The Role of Knowledge Infrastructure in Regional Economic Development: The Case of the Research Triangle

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Introduction

A few weeks after moving to the Research Triangle region back in 1982, the author was driving from Chapel Hill to Durham on a Friday afternoon and noticed the sign on the roadside. It said, "Welcome to Durham, City of Tobacco." Three days later, I happened to be driving the same route doing another errand. Upon reaching the boundary line between Chapel Hill and Durham, the old sign was gone and a new one had been put up. The new one said: "Welcome to Durham, City of Medicine."

The abrupt change in the welcoming sign is a wonderful metaphor for how the economic development process has unfolded in this region over the last fifty or so years. There are probably few regions in the United States that have undergone such a vivid structural transformation within such a relatively compressed period of time. Although many descriptions of the Research Triangle region have focused on the role of the Research Triangle Park in the region's economic transformation, the thesis presented here is that the investment in the region's *knowledge infrastructure* has been the basic propulsive factor in the region developing into one of the world's leading high tech centres. The gains in economic well-being, in turn, allowed further investments in the region's knowledge infrastructure, a process of "cumulative causation" to use Myrdal's (1957) term. A region's knowledge infrastructure, however, varies not only in its scale and efficiency, but also qualita-

© Canadian Journal of Regional Science/Revue canadienne des sciences régionales, XXVIII: 2 (Summer/Été 2005), 199-220.
ISSN: 0705-4580 Printed in Canada/Imprimé au Canada

tively in its components and how they are linked. So we will also relate how the particular character of the region's knowledge infrastructure has shaped its economic development structure and outcomes.

The concept of a "knowledge infrastructure", as we shall see, has roots in the European regional development literature on milieu and creative regions, as well as in endogenous growth theory inspired by Romer, Krugman, and others. It is also closely related to other concepts discussed in the literature including technology infrastructure and regional innovation systems.

The article is organized as follows. First, we briefly review the relevant regional development literature to place the concept of a knowledge literature in context. Then, we begin the empirical section of the paper with an historical overview of the emergence of the Research Triangle region as a high-tech economy, and include some indicators of the path of its regional economic development over the last 50 or so years. This is followed by a description of the development of the region's knowledge infrastructure, and this is related to particular characteristics of the economic development structure and performance of the region to-date. Finally, the argument is summarized, a brief gaze into the future is provided, and a conclusion drawn.

Knowledge Infrastructure and Related Concepts in the Literature

The term "knowledge infrastructure" is relatively recent in the literature in regional development theory, but the concept has been prominent for nearly fifty years when Hirschman (1958) discussed infrastructure as 'social overhead capital'. Hirschman makes a distinction between directly productive activities and social overhead capital, in that the later is defined as "comprising those basic services without which primary, secondary, and tertiary productive activities cannot function." (p.83). He then goes on to list the conditions for including an activity under the category of social overhead capital: (1) the services provided by the activity facilitate the a large variety of economic activities to be performed; (2) the services provided by the activity have several significant public goods aspects to them: there is no charge, or at least rates are publicly regulated, consumption is often difficult to exclude, and the services are often provided by public sector organizations; (3) the services cannot be imported. What is notable here is that Hirschman's concept includes not only transportation, communications, power, and water services, but also public health, education, law, and governance.

The relatively recent concept of 'technology infrastructure' (Tassey 1991; Justman and Teubal 1995) is highly similar to Hirschman's view of infrastructure, though more narrowly targeted to those producers that employ scientific and technological knowledge as a principal input to their production processes. Technology infrastructure is defined by Tassey (1991) as "science, engineering, and technical knowledge available to private industry." This is rather inclusive, as it includes generic technologies, R&D results, and technical information, but also

information relevant to technology-based firms' strategic planning and marketing, forums for collaboration among researchers and among organizations, and assignment of intellectual property rights. Like Hirschman, there is a strong public goods dimension to technology infrastructure, and indeed Tassey has been an ardent supporter of the need for increased public sector investment in our nation's technology infrastructure because of low incentives for individual firms to invest in it.

The development of the concept of innovative milieu by members of the GREMI group in the 1980s emphasized the centrality of cultural norms and social relationships into the type of infrastructure that could support and nurture innovation and creativity, as these were missing from Hirschman and subsequently from Tassey. A 'milieu' is conceived as a coherent whole in which a territorial production system, a technical culture, and firms and institutions are linked (Maillat and Lecoq 1992). An effective innovative milieu is characterized by high levels of trust and norms of reciprocity among actors, and the development of a set of institutions that link these actors. In this way, the milieu provides positive externalities to actors within it by reducing uncertainty (Camagni 1991; Maillat 1990). Indeed, it appears that much of the more recent literature on the role of networks and social capital as factors in regional development was implicitly anticipated by the emergence of the earlier literature on innovative milieu.

Building upon the centrality of interaction of the innovative milieu literature, 'regional innovation systems' (Cooke 2001) focus more explicitly on the types of linkages among organizations and provides for a clearer division of functional roles. Here intermediary organizations are deliberately designed to make it easier for interaction and knowledge transmission to occur, and for the kind of "soft" services to be delivered to producers that Hirschman had in mind in his concept of social overhead capital. Here local government organizations play important facilitative and leadership roles, and higher level government organizations provide resources for the provision of particular services that R&D and small and medium sized producers depend upon. Institutions of higher education have several critical roles in the innovation system. Governance and management of such systems often are in the form of public-private partnerships.

The term "knowledge infrastructure" itself emerged in the early 1990s, having been stimulated by the work of Romer (1990), Krugman (1991) and others in the development of endogenous growth theory. Some have considered it to be the *stock, or pool* of knowledge within a region, as one of the inputs to economic growth (Mehra 2001). For our purposes, that is too narrow, as it should include the institutional and organizational apparatus that supports growth in the stock of knowledge. This is consistent with the regional innovation system concept.

