At the Crossroads:

North Carolina's Place in the Knowledge Economy of the 21st Century

prepared for

North Carolina Alliance for Competitive Technologies
North Carolina Board of Science and Technology

by

Edward J. Feser
Harvey A. Goldstein
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Principal Investigators

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Research Associate

Department of City and Regional Planning
University of North Carolina at Chapel Hill

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Summary

The North Carolina economy today is a picture of stark contrasts: a predominance of traditional manufacturing sectors and an expanding core of high technology activity; a low-wage, low-skill, but highly productive workforce and a growing concentration of highly skilled research and professional workers; a below average volume of R&D in industry and well above average rates of R&D growth in universities and teaching hospitals. The general economic and research trends offer both positive and negative perspectives on the state's future. Overall, they suggest impending restructuring of considerable magnitude that will require creative responses from policy makers, industry leaders, and educators.

This report is intended to stimulate our thinking about how to meet the challenges of the 21st century. In doing so, it raises some old and difficult questions: what can be done to ensure a smooth transition from a traditional manufacturing to a knowledge-based economy? And, how can we help expand knowledge resources more broadly in geographic terms, so that R&D can occur in non-metropolitan counties with small and medium sized manufacturing establishments? Accomplishing those two tasks will help prevent chronic displaced worker problems, and will help increase incomes in the state.

The report provides a few principles. Generally, these have been followed in the development of policy in North Carolina. But they suggest some additional actions that can be taken.

■ *Put resources where there is likely to be a payoff because of existing critical mass.*

The report identifies where industrial and university strengths coincide. Efforts are already underway in some of those sectors (the Biotechnology Center with pharmaceuticals; MCNC with telecommunications and electronics). Further efforts could be made toward other clusters, e.g., industrial chemicals and environmental technologies.

■ *Identify industries that are likely to be winners.*

The limitation of any type of industrial policy is in being able to pick winners and avoid losers. Indeed, the market does that reasonably

Report Documents

Findings from this study are contained in three documents. This report contains the main report findings and methodology. *At the Crossroads: Technical Appendix* contains extensive technical notes and a set of tables that provide detailed supporting information. *At the Crossroads: Report Summary* constitutes a synopsis of the findings and policy implications. Copies of all documents are available from the North Carolina Board of Science and Technology. ■

well. But, to pull the economy up the trajectory, the state needs to be proactive. Our analysis has identified some good business development targets. For example, twenty-five industries are technology-intensive and growing in terms of jobs and wages.

■ *Develop home grown businesses that may emerge as headquarters and/or research centers.*

The payoff from successful start-ups and spin-offs is substantial– the creation of quality jobs and income growth at SAS, Sphinx, Emrex, and Quintiles are cases in point. The North Carolina economy is much riper for entrepreneurial development today than it has ever been.

■ *Invest in knowledge infrastructure.*

The old mindset among industrial developers was that roads needed to be built to ensure that jobs would come, especially in non-metropolitan areas. As we move into the 21st century, knowledge infrastructure plays that role. To get growth into regions that need it, we need to consider the strategic use of telecommunication links, business parks, institutions of higher education (and training), in addition to transportation nodes. The Global TransPark is one model for that.

■ *Invest in people.*

As traditional industries continue to downsize and new businesses start-up and expand, our workforce needs to be upgraded so that employees can make the transition. Similarly, entry-level workers (in high school) need to be prepared for work that requires computation and a higher level of skills than in the past. This suggests a host of school-to-work and displaced worker programs. It also implies a rethinking of traditional methods of training and education delivery, as well as a better meshing of the needs of industry with the missions' of the state's universities and community colleges.

Acknowledgments

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Introduction

North Carolina's economy is at a crossroads. With about one-quarter of its workforce in manufacturing, almost ten percentage points higher than the national average, the state still ranks as the most manufacturing-intensive economy in the U.S. Each year, North Carolina attracts more new manufacturing plants than most other states. Although there is also a high rate of plant closings, the state's economy is generally healthy, with a statewide unemployment rate near 4 percent. Some of the state's new manufacturing growth is in emerging sectors, notably in software development, health, and pharmaceuticals. A growing complex of knowledge resources (universities, medical centers, and research institutes), particularly in the Research Triangle area, has induced considerable high tech growth, including a sizable number of new start-up and spin-off companies. General economic growth, especially in the high technology industries, has pushed personal income up, rising by 6.6 percent between 1995 and 1996 for the state as a whole.

While these trends are indeed positive, the state must not be lulled into a false sense of security about its economic future. *At the Crossroads* considers North Carolina's economic prospects by assessing its research strengths in industry and the academy as well as its likely ability to respond to shifting R&D funding priorities in Washington. Our focus on R&D recognizes that successful economies in the early 21st century will be those with a strong knowledge base. In particular, the competitive position of North Carolina in the global economy of the future will likely rest on the ability of businesses and universities to work together to create and commercialize new products and processes.

The report suggests that North Carolina's current volume and distribution of knowledge-based resources raises some concerns about the state's future. North Carolina's traditional economic base consists of industries that are declining nationally, and which depend upon relatively modest amounts of R&D inputs. Because of the sectoral mix, and the prominence of manufacturing branch plants, research and development activity in the state is generally relatively low. Moreover, much of the state's R&D activity is concentrated in only a few technology sectors, institutions, and regions. Limited R&D activity is desirable only in the sense that it renders the state less vulnerable to cutbacks in federally-funded, defense-related R&D. But, on balance, it is potentially problematic for at least three reasons.

First, R&D that leads to *process innovations* increases industry productivity. Productivity, in turn, enables North Carolina businesses to prosper in the ever-competitive global marketplace. Fewer workers per dollar of output may be employed, but those who remain in the workforce earn higher wages. That is essential if the state is to rank higher among states in per capita income (despite a strong economy, it has not been able to rise above 33rd in rank during the 1990s). Although North Carolina firms may certainly continue to adopt best-practice process technologies developed outside the state, the comparative absence of R&D (and headquarters) operations of major corporations means that North Carolina's economic destiny is subject to greater external control than is the case for many otherwise comparable manufacturing states.

Second, R&D leading to new *products* enables the state to grow new businesses. New business development is critical to absorb the workers displaced in traditional industries as a result of the inevitable movement of labor-intensive production offshore, as well as the continued process of automation here. In other words, new process technologies drive productivity advances, raising incomes but freeing up labor that must be absorbed elsewhere in the economy. New enterprise start-ups as a result of research and development activity in existing industry and universities are necessary to provide new employment opportunities.

Finally, a more even geographic and sectoral distribution of knowledge resources helps reduce geographic economic inequities. Research demonstrates that firms benefit from proximity to research universities and institutes through the increased access to knowledge and expertise as well as trained labor. Firms also benefit, for many of the same reasons, from proximity to R&D performing industries. And, of course, a more even distribution of knowledge-intensive, higher wage jobs means a more even distribution of income. In North Carolina, the better-paying, high tech jobs are concentrated in a relatively small number of counties (primarily in the Raleigh-Durham and Charlotte regions). In 1995, for example, per capita personal income ranged from $12,334 in Hoke county to $28,520 in Mecklenberg county.

Scope of the Report

The report raises some old and difficult questions for policy makers: what can be done to ensure a smooth transition from a traditional manufacturing to a knowledge-based economy? And, how can we help expand knowledge resources more broadly in geographic terms, so that R&D can occur in non-metropolitan counties with small and medium sized manufacturing establishments? Accomplishing those two tasks will help prevent chronic displaced worker problems, and will help increase incomes in the state.

The report is organized into five main sections. The first section elaborates the importance of R&D for economic development. The second section characterizes North Carolina's current economy in terms of R&D activity. The third section assesses the potential for the economy to develop leading R&D industries and knowledge resources (universities, medical centers, and research institutes). The fourth section simulates the effect of changes in R&D spending by the Clinton administration on the state, considering its industry and university R&D patterns and capabilities. The final section proposes some policy actions that would help move the state into the emerging knowledge economy of the 21st century.

R&D for Economic Development

Research and development is critical to a knowledge-intensive, technology-based economy. It supplies the new ideas and products that keep businesses on the leading edge of their respective industries, as well as the innovations that lead to productivity-enhancing improvements in process technology. Current trends suggest that the U.S. economy will likely become even more knowledge-intensive and R&D dependent as global competition intensifies. While many other countries compete on the basis of a ready supply of traditional low cost factors (e.g., labor and land), the U.S. offers a highly skilled workforce, advanced infrastructure, and world-leading research facilities and expertise.

