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University decentralization as regional policy: the Swedish experiment

Roland Andersson, John M. Quigley** and Mats Wilhelmson****

Abstract

During the past 15 years, Swedish higher education policy has emphasized the spatial decentralization of post-secondary education. We investigate the economic effects of this decentralization policy on productivity and output per worker. We rely upon a 14-year panel of output and employment for Sweden's 285 municipalities, together with data on the location of university-based researchers and students, to estimate the effects of exogenous changes in educational policy upon regional development. We find important and significant effects of this policy upon the average productivity of workers, suggesting that the economic effects of the decentralization on regional development are economically important. We also find evidence of highly significant, but extremely localized, externalities in productivity. This is consistent with recent findings (e.g., Rosenthal and Strange, 2003) on agglomeration in 'knowledge industries.'

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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 analyse one aspect of this policy, its economic effect, and we provide evidence on the effects of the decentralization policy upon regional development.

From a broader perspective, there has been intense debate during the past decade about the role of university research, and the spin-offs of that research, in affecting regional growth. The popular press 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 may affect the geographical distribution of economic activity as well as its level.

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At a more theoretical level, Alfred Marshall's insights about agglomeration economies have been made more precise in the work of Barro and Romer, and the role of spatial arrangements in affecting economic growth and development is suddenly respectable in scientific circles. It was only in past decade that these external economies ('economies of localized industry' in Marshall's terms) were formally modeled as endogenous outcomes, literally caused by the co-location of individuals and firms in urban areas. This powerful insight, the new growth theory, has opened up an enormously powerful range of theoretical and empirical research.

In any case, it is now quite natural to consider the putative 'productivity gains from the geographical concentration of human capital' (Rauch, 1993) and to measure spillovers in the returns to the geographical concentration of knowledge industries (Jaffe et al., 1993).

This paper analyses the consequences of the decentralization policy introduced in higher education in Sweden in 1987. We trace the implications of this exogenous change in regional conditions and geographical access upon economic output and productivity. In particular, we investigate the effects arising from decentralizing the concentrations of technical labor (i.e., university-based researchers and technicians) as a concomitant of higher educational policy in Sweden.

Section 2 provides a brief review of Swedish university policies during the recent past. Section 3 surveys the literature on knowledge spillovers and concentrations as they affect economic growth. Section 4 presents the models used in our statistical analysis. Section 5 summarizes our results and conclusions.

2. Swedish university policy

As late as 1977, only six universities operated in Sweden, a country of eight 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: the Royal Institute of Technology; the Karolinska Institute of Medicine; and the Stockholm School of Economics; and two others: the Chalmers Institute of Technology in Göteborg; and the Institute of Agriculture near Uppsala. The locations of these 11 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 new institutions, raising the status of the 14 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.

In almost all cases, the sites chosen for the 11 new institutions of higher education were formerly occupied by teacher training schools, or by military training facilities. 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). In only one instance is there any indication that regional economic considerations affected the location chosen for a new institution.[1]

1 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 training activities. See *De första 20 åren*, 1998, for an extensive discussion.

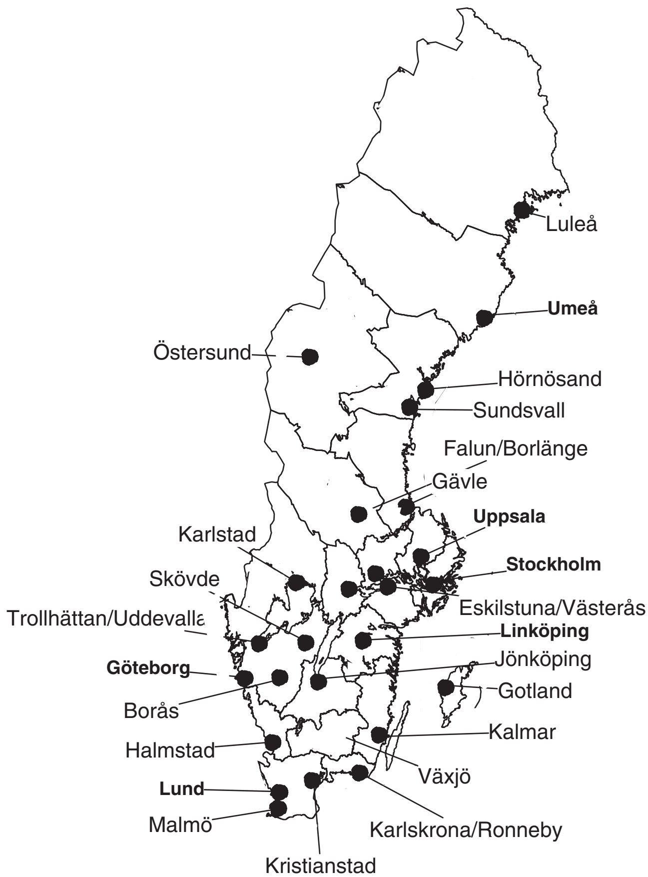

Figure 1. Location of institutions of higher education in Sweden.