We thus start with Smith's (1997) definition of *knowledge infrastructure* as a complex of public and private organizations and institutions whose role is the production, maintenance, distribution, and protection of knowledge. With this definition, a region's knowledge infrastructure includes private sector organizations and institutions such as industry associations, training centres, trade publications, collectively established technical standards, and R&D branch plants as well as independent R&D firms. Public sector entities include research councils, patent offices, institutions of higher education, libraries, data bases, and the legal and administrative regulations to support the well-functioning of these entities.

Smith's concept and definition are modified in several ways here. First, the role of knowledge infrastructure in the context of regional economic development is extended to include enhancing the learning capacity and innovativeness of the region's firms, workers, and other organizations. Second, a region's knowledge infrastructure consists not only of the organizational nodes, but also the linkages and connections among the nodes. That is, the knowledge infrastructure has network qualities, just as transportation and utility systems have. And third, we exclude private R&D branch plants and those independent R&D firms that are directly oriented to product development, rather than knowledge generation, from the regional knowledge infrastructure. This serves to distinguish the knowledge infrastructure from the regional economic development outcomes themselves, for purposes of assessing causality, though it is recognized there may be overlap both conceptually and empirically.

The Emergence of the Research Triangle Region

The Research Triangle region is a three county area of Durham, Orange, and Wake located in the central portion of North Carolina (Figure 1). These three counties formed the core of the larger five-county Raleigh-Durham metropolitan statistical area (MSA).[1] The name comes from the location of three major research universities – the University of North Carolina, Duke University, and North Carolina State University -- located in the cities of Chapel Hill, Durham, and Raleigh, respectively. These three cities form the vertices of a triangle within which lies the Research Triangle Park, now one of the world's largest and most successful research, or science, parks. The population of the three county region in 2002 was 1,028,000 and total wage and salary employment was 647,000. But in the late 1950s, with a population of only 297,000, the area could be accurately characterized as two small cities and one university town, spatially separated, with virtually little development in between. The area was largely missing the features of agglomeration and urbanization with which we associate dynamic regions.

Local Conditions and Resources

In the mid-1950s, the state of North Carolina had the second lowest per capita income of any state. The region's employment base was concentrated in low wage manufacturing industries (textiles, tobacco, furniture), marginal farming, state government, and higher education. The latter two sectors helped make the region better off than the state as a whole in terms of its average wage and salary levels,

1. After the 2000 Decennial Census, the former Raleigh-Durham-Chapel Hill MSA was divided into two contiguous MSAs: Durham MSA, consisting of Durham, Chatham, Orange, and Person counties; and Raleigh-Cary MSA, consisting of Wake, Franklin, and Johnston counties.

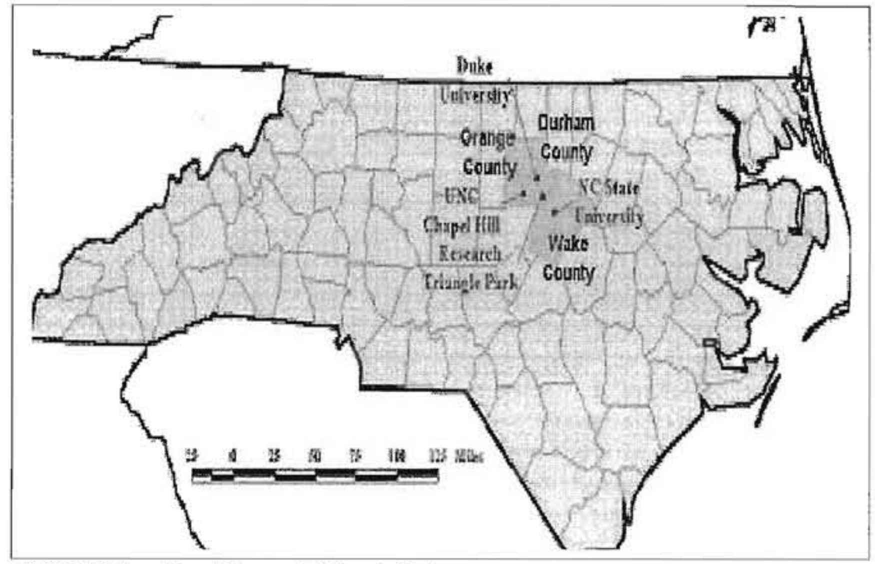

FIGURE 1 Location of Research Triangle Park

working conditions, and job stability. Yet there was a marked absence of high-tech employment sectors (3.3 % in the region compared to 10.3 % for the U.S. as a whole), and little or no tradition of entrepreneurial activity. The R&D activity was almost all within the three research universities, and then concentrated in the basic sciences. The combination of universities with high quality doctoral programs and the lack of job opportunities for highly skilled scientists and engineers had led to a brain drain from the state of serious proportions.

The resident labour force was highly bimodal, with a disproportionate concentration in professional and administrative occupations employed largely in the universities and state government, and a disproportionate concentration in semi-skilled and unskilled occupations. It was significantly under-represented in the skilled trades and technical occupations. While the percentage of residents who had attended college was well above the national average in 1960 (24.2 % versus 16.5 %), the median number of years of school completed was only slightly above the national average (10.8 years versus 10.6). An ambitious investment in a large number of two-year community colleges had begun under Governor Luther Hodges, in the late 1950s, in recognition that the lack of technical training was a barrier to economic development in the state. Despite this investment, the problem of a scarce number of skilled technicians, and more generally, a poorly educated resident labour force persisted (Luger and Goldstein 1991).

Forty years ago, the area was not only small, but it was also peripheral. Although situated on the north-south axis of the interstate highway system (I-85), the region was 400 kilometres from Washington D.C., and over 600 kilometres from Atlanta, the southeast's regional centre. The Raleigh-Durham airport now serves 8.9 million annual passengers, has over 300 flights and non-stop flights to

50 cities daily, including London-Gatwick, but air connections to major business centres in the United States were still rather poor in 1960.