Over forty years ago, noted economists demonstrated that technological change is a major contributor to economic growth. More recently, research has shown that technical change can be induced by R&D activity and that the growth prospects of particular cities and states depend to an increasing degree on the condition of their ‘knowledge infrastructures.’ Regions with strong knowledge bases and the capacity to innovate generate new productive activity from within. They also attract additional technology-based enterprises and workers from outside, which provides further resources and impetus for improvements in schools and universities. This relates to what has become known as endogenous growth theory: “As the skill or knowledge base of a regional labor force is perpetually enhanced from within it becomes a continuous internally created source of competitive advantage . . . for an economic system.”[1]

That is important for North Carolina. R&D can help provide a competitive advantage for its existing industries that are subject to increasing pressure from offshore manufacturers. R&D may lead to process innovations, enabling goods to be produced at lower unit cost, and to the development of new products. If existing goods are produced more capital intensively, for example, there would be less labor input per unit, but if market share increased, there could still be more employment, but at a higher wage. The state’s textiles industry is a case in point: value-added has continued to grow in the sector since the mid-1980s, even though employment has been cut. Between 1989 and 1994, real GSP growth in SIC 22 averaged 5.3 percent annually, over twice the state average, while employment fell 1.5 percent annually. In short, the introduction of new equipment, and presumably, better methods, has kept the industry afloat. Another example of R&D in a traditional industry is the introduction of numerically-controlled machines in the apparel industry. Garments are fabricated with less labor input, but the automation has kept the manufacturers viable in world markets, muting the loss of employment in that industry. R&D also has led to new products with substantial new employment in pharmaceuticals—for example, the development of a variety of protease inhibitors by Glaxo-Wellcome—and in software.

The location of the R&D is important. Several researchers have demonstrated a distinct R&D impact gradient: the economic benefits of research and development are greater the closer one is to the site of the innovation. From North Carolina's perspective, then, it is not enough to have R&D conducted for the apparel industry in Massachusetts or Italy (wherever headquarters or the lab may be), and applied in North Carolina. Chemicals manufacturers cannot continue to rely on innovations generated in Ohio or Michigan. Likewise, that is true for every industry in the state. Plants that primarily import process and product innovations remain vulnerable to closures designed to move production to lower labor cost sites. They also tend to employ a lower-skilled and lower-paid mix of workers. A purely production focused economy, particularly one dominated by branch plants, is subject to a high degree of external control (through non-local headquarters and R&D operations of parent companies). It is, in effect, less in charge of its own destiny.

The North Carolina Economy Today

The North Carolina economy today is a picture of stark contrasts: a predominance of traditional manufacturing sectors and an expanding core of high technology activity; a low-wage, low-skill, but highly productive workforce and a growing concentration of highly skilled research and professional workers; a below average volume of R&D in industry and well above average rates of R&D growth in universities and teaching hospitals. The general economic and research trends offer both positive and negative perspectives on the state's future. Overall, they suggest impending restructuring of considerable magnitude that will require creative responses from policy makers, industry leaders, and educators.

One of the most significant features of the North Carolina economy is its continued manufacturing-intensity. The shift away from manufacturing toward other sectors (retail trade, services, government and FIRE) has been somewhat more gradual in North Carolina than in most other states. Indeed, the share of gross state product (GSP) in manufacturing in 1994 in North Carolina remained at 31.5 percent, compared to 19.4 percent in the ten largest manufacturing states and 18.4 percent for the U.S. as a whole. The state was the most manufacturing-intensive economy in the country in 1994. Conversely, North Carolina's service sector share of total GSP ranks 48 among the 50 states and the District of Columbia.

Manufacturing-intensity does not necessarily imply low performance. North Carolina has consistently paralleled average GSP growth in the south since 1986; in 1994, the state's real GSP growth significantly exceeded other southern states, the top ten manufacturing states, and the U.S. as a whole. Annual real growth in gross state product from 1989 to 1994 averaged 2.06 percent.

In terms of employment, North Carolina has outpaced the manufacturing state average since 1969, the earliest year for which comparable data exist. It paralleled national growth trends closely until the post-recession years of 1983-4. Employment in the state recovered more quickly than the national average over that period and has continued an upward divergent trend since. Notably, the state also recovered from the early 1990s recession more quickly than the U.S. as a whole, the top ten manufacturing state average, and the south. Overall, however, the state's rate of employment growth has not matched the south's over the full 1969-1994 period. Annual employment growth in North Carolina during the 1989 to 1994 period averaged 2.0 percent.

Key specializations in North Carolina (using GSP as a measure) include traditional low-technology industries such as tobacco, textiles, apparel, furniture, and farming, as well as several more technology-intensive sectors, including chemicals, rubber and plastics, electronics, and air transportation. Potentially emerging specializations include motor vehicles and equipment, instruments, fabricated metals, primary metals, and health services. The industries with the highest rates of GSP growth between 1989 and 1994 include farming; agricultural services, forestry and fishing; textiles; rubber and plastics; electronics; industrial machinery and equipment; motor vehicles and equipment; trucking and warehousing; air transportation; communications; wholesale trade; banking (nondepository institutions and holding and investment companies); business services; and social services and membership organizations.[2]

Research and Development Activity

In 1993, scientists in North Carolina conducted $2.75 billion in research and development, ranking the state eighteenth overall, and eighth among the top ten manufacturing states. By way of comparison, expenditures for research and development (from all sources, federal, industry and government) exceeded $33 billion in California, $10 billion in Michigan and Pennsylvania, and $2.9 billion in Virginia and Minnesota. North Carolina total R&D expenditures relative to other states are increasing, however. The state ranked twenty-first in total R&D expenditures in 1975.[3]

In 1993, North Carolina's R&D intensity (typically measured as the ratio of total R&D expenditures to gross state product) stood at 1.6 percent, up from 1.3 percent in 1985. That was below all major manufacturing states except Texas and Georgia, and was significantly below the U.S. average of 2.7 percent. Thus, despite the success of Research Triangle Park and a number of highly visible R&D performers in the state, North Carolina conducts a significantly below-average volume of R&D in relative terms.

Among R&D performers, the state's universities and colleges conducted $604 million of North Carolina's $2.75 billion in R&D spending in 1993. That 22 percent share is 10 percentage points higher than the national average, and higher than all other major manufacturing states (Figure 1). By contrast, industry R&D constitutes a somewhat smaller share of total R&D expenditures in North Carolina (at $1.93 billion or 70 percent in 1993) compared to the national and manufacturing state averages (71 and

80 percent, respectively). Other non-profits and federal agencies also play a smaller role in the North Carolina R&D enterprise while there are no university-administered federally funded research and development centers (FFRDCs) in the state.

Industry and the federal government are the two principal sources of R&D funds in the United States. The federal government provided 21 percent of the total R&D funds expended in the state in 1993, a full 13 percentage points below the national average of 34 percent. The state's industry makes up the difference at 72 versus 58 percent nationally. Other funding sources include state and local governments, intra-university funds, and foundations and other non-profits (all of which, together, account for roughly 7 percent of R&D funds).

Industrial Research and Development. North Carolina industry conducts somewhat less research and development than many comparable manufacturing states and the national average, though recent 10 to 15 year trends indicate significant above-average rates of growth (Table 1). In 1979, total industrial R&D expenditures in North Carolina stood at $327 million. By 1993, they had reached $1.93 billion, a 490 percent increase (compared to 210 percent nationwide). The high rate of growth is in part due to the small base in which the state started. However, industrial R&D growth in North Carolina still outpaced Indiana and Georgia, states with a similar small base of activity in 1979.

Industrial R&D expenditures for 1993 place the state's industrial R&D intensity (the ratio of industrial R&D expenditures to gross state product)

TABLE 1: Trends in Industrial R&D Spending by State

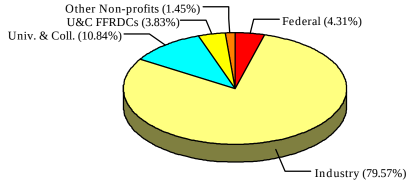
Top 10 Manufacturing States and Selected Others

	Total Industrial R&D (Millions)			R&D Intensity		
	1979	1993	% Change	1979	1993	% Change
Top 10 Manufacturing States	21,891	72,230	230.0	1.6%	2.1%	30.6
California	7,437	26,541	256.9	2.5%	3.2%	24.9
Texas	1,233	4,882	295.9	0.7%	1.1%	54.3
Ohio	1,635	5,144	214.6	1.4%	2.0%	46.1
Michigan	3,614	9,924	174.6	3.5%	4.6%	31.0
Illinois	1,673	5,242	213.3	1.2%	1.7%	41.0
New York	2,959	8,820	198.1	1.4%	1.6%	16.8
Pennsylvania	2,143	6,711	213.2	1.8%	2.4%	36.0
North Carolina	327	1,929	489.9	0.6%	1.1%	93.2
Indiana	723	2,177	201.1	1.3%	1.7%	36.4
Georgia	147	860	485.0	0.3%	0.5%	79.3
Selected Other States						
New Jersey	2,191	8,162	272.5	2.6%	3.3%	25.8
Massachusetts	1,690	6,952	311.4	2.7%	4.0%	45.5
Connecticut	985	2,373	140.9	2.7%	2.2%	-16.9
Minnesota	802	2,458	206.5	1.7%	2.1%	23.2
Missouri	746	1,375	84.3	1.4%	1.2%	-19.2
Florida	620	2,425	291.1	0.7%	0.8%	15.8
Virginia	464	1,087	134.3	0.8%	0.6%	-24.0
Wisconsin	420	1,343	219.8	0.8%	4.2%	401.2
Kentucky	209	289	38.3	0.6%	0.4%	-39.5
Oklahoma	174	311	78.7	0.6%	0.5%	-12.3
South Carolina	82	495	503.7	0.3%	0.7%	108.3
United States	38,226	118,334	209.6	1.5%	1.8%	20.2

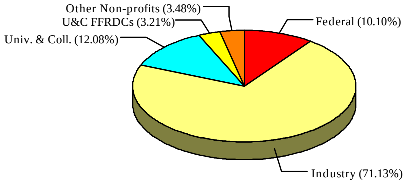
Source: Bureau of Economic Analysis and National Science Foundation. Industry R&D intensity is defined as the ratio of industry spending on R&D to gross state product.