Location of pre-1977 Institutions in Bold.

Despite the change in status, new institutions of higher education developed relatively slowly during the first ten years after reorganization. Thus, the number and distribution of students between the universities and 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 has more than doubled while the number of students at the older universities has increased half again. Moreover, the resources for research at the small and medium-sized colleges have been increased, particularly during the most recent period. By 1998, the small and medium-sized colleges had a total of 84,000 students. At that time, more than a third of all the students enrolled in higher education attended one of these colleges. Figure 2 indicates the growth in enrollment and in research capacity in the newer institutions.

The expansion of these regional colleges is generally considered an important part of the government's regional policy, perhaps the most important one. During this period, a new college was established in Södertörn in the south suburbs of Stockholm; another one was established in Malmö. Four of the larger colleges were upgraded to the status of

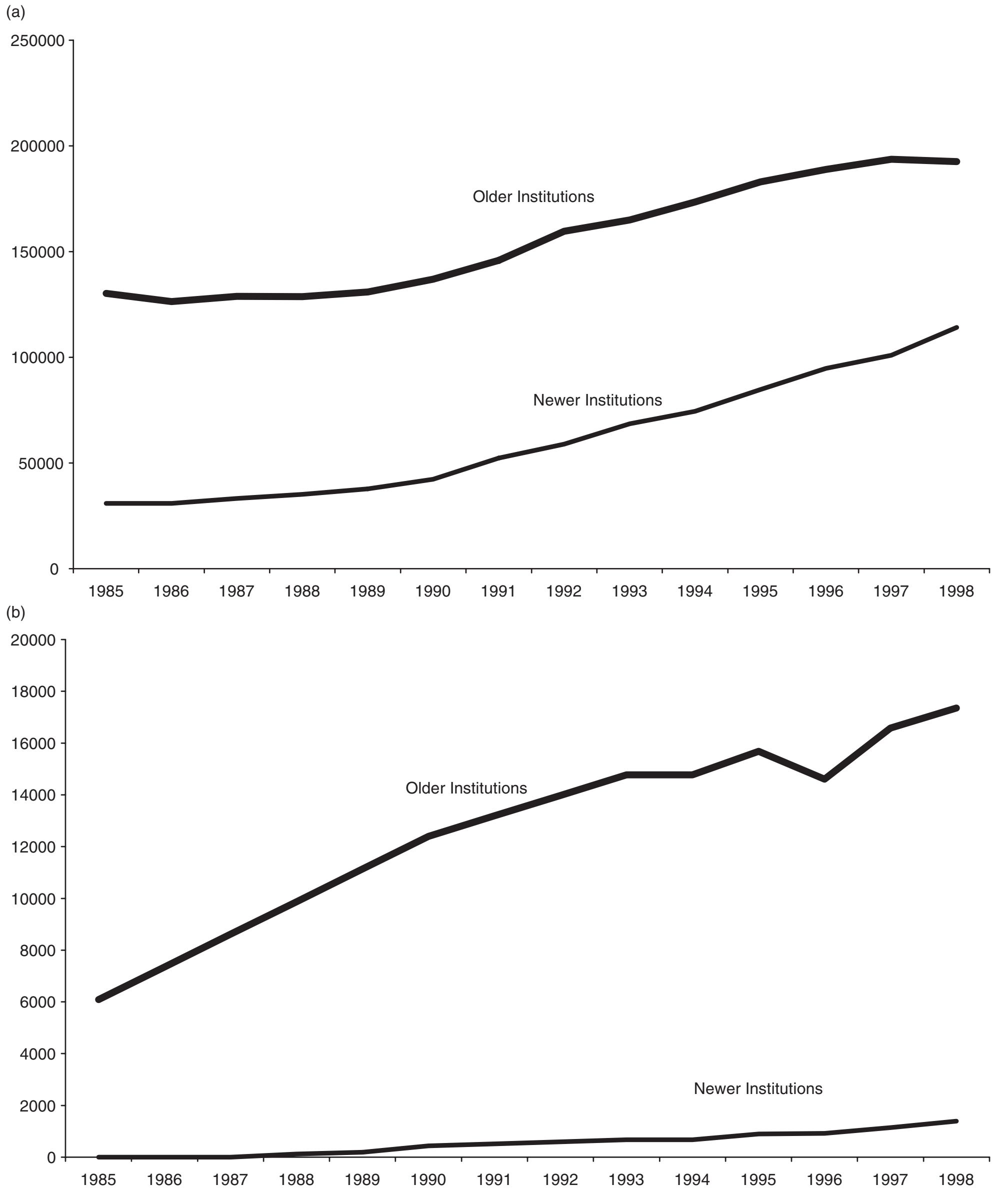

Figure 2. (a) Number of enrolled students at 'old' and 'new' institutions. (b) Number of university-based researchers at 'old' and 'new' institutions.

universities: Luleå, Karlstad, Växjö and Örebro. Today, there are a total of 13 universities and 23 colleges. The policy of deconcentrating universities and colleges throughout the country was rapid and unprecedented.