A group of high-level state political, education, and business leaders, initially brought together by the forward thinking Governor Hodges, began to meet in 1955 to consider strategies to restructure the state economy. In considering the strategic strengths and resources upon which the state could build, it was obvious that one of the two was the state's higher education institutions, and the three research universities, all within 50 kilometres of one another, more specifically. In particular, the University of North Carolina's chemistry department, with a national reputation in organic and biochemistry, had a long tradition of supplying the laboratories of the nation's and the world's major chemical corporations with highly trained graduates. That, combined with North Carolina State University's highly regarded School of Textiles, explains the subsequent success in attracting and developing an early concentration of textile chemistry R&D labs in the region. Later, the strengths of the biomedical research faculty and facilities of Duke University and the University of North Carolina, and the strengths of North Carolina State University's agricultural sciences faculty became instrumental in attracting pharmaceutical and biotechnology research labs to the area. Likewise, the engineering schools at North Carolina State and at Duke, and the computer science department at the University of North Carolina paved the way for microelectronics R&D facilities to locate in the region. But we are getting ahead of the story.

The Creation of the Research Triangle Park

The group formed by Governor Hodges produced a report endorsing the idea that the three research universities could attract a concentration of industrial research labs to the region now known as the Research Triangle to take advantage of faculty expertise and well-trained graduates in particular fields of strength. In turn, the committee report said, economic development would spread to surrounding parts of the state by production facilities locating in some general proximity to their R&D labs, but also in non-metropolitan portions of the state with lower labour costs (Luger and Goldstein 1991).

While the idea in the report was indeed a bold one, how it could and should be implemented -- organizationally, institutionally, and fiscally -- was unclear, though several possible sketches were mentioned. Indeed, at the time there were very few precedents, or models of successful knowledge-based economic development strategies in other regions from which to learn. Not much occurred for two years after the Governor Hodges' committee report was issued, until a retired industrialist was recruited to invest in a privately owned research park on undeveloped land near the small airport close to the middle of the triangle formed by the three cities, but isolated from each of the three research universities. The industrialist failed to attract sufficient private capital, in part because questions of propriety were raised about the promotion of a privately owned research park by public universities and other state government agencies, and in part because the research park concept itself was new and not widely tested.

After another period of inactivity, a group of private citizens and civic-minded corporations bought out the stock of the empty research park. It hired a sociologist, specializing in regional development theory from the University of North Carolina, George L. Simpson Jr., to develop a plan to build and promote the research park concept for the location of industrial R&D laboratories. This group formed a foundation as the organizational entity to own and manage the park. It secured a grant of funds and a gift of land that made it possible to create a nonprofit contract research firm -- the Research Triangle Institute -- as the first occupant of the research park. Still, growth and development of the park was slow, and it looked like the park would fail several times in its first five or six years of operation. In 1965, however, IBM Corporation bought a large site for a major facility. Shortly thereafter, the newly created National Institute of Environmental Health Sciences (NIEHS), a branch of the National Institutes of Health, decided to locate in the Research Triangle Park. The latter decision was heavily influenced by then former Governor Luther Hodges, who had become the federal Secretary of Commerce under President John F. Kennedy in 1960, and by Hodges' successor, Governor Terry Sanford, an early and key political supporter of Kennedy. IBM and NIEHS, in effect, served as anchor tenants of the park, and were instrumental in putting the Research Triangle Park "on the map" as a desirable place for national and international corporations, as well as federal government agencies, to locate their R&D facilities.

The success of the Research Triangle Park was now sealed, and over the next 35 years more than 140 R&D facilities have located in the park, with over 40,000 employees. The foundation's strategy since the beginning was to recruit the branch plants of major, large-capitalized corporations, rather than to emphasize small, technology-based start-up companies. Indeed, the high cost of locating within the park itself, with stringent building and site restrictions, and only very recent investment in multi-tenant, speculative buildings, made the park practically infeasible for small companies to locate there. Since the early 1990s, however, there has been a notable acceleration of new start-up and spin-off companies locating outside, but spatially proximate to the park. On the other hand, there has *not* been the concomitant, secondary effect, of large growth in high-tech *production facilities* within the outlying parts of the Research Triangle region, as the committee established by Governor Luther Hodges had envisioned.

Recent Economic Development

Although the Research Triangle Park has been, and continues to be, a magnet for the attraction of high tech activity to the region, other actors and organizations have become important as engines of economic growth and/or as symbols of this "world-class" high tech centre. One, the Centennial Campus, is a satellite research facility of North Carolina State University created in 1984. It languished for at least its first ten years, but since around 2000 has visibly taken off. Located less than three kilometres from the main university campus, Centennial Campus is designed to house a mixture of university based research facilities (mainly in the engineering sciences), new companies spun-off by faculty from the university's sponsored research projects, and companies that have joint projects, or other direct linkages with the faculty or individual departments or research centres. Although the magnitude of the Centennial Campus and its direct economic impacts are not yet large, its potential success already has had a strong influence on the University of North Carolina at Chapel Hill's planning for a similar satellite campus.

There have been key investments in the physical infrastructure areas, including several expansions of the Raleigh-Durham International Airport and the completion of the Interstate 40 link connecting Durham and Chapel Hill with Raleigh and through the heart of the Research Triangle Park itself in the late 1980s. More recently state government and private utility investments in the state "information superhighway," have benefited the state as a whole, including its rural areas, but at the same time have also made the region relatively more attractive and accessible as a place to do business and create knowledge.

Other public sector investments were the state's creation of the Microelectronics Center of North Carolina (MCNC) and the Biotechnology Center, both in the 1980s. These particular centres were established to try to capitalize upon the two technology areas considered as the region's strategic strengths. While the MCNC has not led to an influx of microelectronics companies to the region, the Biotechnology Center, on the other hand, has helped to create a *milieu* conducive to the location of established pharmaceutical and biotech companies in the region, but also conducive to start-up and spin-off activity in the biotech area.

Finally, the development of the community college system over the last twenty years, with its emphasis on providing customized training programs to meet the labour supply needs of particular firms, has helped to mitigate a serious regional disadvantage of a lack of skilled labour outside of the knowledge sector. In the Research Triangle region there are two community colleges that are active in support of economic development: Wake Tech in Raleigh and Durham Tech in Durham and recently in Chapel Hill.