FIGURE 1:
R&D Expenditures by Sector, 1993

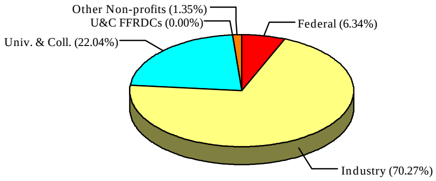
Top 10 Manufacturing States



United States



North Carolina



Source: National Science Foundation

at 1.1 percent (nearly double its 1979 figure), though it still remains well below the national average of 1.8 percent. Many other manufacturing states (including California, Texas, Ohio, Michigan, Illinois, New York and Pennsylvania) conduct significantly more industrial R&D. North Carolina industrial R&D does outpace several nearby states, including South Carolina, Virginia, and Georgia.

Significantly, over 99 percent of industrial R&D spending in North Carolina is derived from company rather than federal sources (Table 2). In 1993, North Carolina firms appear to have garnered only $16 million in federal R&D money, 0.8 percent of total expenditures. The national average breakdown of total industrial R&D expenditures by source is roughly 19 percent federal, 81 percent company. Key comparison states appear considerably more successful or aggressive in pursuing federal R&D funds. The share of industrial expenditures from federal sources exceeds 10 percent in six out of ten major manufacturing states, as well as other comparison states like Massachusetts, Connecticut, Minnesota, Florida and Virginia.[4]

Universities, Colleges and Teaching Hospitals. In 1994, North Carolina universities and teaching hospitals conducted nearly $680 million in research. Overall, academic research institutions in North Carolina account for a 3.2 percent share of the nation's total spending for R&D in academic research institutions, compared to 2.7 percent for North

TABLE 2: Composition of Industrial R&D Spending by State

Top 10 Manufacturing States and Select Others, 1993 (Dollars in Millions)

	Industrial R&D Spending by Source			% Federal
	Total	Company	Federal	Share '93
Top 10 Manufacturing States	72,230	60,095	12,135	16.8
California	26,541	19,078	7,463	28.1
Texas	4,882	4,242	640	13.1
Ohio	5,144	4,114	1,030	20.0
Michigan	9,924	9,771	153	1.5
Illinois	5,242	5,006	236	4.5
New York	8,820	7,428	1,392	15.8
Pennsylvania	6,711	5,569	1,142	17.0
North Carolina	1,929	1,913	16	0.8
Indiana	2,177	2,177	0	0.0
Georgia	860	797	63	7.3
Selected Other States				
New Jersey	8,162	7,784	378	4.6
Massachusetts	6,952	5,074	1,878	27.0
Connecticut	2,373	1,954	419	17.7
Minnesota	2,458	2,080	378	15.4
Missouri	1,375	1,375	0	0.0
Florida	2,425	1,455	970	40.0
Virginia	1,087	492	595	54.7
Wisconsin	1,343	1,343	0	0.0
Kentucky	289	282	7	2.4
Oklahoma	311	309	2	0.6
South Carolina	495	495	0	0.0
United States	118,334	95,521	22,813	19.3

Source: National Science Foundation.

Carolina's share of gross domestic product (GDP). Three of the top forty American academic research institutions in total R&D support—Duke University (26th), the University of North Carolina at Chapel Hill (UNC-CH, 28th), and North Carolina State University (NCSU, 36th)—are located in North Carolina. Those three institutions account for 88 percent of the state's total, though other institutions have prominent R&D support in particular disciplines or technology fields.

The rate of growth of total funding for academic R&D activity has significantly outpaced the nation and a set of comparison states (California, Georgia, Massachusetts, Michigan, Texas, and Virginia). From 1985 to 1994, constant dollar funding for academic R&D grew by 94 percent, compared to 63 percent for the nation, and 60 percent for the composite group of comparable states. Among the three largest institutions, R&D expenditures at Duke grew by nearly 140 percent over the period, at UNC-CH by nearly 100 percent, and at NCSU by nearly 50 percent. Among mid-sized institutions, expenditures at Wake Forest, North Carolina A&T, and East Carolina University at least doubled in real terms. Expenditures at UNC-Greensboro, which started from a small base, grew by over 186 percent.[5]

While the overall level of funding for R&D in North Carolina's academic institutions grew significantly between 1985 and 1994, the sources of funding shifted to a modest degree. Federal R&D support remained at about the same proportion—slightly more than 60 percent—while industry support increased from 6.6 percent to 9.8 percent. During that time state and local government support as a share decreased (from 18.8 to 13.6 percent) while institutional support (including foundations) increased from 8.2 to 9.5 percent. Compared to the nation and the group of comparable states, North Carolina currently has about the same share of federal support, a significantly larger relative share of support from industry and state and local government, and a significantly smaller share of institutional support.

The shifts in the distribution of funding by institution are more dramatic. Industry-funded R&D at Duke and UNC-CH grew by over 260 and 400 percent in real terms, respectively, between 1985 and 1994. At Wake Forest, industry R&D support grew by over 2000 percent. Federal R&D growth significantly exceeded the national average for all North Carolina institutions for which data are available, except North Carolina Central University (NCCU). The latter's federal R&D expenditures grew by 20 percent, compared to the national average 56 percent. Overall, NCCU's R&D expenditures fell by 25 percent in real terms over the 1985-1994 period.

Other measures of R&D performance are innovativeness (patents filed and issued, licenses, royalties, invention disclosures and startups) and enrollments in science and engineering programs. While basic research, along with teaching, are the two traditional functions of research universities, applied research that leads to product and process innovations in the marketplace has become an increasingly important activity for both public and private universities. In fact, by most measures of innovativeness, North Carolina's share of the national total increased from 1991 to 1995. Indeed, the state is second only to Massachusetts and ranks above California, Texas, Virginia, Georgia, and Michigan by most of the measures. Based on this information, we can conclude that North Carolina's academic institutions are becoming prominent players in technological innovation and technology transfer. Contrary to conventional wisdom, in appears that the state's academic institutions are reasonably balanced between basic research and technological innovation and tech transfer.[6]

Many of the students enrolled in graduate science and engineering programs in North Carolina originate from out-of-state, but often remain in North Carolina when jobs are available within their areas of specialization. In this sense, the state's graduate science and engineering programs represent a potential 'brain draw.' Over the 1985-95 period the number of enrolled students in graduate science and engineering programs in the state increased from 6,635 to 9,341, or by 40.8 percent. NCSU and Wake Forest account for the bulk of the increase. That brain draw is critical because of the shortage of trained science and technology personnel that already exists for North Carolina industry (as well as for industry elsewhere).

Non-Profits and Federal Agency R&D Performers

Although industry and universities conduct most research and development in North Carolina, several federal agencies and non-profit research institutes are also important R&D performers. In 1993, expenditures by federal agencies in the state spent topped $174 million. The largest of those are the U.S. Environmental Protection Agency (the EPA Environmental Research Center), the National Institutes of Health (the National Institute of Environmental Health Sciences), the U.S. Department of Defense, and the U.S. Department of Agriculture (USDA Southern Research Station). There is no reliable source of data available of total R&D expenditures by not-for-profit research institutes. However, National Science Foundation surveys indicate that non-profits in the state (not including academic institutions) conducted some $37 million in *federally-funded* R&D in 1993. The largest player among non-profits is the Research Triangle Institute (RTI). RTI, which employs some 1,450, reported over $143 million in revenues from research projects in 1996, 86 percent of which are derived from federal sources. Smaller non-profit research institutes in the state include the North Carolina Biotechnology Center, the National Center for Health Statistics, the National Institute of Statistical Sciences, and the Chemical Industry Institute of Toxicology.