What were the motives for such a policy change? One important motivation for the establishment of these new colleges was desire to make undergraduate education geographically more accessible in all parts of Sweden. Another 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 the access to higher education of different social classes, especially those for which higher education has not been a tradition. Government representatives also claim that by their actions in this area they sought to favor those who would like to stay, to live, and to work locally. The success of this regional policy is based on the premise that the allocation of resources to the newer regional colleges will increase not only the educational level, but also the number of jobs in these regions. To some extent, the government's university policy can be interpreted as the expression of a regional redistribution goal (Andersson, 2001).[2]

This policy could also be interpreted simply as fiscal policy, a central government response to regions where there is persistent unemployment. Alternatively, the decentralization of education and research could result in more permanent employment in the problematic regions, since a more highly educated labor force could help to attract other economic activity. In both these senses, the university experiment during the last decade has been described as a tool in promoting regional growth (Regeringens Proposition 1997/1998, p. 62).

Two effects of this fiscal policy can be identified. The first is the increase in regional employment due to the direct investment, i.e., the construction and the operation of the new facilities (operating, for example, through the local multiplier; see Florax, 1992). The second is the expectation that the institution provides spillovers or externalities that could lead to regional expansion by existing companies or by start-up firms. Perhaps a more educated work force can better attract economic activity. Alternatively, research at a regional college or university could lead to innovation and increased entrepreneurial activity. This is the 'Silicon Valley model', and domestic critics suggest that Swedish policy-makers are obsessed with this vision.

However, building a good research environment at a new institution, even in one narrow field, may take some time, and there may be a substantial lag before any effects can be noticed—in the form of start-up firms, innovations from research results, etc. It also takes some time—three or four years—to educate the students before they can be productive in postgraduate employment. Even beyond any lags in observing responses, the relationship between the emphasis 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 economic activity. Finally, the migratory response of the newly educated students surely matters.

3. Knowledge and agglomeration

More than a century ago, Alfred Marshall identified the important relevant concepts: 'agglomeration effects,' the external returns to scale and scope emanating from a

2 As noted above, there is no evidence that the sites chosen for these new institutions were those poised to benefit, for other reasons, from productivity growth and increased economics activity. Indeed, at least one site seems to have been chosen in response to exogenous reversals in economic fortunes. More generally, during 1968–1976, the cities in which the new institutions were located, grew by 4.9% in population, while those in which the old institutions were located declined by 4.3% (and the remaining cities in Sweden increased by 6.3%). During 1977–1999, the cities in which the new institutions were located grew by 4.6%, while those in which the old institutions were located grew by 1.4% (and the remaining cities in Sweden increased by 7.1%).

concentration or 'cluster' of companies into an 'industrial district' (Marshall 1890, 1920). Agglomeration effects are assumed to exist when resources are more productive in dense and large geographical areas than in small ones. Marshall also identified 'external economies of scale' as an increase in efficiency due to the complementary presence of other companies in a cluster or industrial district. Today, 'knowledge spillovers' is a shorthand expression for the external benefits that may accrue to a company in the form of new knowledge and information emanating from the education and research at universities, as well as from the presence of other knowledge-intensive companies in its surroundings.

Externalities flowing from human capital in regional development had a scientific revival with the endogenous growth models starting with 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 using industry and university research as inputs. Both found a significant and positive effect of university research on output, which they interpreted as evidence of knowledge transfers arising from the presence of the university.

As Marshall and later Krugman (1991), Feldman (1994), Audretsch and Feldman (1996), and Anselin et al. (1997) 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 research and development (R&D) at universities and research centers. If so, it is beneficial for commercial developers to locate close to universities and other centers of basic research. Geographic proximity may be of even greater importance in stimulating applied research. Jaffe et al. (1993) have used patent citations to trace the geographic distribution of knowledge spillovers from university and corporate research, finding clear evidence that spillovers are more likely come from nearby sources. Using different models of spatial econometrics, Florax (1992) showed that income and job opportunities increase in proximity to the universities in the Netherlands. However, he did not find that private investments were larger or worker production was higher in closer proximity to Dutch universities.

Attila Varga (1998) has investigated the importance of agglomeration effects and knowledge spillovers in the US using a production function approach. He measured the output of R&D by regional registrations of more than four thousand product innovations recorded in 1982. His data confirmed the high concentration of innovation in the states of California on the West Coast and New Jersey and New York on the East Coast. As inputs, he measured annual expenditures for research in American universities as well as the number of employees in laboratories and research institutes within private companies. He then related the number of innovations to annual expenditures for university research, finding that important returns to scale and scope exist. Vargas concluded that there is a critical mass relating the density and size of a region to the output of innovative activity.

Several analyses of firm locations and university infrastructure have been undertaken in Sweden. Karl-Johan Lundquist (2001) analysed cross sectional data for Sweden for 1996, finding little or no statistical relationship between the locations of start-ups and the location of colleges and universities. The neighborhood of a college or university is not a significant factor in explaining regional variations in the incidence and location of new start-up companies. In the Swedish language literature, Henrekson (2002) has argued that linkages between university research in Sweden and technology-oriented firms are weak, arising from blunt incentives for researchers to commercialize their results. This argument is controversial.

