographic Localization of Knowledge Spillovers an Evidenced by Patent Citations,*" Quarterly Journal of Economics,* 434: 578-598.

Jaffe, A. and Trajtenberg, M., ed. (2002), *Patents, Citations & Innovations. A Window on the Knowledge Economy,* The MIT Press, Cambridge, Massachusetts, London, England.

Krugman, Paul (1991), "Increasing Returns and Economic Geography," *Journal of Political Economy*, 99(3): 483-499.

Lucas, Robert (1988), "On the Mechanics of Economic Development," *Journal of Monetary Economics*, 22(1): 3-42.

Marshall, Alfred (1890), *Principles of Economics*, London: McMillan Co.

Moretti, Enrico (2004) "Human Capital Externalities in Cities," *Handbook of Regional and Urban Economics*, edited by J. Vernon Henderson and Jacques-François Thisse, Amsterdam: Elsevier North Holland: 2243-2292.

Rauch, James E. (1993), "Productivity Gains from Geographic Concentration of Human Capital: Evidence from the Cities," *Journal of Urban Economics*, 34(3): 380-400.

Romer, Paul (1986), "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, 94(5): 1002-1037.

Romer, Paul (1990), "Endogenous Technological Change," *Journal of Political Economy*, 98: 71-102.

Rosenthal, Stuart S. and William C. Strange, (June 2005, 2005a) "The Geography of Entrepreneurship in the New York Metropolitan Area," unpublished paper.

Rosenthal, Stuart S. and William C. Strange, (May 2005, 2005b), "The Attenuation of Agglomeration Economies: A Manhattan Skyline Approach" unpublished paper.

Rosenthal, Stuart S. and William C. Strange (2003), "Geography, Industrial Organization, and Agglomeration," *Review of Economics and Statistics,* 85(2) 377-393.

Rosenthal, Stuart S. and William C. Strange (2001), "The Determinants of Agglomeration," *Journal of Urban Economics*, 50:191-229.

Saxenian, Annalee (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, MA: Harvard University Press.

Verspagen B. and I. De Loo (1999), "Technology Spillovers between Sectors and Over Time," *Technological Forecasting and Social Change*, 60:215-235.

Varga, Attila (1998), *University Research and Regional Innovation*, Boston, MA: Kluwer Academic Publishers.