A Trajectory of the Region's Economic Development Outcomes

Indicators of regional economic development come in many shapes and sizes. Some frequently used indicators, including total employment, total output, or total personal income, are measures of economic growth vis à vis economic development. If we agree that economic development should include dimensions of economic well-being among its residents and workers, as well as the sustainability of its economic health, then there are other measures of outcomes. A number of organizations including the World Bank and the United Nations have developed systems of indicators of economic and social development. Within the United States two well-known set of economic development indicators are produced by the Progressive Policy Institute and the Corporation for Enterprise Development. The former emphasizes a region's participation in the "New Economy" while the latter emphasizes building local capacity and business dynamism.

We choose two measures that best capture economic development as under

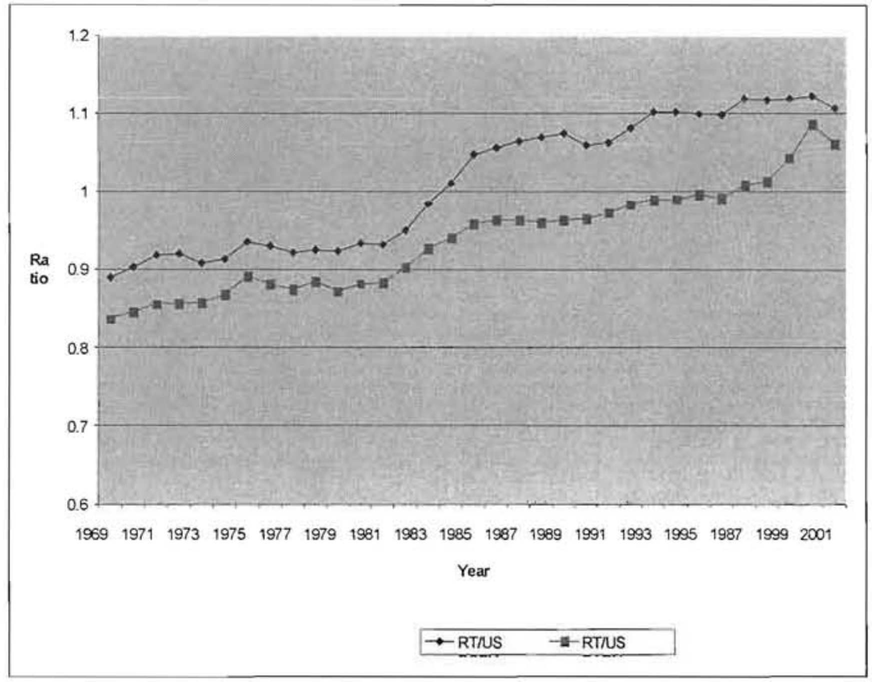

FIGURE 2 Regional Economic Development

stood as level of economic well-being for a region's residents and workers. These are: per capita personal income (PCPY), and average earnings per job. The former includes all types of income -- earned and unearned -- and is based upon the region as a place of residence. Average earnings includes only wage and salary income, and is based upon the region as a place of work. While the two measures clearly overlap, they are also complementary.

The ratio of the Research Triangle's per capita personal income to that of the United States on an annual basis from 1969 through 2001, and the ratio of the region's average earnings per job to that of the U.S. similarly are shown in Figure 2. By graphing the ratios, in effect, we use the national averages as benchmarks, as well as control for inflation over time. The results show in more precise, quantitative terms, what we have verbally described earlier: that the Research Triangle region has experienced dramatic gains in economic development since the start of the period for which consistent data are available. In the case of per capita personal income, the Research Triangle started at below 90 % of the average income for the U.S. in 1969, but was over 110 % of the national figure by 2001. For average earnings per job, the region was below 85 % of the national figure in 1969; by 2001 it was over 105 %. One might offer an alternative explanation that these gains trends were simply as a result of the Research Triangle being located in a growing section of the United States, rather than the result of specific metropolitan factors. In Figure 3 we show the same two measures (in ratio form) calculated for

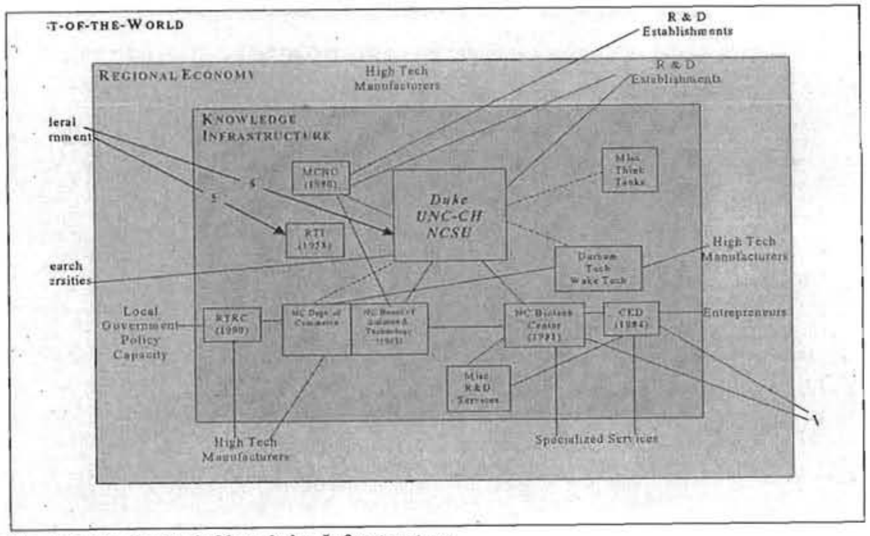

Figure 3 The Region's Knowledge Infrastructure

the southeastern U.S as a whole. The results clearly indicate that being located in an advantaged region, i.e., the Sunbelt, was not responsible for the pronounced relative gains of the Research Triangle region.

A closer look at the graphs in Figure 2 reveals that the gains were not smooth and linear over time. For both measures, the region only grew slightly from 1969 to the early 1980s but then suddenly "took off" in the early to mid 1980s, and then a slowing of the relative regional growth for per capita personal income in the early 1990s.