North Carolina Industry at the Millenium: Poised to Grow or Vulnerable?

There is no universally accepted way to measure the strength of a state's industrial base in terms of "technology." In general, desirable industry is that which pays increasingly high wages and employs an increasing number of workers. Since high wages relate to high labor productivity (which typically comes from investments in technology), the only way to achieve both outcomes is through an increase in the number of growing and innovative businesses. Businesses grow by producing for an expanding world market, and/or by capturing a growing share of that market. To do the latter, an industry has to be innovative.

Those relationships suggest three measures of industry strength in terms of technology: *R&D intensity, patent activity,* and *technology intensity*. R&D intensity (R&D expenditures over net sales) and patent activity in an industry should correlate with innovativeness and growing productivity. In addition, we can consider the technology imbedded in the production process. Technology-intensive businesses are those that produce high tech goods and/or use high tech manufacturing processes.

R&D Intensity

R&D spending data for North Carolina businesses suggest an interesting dichotomy: generally, the industries employing the largest number of workers in the state conduct smaller relative amounts of R&D than industries with relatively little employment. The top seven industries in terms of R&D spending per dollar of sales (with unweighted R&D-intensity scores averaging 20.7), employ only 4.2 percent of the state's workers (Table 3). The industries with the six largest shares of employment (totaling 18.7 percent of workers), on the other hand, have an average unweighted R&D-intensity score of 1.55.

The group of businesses with relatively low R&D intensities include the state's traditional employment leaders: furniture and fixtures, textiles and apparel, and lumber and wood products, among others. In 1994, the state ranked first in terms of employment in furniture and fixtures, tobacco products, and textiles and apparel, third in lumber and wood products, and fifth in stone, clay and glass and radio and television receiving equipment. All of these sectors are significantly less R&D intensive than the national average. (The state ranks tenth in total employment in the U.S.) For these businesses to continue to be employment leaders and compete successfully in the global economy, they must increase their R&D activity.

Among R&D intensive industries, North Carolina ranks third in office, computing, and accounting machines, fifth in drugs and medicines and industrial chemicals, and eighth in communication equipment. The strongest shifts in rank among R&D intensive sectors over the 1989-1994 period were in office, computing and accounting machines (from sixth to third), industrial chemicals (from eighth to fifth), and motor vehicles and motor vehicles equipment (from thirteenth to tenth); see Table 4.

The sectors expected to enjoy the fastest rates of growth between 1994 and 2005 are generally more R&D intensive than the national average. These include computer programming and data processing, R&D and testing services, and drugs and medicines. This does not mean all R&D intensive industries will necessarily grow; office, computing, and accounting machines, communication equipment, scientific and mechani-

TABLE 3: R&D Performing Industries: North Carolina Profile, 1994

(Sorted by National Industry R&D Intensity)

SIC	Industry	Output (Mil.)	Wages (Mil.)	Employment (000s)	Share NC Total: Output	Share NC Total: Emp.	U.S. R&D Intensity 1993
873	R&D and testing services	1,185	414	21.7	0.4	0.6	72.66
357	Office, computing, & accounting machines	2,497	1,267	20.9	0.8	0.6	14.82
737, 871	Computer programming, data processing, etc.	2,417	1,003	26.5	0.8	0.8	13.57
372,376	Aircraft and missiles	258	87	1.6	0.1	0.0	11.82
366	Communication equipment	2,512	692	12.7	0.9	0.4	11.25
381-82	Scientific & mechanical measuring instruments	936	304	7.0	0.3	0.2	10.65
283	Drugs and medicines	4,357	970	17.0	1.5	0.5	9.69
384-87	Optical, surgical, photographic instruments	1,107	283	7.6	0.4	0.2	8.36
367	Electronic components	1,339	280	8.6	0.5	0.3	7.52
281-82,286	Industrial chemicals	5,658	1,061	20.1	1.9	0.6	4.68
371	Motor vehicles and motor vehicles equipment	6,536	1,192	26.3	2.2	0.8	4.40
361-64,369	Other electrical equipment	4,228	1,202	33.9	1.4	1.0	3.39
351-56,358-59	Other machinery, except electrical	6,359	1,769	45.8	2.2	1.4	3.09
48	Communication services	6,013	1,237	29.0	2.0	0.9	2.99
284-85,287-89	Other chemicals	4,010	608	13.1	1.4	0.4	2.87
39	Miscellaneous manufacturing industries	781	224	10.3	0.3	0.3	2.68
30	Rubber products	5,101	1,379	37.8	1.7	1.1	2.37
806-7	Hospitals and medical and dental labs	6,366	3,149	118.7	2.2	3.5	2.33
373-75,379	Other transportation equipment	297	84	2.7	0.1	0.1	2.20
32	Stone, clay, and glass products	2,650	824	24.2	0.9	0.7	2.05
See note.	Other nonmanufacturing industries	143,897	44,168	2254.8	49.0	67.2	1.80
34	Fabricated metal products	3,940	1,066	31.2	1.3	0.9	1.54
27	Printing, publishing, and allied services	3,000	1,019	35.8	1.0	1.1	1.13
26	Paper and allied products	5,193	1,061	24.0	1.8	0.7	1.09
25	Furniture and fixtures	6,272	2,108	84.2	2.1	2.5	1.05
13,29	Petroleum refining and extraction	281	29	2.1	0.1	0.1	0.96
31	Leather and leather products	240	74	3.0	0.1	0.1	0.87
333-36	Nonferrous metals and products	2,443	505	11.2	0.8	0.3	0.81
21	Tobacco products	12,699	1,118	18.5	4.3	0.6	0.81
365	Radio and TV receiving equipment	234	77	2.7	0.1	0.1	0.68
24	Lumber & wood products (exc furniture)	5,088	1,124	45.9	1.7	1.4	0.67
22,23	Textiles and apparel	27,317	6,847	276.4	9.3	8.2	0.62
20	Food and kindred products	10,796	1,498	54.2	3.7	1.6	0.52
331-2,3398-9	Ferrous metals and products	684	143	3.6	0.2	0.1	0.45
49	Electric, gas and sanitary services	7,263	1,242	22.8	2.5	0.7	0.18
All Sectors	Total	293,954	80,110	3356.2	100.0	100.0	4.0

Note: "Other nonmanufacturing industries" includes SICs 07-10, 12-17, 41-2, 44-9, 50-9, 60-5, 67, 701, 73, 75-6, 78-9, 80-1, 83-4, 87, 89.

Sources: National Science Foundation, Minnesota IMPLAN Group, Inc., U.S. Census of Manufactures, U.S. Census of Service Industries, County Business Patterns and U.S. Bureau of Labor Statistics. R&D intensity is defined as the ratio of R&D expenditures to sales as reported by NSF.

cal measuring instruments, and motor vehicles and motor vehicle manufacturing equipment are all expected to suffer significant employment declines over the period at the national level. Neither does it mean that only R&D intensive industries should grow. Some growth is expected in relatively non-R&D intensive non-manufacturing sectors (such as personal services and retail trade). But note that to the degree R&D intensive sectors do increase their relative share of overall NC activity, average wages are likely to increase. R&D intensive sectors pay significantly higher wages than non-R&D performing industries.[7]

TABLE 4: R&D Performing Industries: North Carolina Performance Indicators

(Sorted by National Industry R&D Intensity)