Sörlin and Törnqvist (2000) gathered cross sectional data for some 70 regions in Sweden in 1996. According to their analysis, the Stockholm region has a considerably larger share of research-intensive industries than would be expected on the basis of the university research undertaken in the region. Thus, university capacity is 'too small' in this region. At the same time, the relationship in Göteborg, Malmö, Uppsala, Umeå, Luleå, and other cities and regions is one of excess supply. This provides an explanation for the out-migration of better educated labor, and graduates of regional colleges and newer universities in particular, to the Stockholm region. Research-intensive industry has expanded in Stockholm during the same time that a large expansion of the regional colleges and universities has taken place. Sörlin and Törnqvist thus view the decentralization experiment as a failed regional development policy.

These conclusions are controversial and have received substantial methodological criticism. (See Andersson, 2000; Wibe, 2000.)

4. Empirical analysis

4.1. The data

We investigate the relationship between the decentralization of post secondary education to various regions in Sweden and the labor productivity of those regions. The number of full-time-equivalent research positions at each institution measures the extent of direct university-sponsored research, and the number of full-time-equivalent students measures the overall scale of the university. As reported in Table 1, during the period of 1985–1998, the number of university research positions (R) tripled from 6,091 to 18,737. Most of this increase (R°) occurred at the older established institutions. Beginning in 1987, research positions were established in the newer colleges, and during the subsequent eight-year period, the number of researchers (R^{N}) increased sevenfold. Research positions at these new institutions are only about 6% of the technical and research positions in Swedish post secondary education, but the scale of these positions is expected to grow. These trends are noted in Figure 2.

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

We relate these exogenous changes in educational policy to productivity, output per worker, measured at the level of the community. Annual data are available on gross regional product (Y) for each of Sweden's 285 municipalities beginning in 1985.[3] Employment (E), population (P), and area (km^2) are all available at the municipal level for each year, and the centroid of each municipality has been geocoded.

Table 1 summarizes the temporal variation in these measures during the 1985–1998 period. As noted in the table, aggregate employment declined slightly during the period, from 4.3 million workers to 4.1 million, while productivity (output per worker) increased by an average of 2.3% per year. The variability in productivity across Swedish

3 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).

Table 1. Trends in employment, output, and university scale and dispersion across municipalities, 1985–1998

Year	Employment (E) thousands	Output per worker, (Y/E)		University students (S)		University researchers (R)		University graduates		University graduates/ workforce
		Thousands of SEK	Coeff. of variation	Total	Coeff. of variation	Total	Coeff. of variation	Total	Coeff. of variation	Coeff. of variation
1985	4,322	131,045	0.157	161,091	6.012	6,091	8.333	815,114	2.537	0.387
1986	4,348	137,143	0.225	157,181	5.928	7,350	7.923	853,375	2.552	0.382
1987	4,383	139,982	0.183	162,117	5.856	8,612	7.900	878,997	2.542	0.376
1988	4,443	141,816	0.199	164,001	5.795	9,999	7.686	902,181	2.523	0.371
1989	4,508	145,233	0.196	168,636	5.714	11,321	7.525	952,180	2.487	0.365
1990	4,550	143,506	0.190	179,289	5.623	12,830	7.422	1,100,867	2.559	0.370
1991	4,478	139,921	0.191	198,247	5.430	13,704	7.396	1,119,865	2.545	0.365
1992	4,279	143,321	0.183	218,537	5.364	14,580	7.392	1,168,345	2.559	0.365
1993	4,052	140,579	0.201	233,639	5.146	15,455	7.370	1,214,168	2.574	0.366
1994	4,007	148,423	0.183	247,928	5.068	15,455	7.370	1,293,589	2.659	0.369
1995	4,069	154,890	0.205	267,646	4.956	16,577	7.328	1,333,640	2.673	0.369
1996	4,047	156,633	0.186	283,689	4.805	15,525	7.164	1,372,163	2.695	0.370
1997	4,014	169,859	0.182	294,661	4.687	17,716	7.161	1,415,225	2.731	0.369
1998	4,063	173,786	0.167	306,767	4.496	18,737	7.076	1,452,634	2.755	0.367
Annual change (percent)	−0.4%	2.3%		6.5%		14.8%		5.6%		

Source: Statistics Sweden (SCB) and National Agency for Higher Education (HSV).

communities (measured by the ratio of the standard deviation of productivity measured at the community level relative to the national average) exhibits no trend. The number of university students increased by 6.5% per year while the number of full-time researchers employed at these universities increased by almost 15% per year. The variation in the average number of university students enrolled across communities declined monotonically as did the variation in the number of university-based researchers employed. These reductions in spatial variation are, of course, the outcomes of the government policy of decentralization of university facilities.