A Sketch of the Region's Knowledge Infrastructure

In the case of the Research Triangle region, there is little doubt that the region's three research universities -- Duke University, the University of North Carolina at Chapel Hill, and North Carolina State University -- form the core of its knowledge infrastructure. In addition, though, there are other (non-research) institutions of higher education including community colleges and skill training institutes and centres. The knowledge infrastructure is also comprised of *intermediary organizations* that help transmit both formal and tacit knowledge, provides information and analysis about the regional economy and the labour market, and, supports the development of networks and connectivity among actors and organizations. In this section we first describe the role and development of the region's three research universities that have been the key components of the knowledge infrastructure since the mid-1900s. We then describe other components of the region's knowledge infrastructure, also in historical context, and then identify the key linkages and connections among these nodes.

The Region's Research Universities

The UNC-Chapel Hill is one of sixteen campuses of the University of North Carolina system, and one of the two designated research universities of that system. It is the oldest public university in the United States, having first opened in 1793. Student enrollment is approximately 26,300. The academic core of UNC-CH is the College of Arts and Sciences with undergraduate and graduate degree programs in over 45 departments and curricula. In addition, there are a number of large and nationally prominent professional schools including schools of medicine, dentistry, public health, law, business administration, journalism, information and library science, social work, and education. It should be noted that UNC-CH does not have an engineering school. The total UNC-CH employment in fall 2004 was 10,650; the annual operating budget (expenditures) is $1.683 billion dollars in 2004-05.

North Carolina State University (NCSU) is the other designated research university of The University of North Carolina system. Founded as the state's land-grant university in 1887, NCSU enrolls about 29,600 students in mostly applied and technical areas. The traditional areas have been engineering and agricultural science; these remain NCSU's academic core. But there are also schools of design (architecture), education, the humanities and social sciences, management, natural resources, physical and mathematical sciences, textiles, and veterinary medicine. As a land-grant university, NCSU has a special mission for providing direct service and technical assistance to farmers, businesses, government agencies, and non-profit organizations within the state through a large extension service. NCSU employment (faculty and staff) was 6750 in fall 2004 and the annual operating budget of the university is $881 million in the 2004-05 fiscal year.

Duke University, a private university founded in 1924, enrolls 10,600 students. In addition to its college of arts and sciences covering the traditional disciplines in the sciences, social sciences, and humanities, Duke has schools of engineering, divinity, business, law, the (natural) environment, medicine, and nursing. Many of these professional schools are ranked among the best in the United States, particularly business, law, and medicine. Part of the university is a large medical school and teaching hospital. The total employment of the academic portion of the university (including its medical and health-related faculty and staff was 15,250 in 2005, while the hospitals employed another 9,700. The annual budget for the university, including the medical centre and hospital, was $2.2 billion in 1999.

Duke, the University of North Carolina at Chapel Hill, and North Carolina State are each nationally and internationally prominent institutions of higher education. When viewed collectively as a group, the three research universities, all within 40 kilometres of one another, now comprise levels of academic strength and research capacity that, arguably, can be matched only by a handful of other centres of learning in the United States. But in the 1960s and even through the 1970s, it would be fair to say that each of these universities was considered among the best universities within the southern part of the United States, but were not acclaimed nationally. However, the academic strength of these universities grew

TABLE 1 Number of Doctoral Degrees Awarded by Institution National Ranking, Selected Years

	Duke	UNC-CH	NCSU
1966	36	34	65
1986	77	32	50
1998	60	29	40

Source: National Science Foundation (2001). CASPAR web database.

TABLE 2 Number of Enrolled Graduate Students in Science and Engineering National Ranking, Selected Years

	Duke	UNC-CH	NCSU
1972	95	68	40
1986	105	39	31
1998	108	33	25

Source: National Science Foundation (2001). CASPAR web database.

substantially over the 1970-2000 period. In the cases of UNC-CH and North Carolina State, the gains in academic strength were made possible by significant public investments and budgetary support in an otherwise fiscally conservative and poor state, and predicated on the belief among leaders of the state that there was a linkage between the strengthening of the research universities and the long-term economic health of the region and the state. This growth in academic strength and research capacity is documented with the help of some indicators for selected years from the 1960s through the 1990s in Tables 1 through 5

- *Doctoral Degrees Awarded.* UNC-CH and North Carolina State both moved up in the national rankings of number of doctoral degrees awarded between 1966 and 1986 and between 1986 and 1998 (Table 1). North Carolina State moved up 25 places, and UNC-CH moved a more modest five places. Duke's inconsistent trajectory and lower rankings in general reflect its smaller size as an institution, and emphasizing quality over sheer size of its graduate programs. It also reflected priority given to development and expansion of many of its highly regarded professional schools during this time.
- *Number of Graduate Students in Science and Engineering.* This indicator includes students enrolled in master's degree and professional degree programs, in addition to doctoral programs. As such it may be a better indicator of the degree to which the universities' ability to supply highly trained workers for the full variety of jobs within the high tech sectors of the region, outside of academia. Table 2 shows that both UNC-CH and North Carolina State both made impressive gains in the national rankings from 1972 to 1998. Duke's ranking once again must be interpreted in terms of its smaller size as an institution.

TABLE 3 Total Research Expenditures by Institution National Ranking for Selected Years

	Duke	UNC-CH	NCSU
1972	38	52	43
1986	42	38	34
1999	17	33	29

Source: National Science Foundation (2001). CASPAR web database.

TABLE 4 Industry Support for University Research National Rankings for Selected Years

	Duke	UNC-CH	NCSU
1972	86	72	26
1986	25	136	12
1999	3	93	9

Source: National Science Foundation (2001). CASPAR web database.