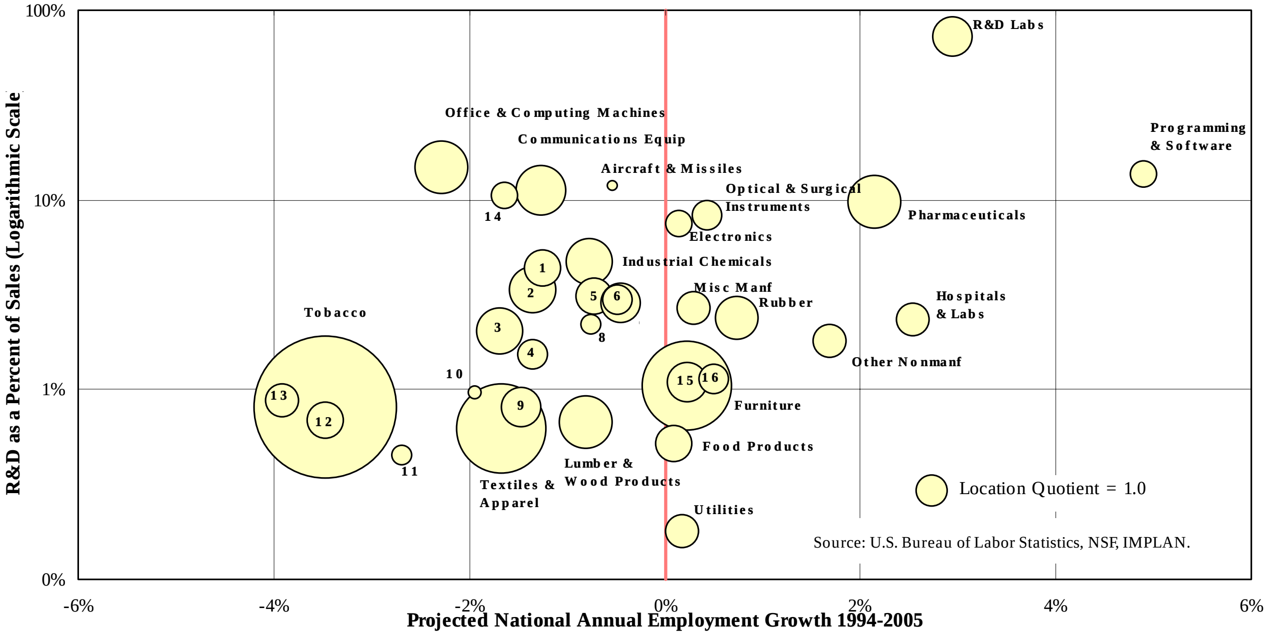
Industry	Avg. Productivity '94 (000s)	Annual % Emp Gro. '89-'94	Nat'l Proj. Yearly Gro. Emp, '94-'05	NC Rank in US		Emp. Rank Shift '89-'94	Emp. Loc. Quotient '94
				Wage '94	Emp. '94		
R&D and testing services	55	11.66	2.94	17	17	0	1.30
Office, computing, & accounting machines	119	-1.83	-2.28	14	3	3	2.01
Computer prog., data processing, etc.	91	8.08	4.90	22	17	1	0.52
Aircraft and missiles	161	-6.37	-0.54	15	30	-2	0.09
Communication equipment	198	-7.13	-1.27	6	8	0	1.76
Scientific & mechanical measuring instr.	135	-3.04	-1.65	25	22	2	0.51
Drugs and medicines	256	5.05	2.14	19	5	2	2.19
Optical, surgical, photographic instr.	145	2.25	0.43	15	13	0	0.65
Electronic components	156	1.09	0.15	26	9	0	0.53
Industrial chemicals	281	0.23	-0.77	26	5	3	1.55
Motor vehicles and motor vehicles equip	249	7.52	-1.25	22	10	3	0.99
Other electrical equipment	125	-0.31	-1.35	24	8	1	1.65
Other machinery, except electrical	139	-0.79	-0.72	20	10	1	0.95
Communication services	207	4.00	-0.49	30	14	0	0.75
Other chemicals	306	0.11	-0.46	17	12	0	1.23
Miscellaneous manufacturing industries	76	-1.39	0.30	32	16	-1	0.89
Rubber products	135	1.92	0.74	17	8	-1	1.34
Hospitals and medical and dental labs	54	8.63	2.54	22	13	-1	0.83
Other transportation equipment	108	-8.11	-0.76	24	22	-3	0.35
Stone, clay, and glass products	110	-0.38	-1.69	40	5	2	1.53
Other nonmanufacturing industries	64	3.09	1.69	30	12	1	0.89
Fabricated metal products	126	0.65	-1.35	34	16	1	0.76
Printing, publishing, and allied services	84	1.17	0.50	31	18	2	0.77
Paper and allied products	216	-0.49	0.22	17	10	1	1.18
Furniture and fixtures	74	-1.33	0.24	36	1	0	5.67
Petroleum refining and extraction	134	3.04	-1.95	40	32	1	0.15
Leather and leather products	81	-2.57	-3.91	14	11	0	0.88
Nonferrous metals and products	217	1.71	-1.46	31	9	7	1.30
Tobacco products	686	-6.74	-3.46	2	1	0	14.89
Radio and TV receiving equipment	87	15.27	-3.47	21	5	4	1.03
Lumber & wood products (exc furniture)	111	1.38	-0.81	36	3	0	2.06
Textiles and apparel	99	-2.13	-1.67	16	1	0	5.68
Food and kindred products	199	0.97	0.09	42	7	2	1.09
Ferrous metals and products	188	5.16	-2.70	30	27	1	0.30
Electric, gas and sanitary services	319	-2.47	0.18	15	9	-1	0.83
All Sectors	88	9.95	1.30	30	10	1	-----

Note: "Other nonmanufacturing industries" includes SICs 07-10, 12-17, 41-2, 44-9, 50-9, 60-5, 67, 701, 73, 75-6, 78-9, 80-1, 83-4, 87, 89.

Sources: National Science Foundation, Minnesota IMPLAN Group, Inc., U.S. Census of Manufactures, U.S. Census of Service Industries, County Business Patterns and U.S. Bureau of Labor Statistics. Ranks are against the 50 states plus the District of Columbia. "All Sectors" projected growth is for nonfarm employment only.

FIGURE 2: Projected Growth by R&D Intensity

(R&D Performing Industries. Dots Scaled by NC Employment Location Quotient, 1994)



Source: U.S. Bureau of Labor Statistics, NSF, IMPLAN.

FIGURE 2 Dot Key

1 Motor Vehicles & Equipment
2 Other Electrical Equipment
3 Stone, Clay & Glass
4 Fabricated Metal
5 Other Nonelectrical Machinery
6 Communications Services
7 Other Chemicals
8 Other Transport Equipment
9 Nonferrous Metals
10 Petroleum
11 Ferrous Metals
12 Radio & TV Equipment
13 Leather Products
14 Scientific Instruments
15 Paper & Allied Products
16 Printing & Publishing

Figure 2 summarizes the relationship between R&D intensity, projected growth, and the present industrial mix in the state. Figure 2 plots national average R&D intensity on the vertical axis and national projected growth on the horizontal axis, while the marker is scaled by the 1994 employment location quotient (or degree of specialization). The graphic suggests two things. First, there is a moderate positive relationship between R&D intensity and projected employment growth. Second, North Carolina's private sector economy remains largely specialized in industries that are neither R&D intensive nor are expected to grow significantly.[8]

Patenting Activity

The patent data tell a similar story. In general, they indicate modest rates of industrial patenting activity (and, by implication, innovative activity) in the state (Table 5). For example, just 6 percent of all U.S. patents related to textile mill products granted between 1986 and 1995 were granted to first-named inventors in North Carolina. This is despite the fact that North Carolina is ranked first in textiles employment in the U.S. Indeed, North Carolina businesses produce 30 percent of U.S. textiles gross domestic product.[9] Four percent of U.S. special industry machinery, 3 percent of primary and secondary non-ferrous metals, and 2 percent of primary ferrous products, household supplies, agricultural chemicals, and drugs and medicines patents were granted to North Carolina inventors. Despite the state's position as the country's tenth largest in employment terms, in no product area does the state's share of national patenting activity exceed 6 percent.

TABLE 5: North Carolina Utility Patents in U.S. Total

All Sectors/Product Areas, Fractional Counts

SIC	Sector	Share of U.S. Total	Location Quotient Equivalent	
		'86-'95	'76-'85	'86-'95
22	Textile mill products	0.06	5.8	3.9
355	Special industry machinery, exc. metal working	0.04	2.8	2.4
333-336,339 (exc. 3399)	Primary and secondary non-ferrous metals	0.03	0.9	2.1
331,332,3399,3462	Primary ferrous products	0.02	2.1	1.4
363	Household appliances	0.02	1.6	1.4
287	Agricultural chemicals	0.02	0.8	1.3
283	Drugs and medicines	0.02	0.9	1.3
354	Metal working machinery and equipment	0.02	1.5	1.2
99	All other SICs	0.02	1.2	1.2
352	Farm and garden machinery and equipment	0.02	1.6	1.1
364	Electrical lighting and wiring equipment	0.02	1.8	1.1
356	General industrial machinery and equipment	0.02	0.9	1.1
359	Misc. machinery, exc. electrical	0.02	1.3	1.1
358	Refrigeration and service industry machinery	0.02	1.1	1.0
34 (exc. 3462,3463,348)	Fabricated metal products	0.02	1.0	1.0
366-367	Electronic components and communications eqp.	0.02	0.8	1.0
362	Electrical industrial apparatus	0.02	0.9	0.9
379-	Misc. transportation equip.	0.02	0.7	0.9
369	Misc. electrical machinery, equip. and supplies	0.02	0.6	0.9
30	Rubber and Misc. plastics products	0.02	1.0	0.9
286	Industrial organic chemistry	0.02	0.6	0.9
361,3825	Electrical transmission and distribution equipment	0.01	1.1	0.9
32	Stone, clay, glass and concrete products	0.01	1.2	0.9
281	Industrial inorganic chemistry	0.01	0.4	0.8
353	Construction, mining, material handling equipment	0.01	0.9	0.8
357	Office computing and accounting machines	0.01	0.8	0.8
38 (exc. 3825)	Professional and scientific instruments	0.01	0.7	0.8
285	Paints, varnishes, lacquers, and allied products	0.01	0.8	0.8
284	Soaps, detergents, cleaners, toiletries, etc.	0.01	0.6	0.7
371	Motor vehicles and other motor vehicle equipment	0.01	0.6	0.7
20	Food and kindred products	0.01	0.6	0.7
375	Motorcycles, bicycles, and parts	0.01	0.4	0.6
373	Ship and boat building and repairing	0.01	0.9	0.6
289	Misc. chemical products	0.01	0.4	0.6
282	Plastics materials and synthetic resins	0.01	0.7	0.6
372	Aircraft and parts	0.01	0.4	0.6
348,3795	Ordinance exc. missiles	0.01	0.4	0.5
351	Engines and turbines	0.01	0.6	0.5
365	Radio and TV receiving equip. exc. comm. types	0.00	0.2	0.3
374	Railroad equip.	0.00	1.1	0.3
13,29	Petroleum and natural gas refining and extracting	0.00	0.2	0.1
376	Guided missiles and space vehicles and parts	0.00	0.0	0.0

Source: U.S. Patent and Trademark Office (USPTO). See *Technical Appendix* for description of USPTO data.