The table also presents information on the total number of people in the Swedish labor force with a university degree. The number of graduates increased by more than 600 thousand during the period 1985–1998, but the coefficient of variation increased—suggesting an increased spatial concentration of highly educated labor in the economy. Finally, the table presents the coefficient of variation of the fraction of college graduates in the workforce. This has declined. Overall, these trends suggest that labor has become more concentrated spatially, but that university graduates have become more evenly distributed throughout the labor force.

Table 2 reports rudimentary information on the spatial character of higher education in Sweden. For each of the six older university cities, the table reports the resident population within 40, 100, and 200 kilometers. The table also reports the unweighted average distance of each of the old university towns to all other communities in Sweden. The table indicates,

Table 2. Resident population at various distances from municipalities containing universities, 1998

A. Cumulative resident population at various distances from locations of older universities	40 km	100 km	200 km
Umeå	109,588	135,663	410,768
Uppsala	234,461	2,288,376	3,420,737
Stockholm	1,568,832	2,325,316	3,580,240
Linköping	186,213	836,283	4,377,098
Lund	624,448	1,146,756	1,766,513
Göteborg	725,386	1,269,268	2,400,353
B. Cumulative resident population at various distances from locations of older and newer institutions			
Newer institutions	3,341,259	5,792,355	8,092,973
Older Institutions	3,353,295	7,852,810	8,755,228
All institutions	6,191,626	8,528,638	8,759,227
C. Minimum average distance (kilometers) of communities to	Average	Std.dev	
Older institutions	116	85	
Newer institutions	62	49	

Note: Total Population 8,841,583.

for example, that the university in the northern city of Umeå is the most remote. Universities in Stockholm and Uppsala are the most accessible. More than a third of the population resides within 200 kilometers of these centers of higher education.

The table also reports the shortest distance from a community to the location of the older universities, averaged over the 285 communities, as well as the shortest distance to the location of the newer institutions.

4.2. Empirical models

We investigate the relationship between educational policy changes and economic activity using a simple stylized model. We relate the average productivity of workers by community to exogenous changes in the size of the universities, measured by enrollment, and the number of researchers. We conduct this analysis at the level of the municipality, using time-series data for 1985–1998. The use of panel data permits us to hold constant a variety of unmeasured region-specific characteristics affecting variations in average productivity, as well as unmeasured factors affecting the course of productivity over time.[4] We estimate models employing fixed effects for municipality and year.

Our models estimate the effects of university students and university-based researchers on the productivity of local areas and 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:

$$log(Y_{it}/E_{it}) = \alpha U_{it} + \sum_{j=1}^{285} \beta_j C_j + \sum_{k=1986}^{1998} \gamma_k T_k + \varepsilon_{it}. \quad (1)$$

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

In various regressions, we measure U by the number of post secondary students (S) enrolled in institutions located in the community or by the number of university-based researchers (R) working in the community. In other regressions, we distinguish between students enrolled in the older established institutions (S°) and those enrolled in institutions newly established after the policy change (S^N). Similarly, we distinguish between university-based researchers employed at the 'old' and the 'new' institutions (R° and R^N, respectively).

Table 3 reports the most basic set of results, regressions, relating average productivity in each community in each year to the number of university students and university-based researchers in each jurisdiction. All regression models include fixed effects for

4 The first year of the panel corresponds to the first year for which output per worker can be measured at the municipal level.

Table 3. Basic regression models of regional productivity (t ratios in parentheses)

Specification	(1)	(2)	(3)	(4)
$S \times 10^5$	0.988			
	(5.19)			
$S^N \times 10^5$		1.625		
		(4.44)		
$S^\circ \times 10^5$		0.774		
		(3.56)		
$R \times 10^4$			0.561	
			(3.92)	
$R^N \times 10^4$				4.003
				(2.84)
$R^\circ \times 10^4$				0.532
				(3.71)
R^2	0.766	0.766	0.765	0.766
Moran's I	9.278	9.447	8.706	8.741

Note: All models include fixed effects for 285 municipalities and 13 time periods. The sample consists of a panel of 3990 observations, one for each municipality for each of 14 years.

285 communities and 13 time periods, so the coefficients are identified by the within-community and within-time period deviations in log productivity.

The regressions explain about three-quarters of the variation in log productivity, and the coefficients of each variable are highly significant. Interpreted literally, an increase of 100 university students in a community is associated with an increase in labor productivity of 0.25% (or about a quarter of a percentage point at the means). University-based postgraduate researchers are about 17 times as important in increasing productivity, as are students. An increase of 100 university researchers is associated with a productivity increase of about 0.6% (or roughly 2.6 percentage points).

It is also clear from the table that the marginal effect of students or researchers at the 'new' institutions of higher education on productivity is larger than the effect of students or researchers at the 'old' institutions—roughly twice as large for students and eight times as large for university-based researchers. These estimated differences are statistically significant.[5]

A major drawback in interpreting these results is the neglect of any intercommunity spillovers arising from the economic activity stimulated by investment in post secondary institutions. An implicit assumption in interpreting Table 3 is that all enhanced

5 In other regressions, available upon request, we estimated analogous models using one-, two-, and three-year lags for both students and researchers. In other regressions, we also included squared terms for both students and researchers in the statistical models. The results reported in the text are robust to those changes in specification.