- *Total Research Expenditures.* Total research expenditures reflects the research capacity and productivity of an institution's faculty as well as its sheer size. Here, all three universities made substantial moves up in the national rankings over the 1972-1999 period (Table 3). This was particularly impressive for North Carolina State which does not have a medical/health sciences school, and UNC-CH which does not have an engineering school. Having three universities ranked within the top 33 nationally is a distinction that no other region in the U.S. could make, including the Boston, New York and San Francisco MSAs.
- *Industry Research Support.* A subset of total research expenditures is that portion whose source is private industry rather than government agencies or foundations. As such it reflects collaborative research activity and the strength of linkages between private industry and the university, though the linkages are not necessarily within the same region. Table 4 shows that Duke and North Carolina State had moved into the top ten nationally from much lower rankings in 1972. UNC-CH's lower ranking reflects that it does not have such applied fields such as agriculture and engineering, and that North Carolina State as the land grant university historically has maintained stronger links with private industry.
- *Reputation Within Discipline.* Our last indicator is the reputation of the strength of the faculty by discipline as judged by panels of senior faculty and department chairs across the U.S. These reputational surveys are conducted periodically and have been sponsored by the national Research Council of the National Academy of Sciences. There have been three such surveys conducted: in 1966, 1982, and 1995. We summarize these rankings by counting the number of departments in the region's universities in science and engineering disciplines that were ranked within the top 10 and the top 30 nation-

TABLE 5 Top Thirty Rankings of Academic Departments in the Sciences and Engineering: Duke, NCSU, UNC-CH

Discipline	1966	1982	1995
Microbiology	n.a.	D (7), U (23)	n.a.
Biochemistry	D (15)	D (16)	D (15), U (27)
Botany	D (7), U (17)	D (11), U (16)	--
Entemology	N (13)	--	--
Pharmacology	n.a.	n.a.	D (5), U (8)
Physiology	D (18)	D (11), U (13)	D (26)
Zoology	D (16)	D (5), U (14)	--
Cell biology	--	--	D (14), U (25)
Ecology	--	--	D (3)
Neurosciences	--	--	D (16), U (26)
Molecular/genetics	--	D (17)	D (15), U (20), N (30)
Astronomy	n.a.	n.a.	n.a.
Chemistry	n.a.	n.a.	U (20)
Geology	n.a.	n.a.	n.a.
Mathematics	n.a.	n.a.	n.a.
Physics	n.a.	n.a.	n.a.
Computer Science	--	--	U (21)
Statistics/biostatistics	--	--	U (15)
Chemical engineering	n.a.	n.a.	n.a.
Civil engineering	n.a.	n.a.	N (23)
Electrical engineering	n.a.	n.a.	n.a.
Mechanical engineering	n.a.	n.a.	n.a.

Note: 1. D = Duke University; U = UNC-CH; N = NCSU.
2. Rankings based on perceived faculty quality.

Sources: Cartter (1966); Jones et al (1982); National Research Council (1995).

ally. Results are shown in Table 5. In 1966, only one academic department in the region was ranked in the top 10 and only six in the top 30 nationally. By 1982, the number of science or engineering departments in the top 10 had increased to two, but the number in the top 30 had increased to 15. And by 1995, four academic departments were within their respective top 10 nationally, and 32 were within the top 30.

In summary, there has been a notable increase in the strength of the region's research universities, both in terms of human capital creation and research capacity. That this occurred approximately during the same time that the Research

Triangle Park had "taken off" does not permit us to statistically *prove* a causal relationship between university capacity and regional economic well-being (Figure 2), but it certainly strongly *suggests* such a relationship.

Other Major Producers of Knowledge and Know-how

A number of organizations other than research universities have played a key role in knowledge and know-how production in the region. These include research organizations or think-tanks, as well as other types of institutions of higher education.

The Research Triangle Institute (RTI International) is a large contract research non-profit organization that was founded in 1958 by a group of university, business and government leaders as a focal point for growth of the just-created Research Triangle Park. Its first research areas were in applied statistics and the environmental sciences and technologies. It has steadily grown in size and scope from a handful of scientists to over 2500 employees working in over 30 countries in areas that span health, social and economic development, education and training, advanced technology, environmental research, and survey research. Its receipts in 2003 of $447 million in research grants and contracts place it only slightly behind Duke University and UNC-CH, and slightly ahead of North Carolina State. Indeed, RTI International is a surrogate research university, albeit without the teaching. There are strong institutional ties between the research universities and RTI International -- the presidents of the three research universities sit on the board of directors of RTI International -- but the incidence of collaboration, joint research, and staff exchange between scientists at the universities and RTI International is even more noteworthy.

The region's two community colleges, Durham Technical Community College (Durham Tech) and Wake Technical Community College (Wake Tech) play prominent roles in the production of know-how to meet the skill needs of high-tech companies already .located in the region but also for prospective companies.

Durham Tech was a charter member of the state's Community College System, established in 1957. At that time the programs were focused on adult education in the fields of nursing, mechanical drafting, architectural drafting, and electronics technology, as well as basic literacy skills. The institution has expanded both the number of students served and its scope steadily from the mid-1960s onward. In 2003, over 21,000 students were enrolled at Durham Tech in one of the divisions. The educational scope now includes Associate degree courses of study in a number of technology areas (business and public service technologies, health technologies including biotechnology, industrial and engineering technologies, and information systems technologies), corporate education, and a Small Business Center, in addition to its original roots in adult education and continuing education. The Corporate Education Center offers customized training to businesses and other organizations in a variety of technical and managerial areas. While these services are available to businesses and organizations already located in the region, they are increasingly used as part of an incentives package, in conjunction with the state

Department of Commerce, to help recruit new businesses that need customized skill training services. The Small Business Center offers technical and managerial assistance tom area businesses in the form of training, counseling, seminars, and an extensive library.

Wake Tech has a similar history and serves a similar set of roles in the region's knowledge infrastructure. It was established in 1958 as an original charter member of the state's community college system, and began operations in 1963 with 304 students and a focus in industrial training programs. Over the next 40 years, it has also expanded its scope to include a Business and Industry Services Division and Occupational Education Division, in addition to the Associate Degree curricula and the Basic Skills Division for adult learners. The Associate degree programs include courses of study in computer information systems, engineering technology, health sciences, and mathematics and science. Wake Tech has been designated as an Advanced Technology Education Center of Excellence, in partnership with the North Carolina Supercomputing Center, for the development of educational programs in high performance computing technology, by the U.S. National Science Foundation. Within the Business and Industry Services Division are apprenticeship programs, Small Business Center seminars, and courses on personnel development and focused industrial training customized for the needs of particular businesses and organizations. In the 2002-2003 academic year the Business and Industry Services Division served over 10,000 individuals. The total number of students served by Wake Tech during 2002-2003 was over 49,000.