This does not mean that the relative rates have not been improving over time. Between 1976 and 1985, inventors in one half of all U.S. states patented more industrial inorganic chemistry inventions than inventors in North Carolina.[10] Between 1986 and 1995, the number of states patenting more inventions in this area fell to one-third. Other product areas with significant improvements in local relative patenting rates include primary and secondary nonferrous metals, general industrial machinery, detergents and cleaners, aircraft and parts, miscellaneous transportation equipment, motor vehicles and equipment, motorcycles and bicycles, and miscellaneous chemical products. On the other hand, relative patenting rates in several other product areas declined significantly between the two ten year periods: railroad equipment, ship and boat building and repairing, and electrical lighting and wiring equipment.

In summary, most patents granted to North Carolina inventors are in sectors that are still relatively small employers. Of course, the very innovativeness of those businesses could result in growth and greater employment as market shares rise. However, that depends on how successful those industries are relative to similar businesses elsewhere. North Carolina patent grants are in the national top ten in only three areas: textile mill products, special industry machinery, and primary and secondary non-ferrous metals. The industries that account for almost half the state's patent total (electrical equipment and communications equipment, professional and scientific instruments, specialized industrial machinery, and fabricated metal products) happen to be highly innovative everywhere, so they may not capture growing shares of world markets.

Technology Intensity

The last measure of industry strength is what we call technology-intensiveness, or the propensity to produce high tech goods and/or employ high tech production processes. Those data are somewhat more encouraging. In 1996, the twenty-five major technology-intensive industries in the state totaled 5,800 establishments and nearly 264,000 workers, 3.1 and 8.3 percent of all private sector establishments and employment. Overall, those businesses experienced a 20.3 percent increase in employment and a 15.5 percent increase in real wages between 1989 and 1996, or 3 percent and 2.2 percent per year, respectively, a trend that is likely to continue. The weekly wage of the average worker in a technology-related business also exceeds the private industry average by 74 percent.[11]

Motor vehicle parts and accessories and several computers, electronics, and software industries dominate the list of fastest growing technology-intensive four-digit SIC industries (Tables 6-8). Among technology-intensive industries generating the most net new employees between 1989 and 1996, three of the top ten are in the computer programming and data services sector; two of the top ten are in the motor vehicles sector. The computer programming and data processing sector also claims six of the top ten four-digit SIC industries generating the most net new establishments between 1989 and 1996; three of the remaining four sectors in the top ten are part of the research, development and testing sector.

To identify technology-intensive businesses in the state, we use an industrial classification scheme prepared by the North Carolina Employment Security Commission that consists of twenty major manufacturing and nonmanufacturing sectors comprised of over 150 detailed four-digit SIC industries.[12] Unlike the industrial classifications systems used by the U.S. Patent and Trademark Office and the National Science Foundation, the classification of technology-intensive sectors includes many emerging non-manufacturing technology sectors, including communications services, engineering services, and a nine-sector breakdown of computer programming, software and data services. ■

TABLE 6: Top 15 Fastest Growing NC Technology-Intensive Sectors in Terms of Employment (Sectors w/ 1,000 or More Employees in 1989)

Third Quarter 1989 to First Quarter 1996

SIC	Description	'96 Estab-lishments	'96 Emp-loyment	% Chng Emp '89-'96
7379	Computer related services, n.e.c.	594	3,991	245.2
7371	Computer programming services	553	5,265	217.8
3679	Electronic components, n.e.c.	47	3,588	181.1
3672	Printed circuit boards	33	2,830	137.3
3663	Radio & tv communications equipment	15	2,835	66.2
3559	Special industry machinery, n.e.c.	55	1,589	57.8
3711	Motor vehicle parts and car bodies	30	5,348	53.7
3564	Blowers and fans	47	2,914	52.6
2836	Nondiagnostic biological products	10	1,813	46.1
3643	Current-carrying wiring devices	34	7,951	45.4
3537	Industrial trucks and tractors	17	1,811	44.8
3841	Surgical and medical instruments	27	3,497	42.1
3624	Carbon and graphite products	3	*s*	*s*
2844	Toilet preparations	11	4,135	37.2
3575	Computer terminals	2	*s*	*s*

Note: "*s*" indicates data suppressed to preserve the confidentiality of data from individual businesses.
Source: North Carolina Employment Security Commission.

TABLE 7: Technology-Intensive Sectors with Most Net New Employees

North Carolina, Third Quarter 1989 to First Quarter 1996

SIC	Description	'96 Estab-lishments	'96 Emp-loyment	Net New Workers
3714	Motor vehicle parts & accessories	102	20,293	4,802
3575	Computer terminals	2	*s*	*s*
7371	Computer programming services	553	5,265	3,608
4812	Radiotelephone communications	141	3,875	3,501
7379	Computer related services, n.e.c.	594	3,991	2,835
3643	Current-carrying wiring devices	34	7,951	2,482
8711	Engineering services	897	11,854	2,376
3679	Electronic components, n.e.c.	47	3,588	2,312
2869	Industrial inorganic chemicals, n.e.c.	25	3,229	2,278
7374	Data processing and preparation	150	7,733	2,038

Note: "*s*" indicates data suppressed to preserve the confidentiality of data from individual businesses.
Source: North Carolina Employment Security Commission.

TABLE 8: Technology-Intensive Sectors with Most Net New Business Establishments, North Carolina

Third Quarter 1989 to First Quarter 1996

SIC	Description	'96 Estab-lishments	'96 Emp-loyment	Net New Estab.
7379	Computer related services, n.e.c.	594	3,991	398
7371	Computer programming services	553	5,265	310
4813	Telephone communications exc. radio	492	19,114	301
8711	Engineering services	897	11,854	294
4812	Radiotelephone communications	141	3,875	112
7372	Prepackaged software	190	4,084	112
8733	Noncommercial research organizations	140	3,410	77
8734	Testing laboratories	150	2,449	76
7373	Computer integrated system design	155	1,902	69
7374	Data processing and preparation	150	7,733	63
7378	Computer maintenance and repair	128	1,138	60

Source: North Carolina Employment Security Commission.

Summarizing Research and Technology in North Carolina Industry

Combining the R&D intensity, patent activity, and technology intensity information, we group R&D performing industries into three types: *high performing, emerging national leaders,* and *national leaders*. High performance industries are those that have grown significantly in the last 5-10 years and/or that are projected to grow significantly through 2005 (based on national-level projections). Emerging national leaders are industries in which North Carolina appears to be developing an advantage or specialization relative to other U.S. states. Finally, current national leaders are large, existing specializations in the state. For each of the three types, we also identify whether the sector is above average in R&D intensity and whether there is evidence of significant increases in associated North Carolina patent activity between 1986 and 1995.[13]

Drugs and medicines, industrial chemicals, stone, clay and glass products, and office, computing, and accounting machines are both current and emerging national leaders. These North Carolina industries have already achieved a critical mass, and are continuing to garner an even greater share of U.S. economic activity. That is in contrast to furniture, lumber and wood products, textiles and apparel, and tobacco, which either already rank first in the U.S. in total employment or have declined in national rank. These sectors are also average or below average in R&D intensity and there is no indication of upward movement in patenting activity.