We also investigated models in which the dependent variable was specified as output, not productivity. In these models, the pattern of significance of the coefficients was identical (although the explained variance in the models was much higher, above 0.99); the importance of students (and researchers) was larger at new institutions than for the older institutions, and the importance was larger for researchers than for students.

productivity stimulated by increased university investment occurs in the same community in which the university is located. Although this simplification may be plausible in very rural regions, it is hardly defensible in denser metropolitan or suburban regions. The last line of the table reports values for Moran's I (distributed as *t*). These test statistics suggest that the hypothesis of spatial dependence among the data can not be rejected. This spatial dependence is simply ignored in Table 3.

Table 4 extends the analysis to address potential spillovers. The table augments the variables included in Table 3 with one additional measure, denoted by *G*. This variable summarizes the distance of each community to all those students and researchers based in other communities, using a gravity representation. In the ordinary least squares (OLS) models, this additional variable is defined for each community as $\sum_{j\neq i} R_j/d_{ij}$ or $\sum_{j\neq i} S_j/d_{ij}$ where d_{ij} is the distance between jurisdictions *i* and *j*. The gravity measure weights the students or researchers in each of the other jurisdictions inversely proportional to the distance to every other jurisdiction. In the nonlinear least squares (NLS) models, a slightly more sophisticated representation is used: $\sum_{j\neq i} R_j e^{bd_{ij}}$ or $\sum_{j\neq i} S_j e^{bd_{ij}}$. Rather than a linear decay, this model specifies an exponential decay, and we estimate the rate of decay, *b*, simultaneously with the other parameters using a grid search. Presumably, the estimate of *b* is negative.

Table 4. Models of regional productivity using gravity models (t ratios in parentheses)

	OLS		NLS		OLS		NLS	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$S \times 10^5$	1.016		1.100					
	(5.36)		(5.60)					
$S^N \times 10^5$		1.734		1.790				
		(4.75)		(4.87)				
$S^\circ \times 10^5$		0.776		0.830				
		(3.59)		(3.83)				
$G_S \times 10^5$	4.275	4.352	0.375	0.333				
	(5.62)	(5.73)	(2.80)	(2.70)				
$R \times 10^4$					0.591		0.600	
					(4.16)		(4.19)	
$R^N \times 10^4$						4.347		4.540
						(3.10)		(3.23)
$R^\circ \times 10^4$						0.561		0.570
						(3.93)		(3.96)
$G_R \times 10^4$					1.998	2.042	0.180	0.190
					(5.16)	(5.28)	(4.32)	(4.53)
b			−0.020	− 0.018			−0.011	−0.011
			(2.86)	(2.80)			(2.85)	(2.88)
R^2	0.768	0.768	0.780	0.780	0.767	0.767	0.767	0.767
Moran's I	8.136	8.125	8.360	8.460	7.902	7.823	7.870	7.790

Note: In the OLS models, G_S represents the estimated coefficient for $\sum_{j\neq i} S_j/d_{ij}^2$ where d_{ij} is the distance between communities i and j. In the NLS models, G_S represents the estimated coefficient for $\sum_{j\neq i} S_j e^{bd_{ij}}$ where b is estimated by a grid search. The definitions of G_R are analogous.

All models include fixed effects for community and time period and are based upon a panel of 3990 observations.

The coefficients of the variables measuring students and university-based researchers are very similar in magnitude and statistical significance to those reported in Table 3. If anything, the estimated magnitudes are slightly larger, but they are generally within the sampling errors reported in Table 3. The pattern of the coefficients is identical. The number of students at the 'new' universities has about twice the impact on productivity as does the number of students at the 'old' universities; the number of university-based researchers at 'new' institutions again has about eight times the effect on productivity as does the number at 'old' established institutions.

The magnitude and statistical significance of the gravity measures provides strong evidence that there are positive spillovers among jurisdictions, but there is little to choose between in the specifications. The simple linear model seems to be almost as accurate as the more sophisticated exponential model, but it implies a somewhat less pronounced decay with distance. Importantly, however, the values of the Moran's I statistic are still quite large, suggesting that neither model captures the underlying spatial relationship very well.

As an alternative, we consider a general spatial lag model to incorporate the spatial structure into the analysis.[6] In its most general form,

$$\begin{aligned} log(Y_{it}/E_{it}) &= \rho \sum_{j \neq i} W^1_{ij} log(Y_{jt}/E_{jt}) + \alpha U_{it} + \cdots + \varepsilon_{it}, \\ \varepsilon_{it} &= \lambda \sum_{j \neq i} \mathrm{W}^2_{ij} \varepsilon_{it} + \mu_{it}. \end{aligned} \tag{2}$$

In this formulation, the productivity of labor in any town also depends upon the productivity of labor in neighboring towns. The spatial lag formulation indicates that productivity depends upon the productivity observed in other municipalities, where W^1_{ij} are the weights. The parameter λ is the coefficient in the spatial autoregressive structure for the distance and W^2_{ij} are the weights for the errors in other towns. If there are no a priori reasons to suppose that the spatial interaction patterns are different, then $\mathrm{W}^1_{ij} = W^2_{ij}$. In this instance, ρ and λ are not separately identified.