The Microelectronics Center of North Carolina (MCNC) has been another key node in the knowledge infrastructure. Created in 1980, MCNC started with state government funding with the intention of spurring further growth and development of the nascent microelectronics industry. The facility for the centre was built in the Research Triangle Park and included extensive laboratory space for joint research that would bring together faculty and advanced graduate students at the three research universities with industry researchers based at private R&D labs located in the region. Through conducting leading edge research that could serve the industry as a whole, and by raising the visibility of the region as a concentration of assets in this technology area, the public policy objective of investing in MCNC was to be able to attract an additional concentration of R&D activity to the region. A high speed super computer was later installed at MCNC not only for the use of the researchers there, but also for the research staff at the universities and other private R&D firms throughout the state. Thus, MCNC primarily served as a knowledge-producing node in the infrastructure, but it also had an intermediary role as well by connecting researchers in the universities with those in industry. Although the objective for the region to become a leading centre for microelectronics research has not been achieved, MCNC has been and continues to be an important available asset.

Several state government agencies produce economic data and indicators, and conduct economic analyses that support technology-based economic development efforts statewide. The North Carolina Board of Science and Technology, a division of the Department of Commerce, was created as early as 1963. Originally used to help in the recruitment of firms that had skill needs in science and engineering, its role evolved in the 1980s and 1990s to investigate areas of emerging science and technology that have the potential to advance the state's economy and to strengthen the state's research institution. It also has an important intermediary role to advise and recommend to elected officials how the state's economic competitiveness can be enhanced through science and technology. The Employment Security Commission of North Carolina produces current labour market information, both statewide and for various sub-state regions, and projects future job openings by occupational category. The state Office of Budget and Management also develops macroeconomic forecasts that support state government budget decisions and fiscal policy, but these forecasts also serve a broader set of businesses and investors in the region. These kinds of services from state government agencies are by no means unique to North Carolina and the Research Triangle region, but they do play an important role that helps the regional labour market to function more efficiently, and to assist economic development policy officials in making efficacious policy choices regarding.

Finally, there are a number of research organizations that have started up or located in the region to take advantage of the demand for specialized research services from larger R&D organizations in the Research Triangle Park or environs, e.g., conducting clinical trials for pharmaceutical firms. This build-up of local know-how, expertise, and technical capacity makes the region more attractive for the location of the larger R&D organizations knowing they have greater flexibility for contracting out particular technical services. Somewhat related has been the significant growth in the region, particularly since the mid-1990s, of legal services specializing in intellectual property, IT consulting, and software developers to serve the internal market.

Key Organizations Serving Intermediary Roles

There are a number of organizations that serve a role in connecting nodal organizations within the knowledge infrastructure, connecting these organizations with private R&D and other high-tech producers within the region, and connecting R&D organizations within the region to knowledge producers outside the region.

Perhaps the prototypical example of an organization that serves all of these intermediary roles is the North Carolina Biotechnology Center. Established in 1981 by the state legislature as a private, non-profit corporation, and located in the Research Triangle Park the Biotechnology Center's mission has been to bring long-term economic and social benefits to the state by helping to grow and nurture the state's biotechnology industry. No biotechnology research is undertaken by the organization. Instead, the Biotechnology Center's programs focus on *connecting* existing and potentially new biotechnology R&D to each other, to informational, financial, human capital, and governmental/public policy resources. Translated, this intermediary and networking role should produce positive externalities for the growth of the biotechnology cluster, including manufacturing and specialized support services, as well as R&D. And while the Biotechnology Center has a statewide mission and recently has expanded its programs to the Winston-Salem and western North Carolina regions, the bulk of its activities and its economic development impacts have been concentrated within the Research Triangle region largely because of the concentration of biomedical research already there at Duke, UNC-CH, and the pharmaceutical firms in the Research Triangle Park.

The Council for Entrepreneurial Development (CED) is an organization that promotes new business start-ups in the region by building and supporting networking among area entrepreneurs, would-be entrepreneurs, and regional and external resources (e.g., venture capital) critical to new business success. It was established in 1984 by a small group of business leaders, entrepreneurs and university faculty. By 1985, membership had already increased to 200 individuals and firms; by 1989 membership was 400, and by 2001 it had swollen to over 5000. Activities of CED include mentorship programs for entrepreneurs, entrepreneurial training in seminars and workshops, hosting technology forums and venture capital fairs, and educational outreach in the community, high schools, and universities on entrepreneurialism. There are close links and programmatic coordination between CED and the respective business schools at Duke and UNC-CH, MCNC, the Biotechnology Center, the Research Triangle Regional Partnership (described below) and both the managing entities for the Research Triangle Park and North Carolina State University's Centennial Campus. CED serves as an example of a "pure" intermediary organization.

The Research Triangle Regional Partnership (RTRP) was initiated in 1990 as a public-private partnership of economic development agencies within the 13 county region that works collaboratively with the state Department of Commerce to "market" the entire region for economic development. The primary economic development focus is to recruit new investment and jobs to the region, but it also works on retention and new business start-ups. On behalf of the local governments within the region, it commissions studies of the economic development needs of, and strategies for, the region. Its most important intermediary role has been to help local governments work collaboratively and as partners in pursuing economic development initiatives, i.e., on a regional basis, as well as to bridge the interests and resources of the North Carolina Department of Commerce and those of local governments.

Other organizations already described under knowledge and know-how production also play a secondary intermediary role in the region's knowledge infrastructure including MCNC, particular units of the research universities including patenting and licensing offices, and several divisions of the North Carolina Department of Commerce.

A "Map" of the Region's Knowledge Infrastructure

The principal nodes outlined above, by function, and the significant linkages among these nodes are shown in Figure 3.