TABLE 9: Classification of R&D Performing Sectors in North Carolina

R&D Performing Sector (NSF Definition)	High Peformance	National Leader Emerging	National Leader Current	R&D Intensive?	Dynamic Patent Field(s)?
Communications services	Yes				
Computer programming and data processing	Yes			Yes	
Drugs and medicines	Yes	Yes	Yes	Yes	Yes
Electronic components	Yes			Yes	
Hospitals; medical and dental labs	Yes				
Motor vehicles and equipment	Yes	Yes		Yes	Yes
R&D and testing services	Yes			Yes	
Radio and TV receiving equipment	Yes	Yes			Yes
Rubber and miscellaneous plastics products	Yes		Yes		
Food and kindred products		Yes			
Industrial chemicals		Yes	Yes	Yes	Yes
Nonferrous metals and products		Yes			Yes
Office computing & accounting machines		Yes	Yes	Yes	
Stone, clay and glass products		Yes	Yes		
Communication equipment			Yes		
Furniture and fixtures			Yes		
Lumber and wood products			Yes		
Textiles and apparel			Yes		
Tobacco products			Yes		

See *Technical Appendix* Tables 26-28 for details, text for definitions.

Among both the high performance and emerging sectors are drugs and medicines, radio and television receiving equipment, and motor vehicles and motor vehicles equipment. These sectors are not only growing rapidly in relative terms, but are also ranked tenth or better in the U.S. in terms of total employment. A number of high growth sectors, notably computer programming and data processing and R&D and testing services, do not yet account for a significant share of national activity. Yet they clearly have significant growth potential and represent what the state's economy may come to look like in the coming decades as it continues its shift away from traditional manufacturing.

The Promise of North Carolina's Academic R&D Infrastructure

The R&D strength of universities is as difficult to measure as the strength of industry. We measured academic research strength in terms of total annual R&D funding received in 1994, the perceived quality of the graduate faculty, the number of publications appearing in peer-reviewed journals per faculty member, and the number of times faculty publications have been cited in peer-reviewed journals. We limited our analysis to the (natural) sciences and engineering.

Nationally Competitive Programs

Nineteen academic *programs* qualified as "nationally-competitive," using the measure we devised (Table 10). Eight of those are housed at Duke, eight at UNC-CH, and three at NCSU. Six programs received "nationally-competitive" status at *both* UNC-CH and Duke: cell and development biology, pharmacology, biochemistry and molecular biology, physiology, molecular and genetic sciences, and neurosciences. Among the engineering programs in the state, three at NCSU (electrical, materials science, and chemical) and one at Duke (biomedical) were judged "nationally-competitive." Some of these programs are getting stronger as well, as they are also classified as emerging national competitors (Table 11). Among those that are on a competitive trajectory but have not yet achieved national prominence include five programs at NCSU (physics, mathematics, chemistry, civil engineering, and statistics) and one program at Duke (mechanical engineering).

Although only programs at Duke, UNC-CH, and NC State achieve composite rankings sufficiently high enough to classify them as nationally competitive, programs at other academic institutions in the state have achieved excellence within their regions. Because many of those programs are positioned to provide R&D support, serve as R&D partners with industry, or complement strengths in R&D activity in the state's primary research universities, they should not be overlooked. Moreover, those programs often form the basis for important university-industry linkages

TABLE 10: Strongest Science and Engineering Programs

Program	Institution	Score
Biochemistry and Molecular Biology	Duke	10.0
Cell and Development Biology	Duke	10.0
Pharmacology	Duke	9.8
Cell and Development Biology	UNCCH	9.7
Biochemistry and Molecular Biology	UNCCH	9.5
Electrical Engineering	NCSU	9.5
Ecology, Evolution and Behavior	Duke	9.3
Pharmacology (1)	UNCCH	9.2
Chemistry	UNCCH	9.1
Pharmacology (2)	UNCCH	9.1
Physiology	Duke	9.1
Materials Sciences	NCSU	8.9
Molecular and Genetic Sciences	Duke	8.9
Chemical Engineering	NCSU	8.8
Neurosciences	Duke	8.7
Neurosciences	UNCCH	8.7
Molecular and Genetic Sciences	UNCCH	8.6
Biomedical Engineering	Duke	8.5
Physiology	UNCCH	8.5

(1) Rank is for interdisciplinary program. (2) Rank is for School of Arts and Sciences. See sidebar for scoring methodology. Sources: National Research Council, Research-Doctorate Programs in the United States; National Science Foundation, CASPAR database; authors' calculations.

within their respective regions. There is also potential that some of them may become national programs in their own right. The national within-discipline rankings of academic programs in terms of R&D funding for the sixteen institutions for which data are available are provided in Table 12.[14]

Nationally Competitive Disciplines

To identify nationally competitive disciplines, our first approach is simply to sum the composite scores for all NC programs in each given discipline. Using that method, the most competitive discipline in the state *relative to its discipline nationally* is clearly pharmacology (see Table 13). At a second level in degree of national competitiveness (again, within their respective disciplines) are cell and development biology and biochemistry and molecular biology. At a broader third level are physiology, molecular and genetic sciences, ecology, chemistry, neurosciences, statistics/biostatistics. That level is more heterogeneous (with scores ranging between 24.0 and 31.2) than the fourth level suggested by the breaks, which includes physics, computer science, mathematics, civil engineering, and biomedical engineering. The remaining disciplines are significantly less competitive at the national level.

The six most competitive disciplines in the state are all biosciences, while the seventh through ninth most competitive (including statistics/biostatistics) are closely related fields. Those results are driven by both the success and critical mass of biosciences research at the state's major universities. Although there are a number of prominent engineering programs in the state (particularly at NCSU), there is not the critical mass in these areas that there is in the biosciences.

If we average the scores of only those programs within a given discipline that achieve a score of 7.0 or greater, the results change somewhat (see Table 13). The most competitive North Carolina discipline, *within its discipline nationally*, under this approach is electrical engineering, followed by cell and development biology, biochemistry and molecular biology, and pharmacology. Thus, the engineering disciplines are much better represented; they comprise four of the top ten most competitive disciplines (electrical, materials, chemical, and biomedical). Nevertheless, the dominance

TABLE 11: Emerging or Most Dynamic Science and Engineering Programs in North Carolina

Discipline	Institution	Score
Neurosciences	Duke	9.2
Physics	NCSU	9.2
Electrical Engineering	NCSU	9.0
Mathematics	NCSU	9.0
Pharmacology	Duke	9.0
Pharmacology (1)	UNCCH	9.0
Chemical Engineering	NCSU	8.8
Materials Sciences	NCSU	8.8
Mechanical Engineering	Duke	8.8
Biochemistry & Molecular Biology	UNCCH	8.6
Chemistry	NCSU	8.6
Civil Engineering	NCSU	8.6
Molecular and Genetic Sciences	Duke	8.6
Pharmacology (2)	UNCCH	8.4
Statistics/Biostatistics	NCSU	8.2
Cell and Development Biology	UNCCH	8.0
Chemistry	UNCCH	8.0

(1) Interdisciplinary program. (2) School of Arts and Sciences. See sidebar for scoring methodology. Sources: National Research Council, *Research-Doctorate Programs in the United States* ; National Science Foundation, CASPAR database; authors' calculations.

TABLE 12: National Rankings of North Carolina Academic Programs, 1994

	ASU	Bennett	Duke	ECU	ECSU	FSU	Johnson	NCA&T	NCCU	NCSU	Shaw	UNCCH	UNCC	UNCG	WFU	WCU	WSSU
Aerospace Engineering	65																
Chemical Engineering																	
Civil Engineering										8							
Electrical Engineering																	
Mechanical Engineering								52									
Materials Engineering	101									3							
Other Engineering								69									
Astronomy																	
Chemistry						242	188		275						149	307	321
Physics			31			223	167		224					240	207		
Other Physical Sciences					57												
Atmospheric Sciences	61																
Earth Sciences												15					
Oceanography				45													
Other Geosciences					120												97
Mathematics and Statistics											224						
Computer Science					181												
Agricultural Sciences							115	66		9							
Biological Sciences		336	7			320	206					9				309	224
Medical Sciences			40	111										170	42		
Other Life Sciences				100					156			10		83			

Ranked according to total R&D funding. Source: National Science Foundation, CASPAR database and authors' calculations.

How Were North Carolina's Academic Programs Ranked?

To identify the *strongest individual academic programs* in the state, we calculated scores based upon each program's national within-discipline ranking under four indicators: total annual R&D funding received in 1994, perceived quality of the graduate faculty, total publications in peer-reviewed journals (over the 1988-92 period) per faculty member, and total citations of faculty publications in peer-reviewed journals (over 1988-92). We allocated points (1-10) for each indicator according to where each program's national rank fell in terms of deciles within its discipline. For instance, a program ranked within the top 10 percent of all U.S. programs in its discipline in terms of R&D funding received a maximum of 10 points for that indicator. A program ranked in the second decile on the same indicator received 9 points, a program ranked in the third decile received 8 points, and so on. We then computed an overall program score as a weighted average of the points for each of the four indicators. Total R&D funding and perceived faculty quality were assigned weights of 0.3 each, while we gave publications per faculty member and citations weights of 0.2 each. Thus success in winning external grants and quality of the faculty were given slight emphasis in our calculations. Note that we also emphasize volume of R&D funding, as opposed to R&D funding per faculty member. We assume that critical mass and size of program are integral to the national competitiveness of North Carolina universities.