In this spatial application, we assume $\mathrm{W}^1_{ij} = W^2_{ij} = 1/d^2_{ij}$ 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 (2), we can estimate the Spatial Autoregressive Model (SAR):

$$log(Y_{it}/E_{it}) = \rho \sum_{j \neq i} [1/d^2_{ij}] log(Y_{jt}/E_{jt}) + \alpha U_{it} + \cdots + \varepsilon_{it} \tag{3}$$

Alternatively, if λ defines the autoregressive spatial structure, we can estimate the Spatial Error Model (SEM):

$$\begin{aligned} log(Y_{it}/E_{it}) &= \alpha U_{it} + \cdots + \varepsilon_{it}, \\ \varepsilon_{it} &= \lambda \sum_{j \neq i} \varepsilon_{jt}/d^2_{ij} + \mu_{it}. \end{aligned}$$

6 Anselin (1988) is the standard reference documenting these spatial models.

Table 5 reports the coefficients of the SAR and SEM models, estimated by maximum likelihood methods, assuming normality of the errors ε and μ. 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. Either measure of spatial dependence, ρ or λ, is highly significant, and the statistical insignificance of the LM statistic (distributed as χ^2) confirms that the SAR model controls adequately for the spatial autocorrelation in the data.

In models relating productivity to university scale as measured by the number of students, the coefficient on the number of students in the same community is only

Table 5. Spatial autoregressive models of regional productivity (asymptotic t ratios in parentheses)

	SAR		SEM		SAR		SEM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$S \times 10^5$	0.084		0.098					
	(1.42)		(1.66)					
$S^N \times 10^5$		0.045		0.018				
		(0.18)		(0.07)				
$S^\circ \times 10^5$		0.085		0.103				
		(1.41)		(1.69)				
$G_S \times 10^5$	0.644	0.641	0.668	0.669				
	(3.49)	(3.47)	(3.29)	(3.29)				
$R \times 10^4$					0.102		0.124	
					(1.51)		(1.81)	
$R^N \times 10^4$						3.069		3.043
						(2.16)		(2.15)
$R^\circ \times 10^4$						0.098		0.119
						(1.44)		(1.75)
$G_R \times 10^4$					0.928	0.944	0.971	0.984
					(4.34)	(4.41)	(4.09)	(4.14)
λ			0.199	0.197			0.181	0.182
			(29.41)	(28.81)			(25.97)	(25.96)
ρ	0.205	0.207			0.193	0.196		
	(110.07)	(110.66)			(108.43)	(109.80)		
LM test	0.235	0.256			0.279	0.238		

Note: Spatial autoregressive models (SAR) are of the form:

$$log(Y_{it}/E_{it}) = \rho \sum_{j \neq i} [1/d_{ij}^2] log(Y_{jt}/E_{jt}) + \alpha U_{it} + \cdots + \varepsilon_{it}$$

Spatial error models (SEM), are of the form:

$$log(Y_{it}/E_{it}) = \alpha U_{it} + \cdots + \varepsilon_{it}$$

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

G_S and G_R represent the estimated coefficients for $\sum_{j \neq i} S_j/d_{ij}^2$ and $\sum_{j \neq i} R_j/d_{ij}^2$ respectively.
All models are estimated by maximum likelihood assuming normality of the error terms.
The Lagrange Multiplier (LM) statistic is distributed as χ^2 with one degree of freedom.

significant at the 0.20 level. However, the gravity measure of distance to university students remains highly significant in all cases.

As before, the results are somewhat stronger for the models that rely upon university-based researchers. 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.

5. Conclusion

During the past 15 years, Swedish higher education policy encouraged the decentralization of post secondary education. We investigate the spatial and economic effects of this decentralization on productivity and output. We rely upon a 14-year panel of output and employment for Sweden's 285 municipalities, together with data on the location of university researchers and students, to estimate the effects of exogenous changes in educational policy upon regional development.

We provide several tests of the hypothesis that the establishment or expansion of university research in a region enhances regional productivity. We find systematic evidence that the average productivity of labor is higher in regions that have received larger university-based investments as measured by the number of researchers employed on staff or the number of students enrolled. We also find that productivity gains are larger in regions in which the 'new' colleges and universities are located. Finally, we find the effects of university-based researchers are considerably larger than the effects of the size of the student body. Both influences are larger for newly established institutions than for the older universities.

These results are based upon data on output and employment for each of Sweden's municipalities over an extended period, as well as data on the course of higher educational policy by municipality over the same period. Our analysis permits us to incorporate fixed effects for municipalities and time, thereby improving the precision of estimates. By framing the analysis at the municipal level, we focus on very local effects of university expansion on productivity.