While the figure is drawn to show the separation of the region's knowledge infrastructure from the regional economy itself, it also makes clear that the knowledge infrastructure is imbedded within the region, with a number of two-way linkages between the organizations that comprise the infrastructure and other regional organizations. On the other hand, the organizations that comprise the knowledge infrastructure also have important links with organizations outside the region.

Finally, we emphasize that the figure is not meant to be comprehensive (and may not even be possible), but to show the most (arguably) prominent and important components of the infrastructure and inter-organizational linkages.

An Interpretation of the Role of the Region's Knowledge Infrastructure in the Region's Economic Transformation

As stated earlier, the Research Triangle Park, created in 1958, has been popularly regarded as the region's engine of regional economic growth and development. This view is much too simplistic for reasons discussed below. Instead, we argue that it was the development of the region's knowledge infrastructure that was the foundation for the dramatic transformation of the regional economy.

The argument consists of three strands. First, the success of the Research Triangle Park, which was by no means instantaneous, was dependent upon the development of the region's knowledge infrastructure, and specifically on the knowledge assets and leadership of the region's research universities. Second, the research universities were not yet strong enough in the late 1950s and 1960s to attract and build (endogenously) the other key components of the knowledge infrastructure. As a result the economic development strategy of the region had to continue to be based upon the recruitment of R&D branch plants from large national corporations. Third, the progress that the research universities had made in research capacity and reputation by the mid- to late-1980s was critically important for the "fleshing-out' and broadening of the emerging knowledge infrastructure such that it became a productive force for regional economic development.

Although the Research Triangle Park was created in the late 1950s, it nearly went "belly-up" several times within its first ten years. Even after IBM located its branch research facility in the Park in 1965 and NIEHS located its research facility shortly thereafter as a result of the political connections of Governor Terry Sanford -- both of which served as "anchors" in the parlance of retail shopping centres -- the strategy for the development of the Research Triangle Park and the region generally continued to be based upon the recruitment of R&D branch plants of large national (and international) corporations. In short, an endogenous development strategy based upon the expansion of existing R&D firms and the start-up of new ones was *not* feasible because the region lacked a highly developed knowledge infrastructure plus a breadth and depth of business services to support and nurture small and medium sized companies and technology-based entrepreneurial activity. The inability to pursue an endogenous development strategy hindered the overall rate of regional economic development, and given the highly competitive nature of the corporate recruiting game, made for an unsustainable path of economic development. It was not until sometime in the first half of the1990s that the region's knowledge infrastructure (outside the research universities) had broadened and developed sufficiently to support an endogenous development path.

The central role of key individuals from the three research universities -- particularly from UNC-CH and NCSU -- in the creation of the Research Triangle Park has been described earlier. But what should be clear is that the feasibility of the *idea* that the Park could attract the R&D branch plants to the region rested firmly upon the knowledge assets in the scientific disciplines of chemistry, environmental sciences, the biological sciences (including medicine), and engineering within the combined universities that existed in the late 1950s. At the time of the creation of the Park in the late 1950s, the overall assets and research capacity of the three research universities, even when combined, were good -- likely the best in the South -- but by no means among the strongest in the U.S. nor 'world-class'. It would take the period between 1960 and the mid-1980s before more than a handful of departments in science or engineering ranked in the top 30, and until the mid-1990s until more than a few programs were ranked in the top 20 nationally within their respective disciplines. Hence we suggest the only modest pace of economic development in the region for much of the 1960s and 1970s may be a result of the relative position and ranking of the region's research universities in science and engineering fields.

On the other hand, there is little doubt that the economic development that did occur in the region during this period helped the region's research universities improve their research capacity and rankings. One reason was that higher education officials were able to make the case that the economic development success of the region (and thus the state) up to that time could be attributed largely to the universities -- the true engines of growth -- and hence the imperative for the state to further invest in their research capacity. It was only after a *broad* number of academic science and engineering departments had achieved top 20 rankings that the region gained the recognition of a world-class centre of knowledge creation. This recognition, we suggest, helped attract talented and creative individuals, small innovative firms, entrepreneurs, venture capital, and specialized business services -- attracted by the *milieu* that the knowledge creating institutions had created -- that could enable the region to develop on an *endogenous* development path.

It would be a heroic attempt, but one doomed to failure, to try to *quantitatively* estimate the effect of the investment in the region's knowledge infrastructure on its subsequent. economic development. The measurement problems alone are daunting enough, before having to solve the attribution problem of a number of different plausible causal factors operating at about the same time. Nevertheless, another examination of the temporal pattern of regional economic development in relationship to the development of the knowledge infrastructure (qualitatively) provides support for the view just described. If the creation and growth of the Research Triangle Park had been the major force in the region's economic development we would expect to see a higher rate of growth of the indicators in the period prior to then 1980s. The explanation for the early meager gains we suggest, was the inability to develop endogenously. That ability required a filling out of the knowledge infrastructure. While many of the organizations existed -- the three research universities, the Research Triangle Institute, the Board of Science and Technology, and the two community colleges -- their functional contributions were limited either because of scale or mission. The slowing of the growth of the Research Triangle Park and recognition that the strategy of relying mostly upon the recruitment of R&D branch plants was not sustainable, led to the creation of a number of new organizations in the early- to mid- 1980s -- MCNC, the Biotechnology Center, and CED -- as well as a change in the mission and emphases of the community colleges, and significant investment in the research capacity of the research universities. It was this process of the growth and maturation of the knowledge infrastructure that led to regional conditions conducive to tech-based start-ups and entrepreneurial activity generally, venture capital, the location of specialized business services, spin-off businesses from the universities, and the in-migration of highly talented individuals. So by the start of the twenty-first century, the region's economic development was no longer dependent upon the continued growth of the Research Triangle Park or the research universities directly. The universities (as well as the Park) had created an environment that would attract innovative economic activity to the region because of the concentration already there, and offer significant external economies to support development from within. The Research Triangle region still does not have the dynamism of Silicon Valley, but the development of its knowledge infrastructure has been instrumental in coming a long way towards it within the last twenty years.

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