We analyse spillovers among jurisdictions, emphasized in the modern theoretical literature on agglomeration, using a variety of techniques. We summarize the spatial distribution of university students and workers using gravity models in two formulations. We also investigate several explicit models of spatial autocorrelation.

The results are broadly consistent across theoretical models and statistical results. There is strong evidence that an expansion of university presence in a municipality, measured by the size of the student body or the number of university-based researchers, is associated with increases in the average productivity of labor in that community.

The scale of the university as measured by the number of researchers is consistently more important in increasing productivity than the scale as measured by the number of students. This may arise for several reasons. New researchers are more-or-less bound to the local area by their worksites; new graduates are not. It takes three to five years before a student matriculates and enters the workforce, and many matriculate without technical expertise. Researchers are productive in technical jobs as soon as they are recruited.

Table 6. Cumulative productivity gains at various distances from university (As a percentage of total gains)

Distance (km)	Students				University-based researchers			
	Old		New		Old		New	
	SAR	SEM	SAR	SEM	SAR	SEM	SAR	SEM
1	15.34	15.58	14.62	14.11	15.01	15.20	40.47	39.56
2	22.11	22.33	21.44	20.98	21.80	21.98	45.23	44.39
5	32.71	32.91	32.14	31.74	32.45	32.61	52.69	51.97
8	38.60	38.77	38.07	37.71	38.36	38.50	56.83	56.17
10	41.46	41.63	40.96	40.61	41.23	41.36	58.84	58.21
15	46.73	46.88	46.27	45.95	46.52	46.64	62.54	61.97
20	50.51	50.66	50.09	49.79	50.32	50.43	65.21	64.67
100	72.04	72.12	71.80	71.63	71.93	71.99	80.34	80.04

Note: Distance is measured in kilometers from the center of the municipality containing the university.
Source: Estimates are based on the coefficients reported in Table 5 in columns 2, 4, 6, and 8 respectively.

The importance of the university in affecting productivity is consistently larger for the new institutions. This could arise if the new institutions are more like vocational and technical institutions than like more traditional regional colleges. Of course, some of the new institutions are, in fact, upgrades of former technical colleges. So this may explain some of the differences.

But the productivity boost, from whatever source, also extends to communities located near these university facilities. The statistical results denoting productivity gains and spillovers are highly significant and are robust to alternative statistical methods and specifications. These externalities are highly localized, however. Table 6 summarizes the localization of these externalities as measured by the coefficients of the models reported in Table 5. The coefficients are used to estimate the effect of an increase in students or university-based researchers on productivity in the community containing the institution and on productivity at various distances from its border. The table presents the fraction of the net productivity gain which is achieved at various distances from the municipality. It is clear that external benefits are highly concentrated geographically. More than half of the total productivity gain from university expansion is reported to occur within 20 kilometers of the municipality containing the institution of higher education; about 75% occurs within 100 kilometers of the border.

It is also possible, at least in principle, to estimate the *net* change in output arising from the spatial rearrangement of students and researchers. Using the results presented in Table 5, for example, worker productivity in each municipality 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 in 1998, as well as the students attending them, back to the 11 institutions which had been in existence in 1987. We reallocate researchers and students to the pre-existing institutions in proportion to their distribution in 1987. Data on the number of workers in each municipality allows us to estimate total output in the economy. A comparison of this counterfactual with realized output yields the net change in GDP arising from the decentralization of higher education. Using the coefficients in equations (6) and (8) in Table 5 (which we prefer on statistical grounds), we estimate the net effect of this spatial rearrangement to be an increase in GDP of between 0.113% (equation (6)) and 0.066% (equation (8)).[7] If this gain in output were attributable entirely to the decentralization of university researchers, these results suggest that the increment of GDP is roughly the same order as the initial contribution to the GDP of these workers.[8]

This finding is 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 is more likely to spill out locally if it originates in a small firm. Rosenthal and Strange (2003) found that small establishments in the knowledge industry have larger effects on locational attractiveness than larger ones. In a recent paper using micro data from Dunn and Bradstreet, Rosenthal and Strange (2001) found that proxies for knowledge spillovers in the US affect firm agglomeration only at the very local (postal code) level. Adams (2002) compared the localization of academic and industrial spillovers in the US, concluding that spillovers from academic institutions are quite localized. Our Swedish data also suggest significant, but highly localized, productivity effects arising from the geographical locations chosen for these institutions.

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

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7 Note that we have no statistical confidence in the magnitudes of these estimates. The counterfactual effects calculated from the results in Table 5 are well within the standard error of the estimate for any of the regression results reported.

8 The annual direct and indirect cost of a university-based researcher is roughly 600 thousand to 1 M SEK, or up to 2 B SEK for 2000 researchers. The total gain from decentralization is estimated (from Table 5, equations (6) and (8)) to be 1 B SEK to 4 B SEK. But these magnitudes, too, should be taken with a grain of salt.

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