We used the same basic procedures to identify *emerging or exceptionally "dynamic" academic programs*, except that the indicators include two measures of change: total R&D funding between 1985 and 1994; change in rank of perceived faculty quality over the 1988-92 period; and change in total publications per faculty member over the 1988-92 period. The three indicators were assigned weights of 0.4, 0.4, and 0.2, respectively. Note that our rankings show some programs as both current and emerging strengths, an indication of present national competitiveness and significant potential for an even stronger competitive position in the future.

The identification of the state's *strongest science and engineering disciplines* takes into account the number and relative strength of highly rated academic programs within a discipline, among all academic institutions in North Carolina. Using two formulas, we generated two alternative lists of most competitive disciplines. For the first list, we summed scores of every program within a given discipline in the state to arrive at an overall score for that discipline. For the second list, we averaged the scores of only those programs within a given discipline that met a minimum threshold of 7.0. The first formula takes into account the presence of all academic programs within a discipline in the state, albeit weighted by their respective strength. The second formula only takes into account the most highly rated programs nationally, and therefore regards "middle-of-the-road programs" as less significant contributors to the state's academic R&D infrastructure. The second approach tends to limit the critical mass effect for some disciplines that have many programs in the state. We used only one formula to generate a single list of emerging disciplines in the state: the sum of program scores at or above a threshold level of 7.0. ■

of biosciences in the state remains. Biosciences make up six of the ten most competitive disciplines, and, among the second through ninth most competitive disciplines, there is a very narrow range of scores (from 9.0 to 8.7). Thus the two composite scoring methods are largely reinforcing in their general findings.

The ranking of *emerging academic disciplines* finds electrical, chemical, and materials engineering, followed by molecular and genetic sciences, neurosciences, and pharmacology among the state's most dynamic disciplines. Note that the electrical, chemical, and materials engineering disciplines are comprised of only one program each (at NCSU). Therefore, the critical mass in these disciplines is relatively low.

One alternative way of generating evidence of disciplinary strengths in the state is to look at North Carolina's share of the total national research funding generated by all North Carolina academic programs, within a discipline, and compare that to North Carolina's share of total national research funding in all disciplines.[15] Those data generally confirm that the biological and medical sciences are currently the most competitive disciplines in North Carolina at the national level.[16]

TABLE 13: North Carolina's Strongest and Most Dynamic Disciplines

Strongest Disciplines - Formula 1	Score	Strongest Disciplines - Formula 2	Score	Most Dynamic Disciplines	Score
Pharmacology	45.0	Electrical Engineering (3)	9.5	Electrical Engineering (3)	9.0
Cell & Development Biology	35.8	Cell & Development Biology (1)	9.0	Chemical Engineering (1)	8.8
Biochemistry & Molecular Biology	35.3	Biochemistry & Molecular Biology (3)	9.0	Materials Engineering (1)	8.8
Physiology	31.2	Pharmacology (1)	9.0	Molecular & Genetic Sciences (3)	8.6
Molecular & Genetic Sciences	28.5	Materials Sciences (2)	8.9	Neurosciences (2)	8.5
Ecology, Evolution & Behavior	28.0	Chemical Engineering (2)	8.8	Pharmacology (1)	8.4
Chemistry	26.8	Physiology (2)	8.8	Physics (1)	8.3
Neurosciences	25.7	Molecular & Genetic Sciences (3)	8.8	Civil Engineering (1)	8.3
Statistics/Biostatistics	24.0	Neurosciences (1)	8.7	Mechanical Engineering (1)	8.2
Physics	21.5	Biomedical Engineering (1)	8.5	Statistics/Biostatistics (2)	8.2
Computer Science	21.2	Chemistry (1)	8.5	Chemistry (2)	8.1
Mathematics	21.2	Computer Science (2)	8.0	Cell & Development Biology (1)	8.0
Civil Engineering	20.7	Ecology, Evolution & Behavior (2)	8.0	Mathematics (2)	8.0
Biomedical Engineering	19.3	Statistics/Biostatistics (2)	8.0	Industrial Engineering (4)	7.9
Oceanography	16.9	Mechanical Engineering (2)	7.8	Biochemistry & Molecular Biology (2)	7.9
Electrical Engineering	15.7	Physics (4)	7.7	Physiology (2)	7.5
Mechanical Engineering	15.5	Civil Engineering (2)	7.6	Computer Science (1)	7.0
Geosciences	13.9	Mathematics (2)	7.4		
Materials Sciences	13.9	Geosciences (3)	7.0		
Chemical Engineering	13.4				
Industrial Engineering	6.8				
Aerospace Engineering	4.2				

Formula 1 is based on aggregate scores with all programs included. Formula 2 is the average score for programs scoring 7.0 or higher. Numbers in parentheses are numbers of programs included in calculations. See text and *Technical Appendix* for additional detail. Sources: National Science Foundation, CASPAR database; National Research Council, *Research-Doctorate Programs in the United States*; authors' calculations.

The Industry-University Connection in North Carolina

We should expect some correlation between the strength of university-based research and the state's industrial base. On the one hand, economists have demonstrated that footloose knowledge-based industries tend to seek locations close to appropriate knowledge resources. Silicon Valley developed as a site of high tech research, in part, because of the proximity to Stanford University. Similarly, surveys indicate that firms have located in the Research Triangle region to be close to labs, expertise, and a well-trained professional labor force from the area's universities.

The causality between industry base and university strength goes in the other direction too, however. Existing industries often contribute equipment, research funds, unrestricted resources, and professional expertise to local universities. In addition, footloose academic researchers specializing in a technology area like to be located near the pertinent industry cluster. It is not surprising, then, that UNC-CH, Duke, and NCSU have grown in national stature in science and technology areas during the past several decades, while the industry base in the Triangle was deepening.

CLUSTER 1: Electronics and related (electrical engineering, materials science, computer sciences).

CLUSTER 2: Life sciences and related (cell and development biology, biochemistry and molecular biology, pharmacology, physiology, molecular and genetic sciences, neurosciences, chemistry, biomedical engineering).

CLUSTER 3: Other chemicals (chemistry and chemical engineering).

CLUSTER 4: Environmental (geosciences, oceanography, and ecology/evolution and behavior). ■

The correlation between university and industry strength can be seen by comparing information contained in different parts of this report. The strongest disciplines, by any of the scoring methods used, can be arranged into broad research clusters. The following four research areas stand out as current or emerging disciplinary strengths in North Carolina. The groupings are not meant to be exact; some related disciplines are omitted and there is some double counting. They are intended primarily to provoke critical thinking about the condition and potential of North Carolina's R&D enterprise.

Not surprisingly, there are industry clusters in these same three areas. Table 14 illustrates the concentration of industries in the areas of academic strength, considering the three ways industrial strength was measured. Other research strengths in the state may be added to this framework, including the strong presence of environmental research and consulting firms (including the Environmental Protection Agency) as well as contract research organizations and the National Institute of Environmental Health Sciences.

Another indicator of the dynamic link between industries and universities is the incidence of spin-offs from universities (of course, there are also spin-offs from other businesses). Our research identified a total of 32 high-technology spin-offs from North Carolina universities between 1972 and 1997 (Table 15). Sixteen of those taken place since 1991, implying a considerable increase in spin-off activity in recent years, though trend is difficult to assess since older spin-offs are more difficult to identify. Unsurprisingly, the state's three largest research universities, UNC-CH, Duke, and NCSU, generated almost all the spin-offs, and most were located in the Research Triangle area.

Some of the university-based companies founded in the 1970s and 1980s have subsequently grown into successful, large, and well-known businesses. Statistical software maker SAS Institute (NCSU, 1972) currently employs 3,300 people in the Triangle, while Quintiles Inc. (UNC-CH, 1982) has become a leader among contract research firms in testing the effectiveness and safety of pharmaceutical products. In addition to the 900 employees in Research Triangle Park, Quintiles employs another 1,100 worldwide. Another successful spin-off, Sphinx Pharmaceutical Corporation, founded in 1987 by a Duke professor of biochemistry, is currently undergoing a major expansion that will double the company's staff to about 200 and triple its laboratory space. In 1994, the company was acquired by Eli Lilly and Company and is now a drug-discovery division for Lilly. Embrex (NCSU), a biotechnology company specializing in finding biological solutions to problems in poultry production, was founded in 1985 and public in 1991. The company currently employs over 100 workers. Most post-1990 spin-offs are relatively small biotechnology and health-related firms.

TABLE 14: Disciplinary and Industrial Research Strengths/Specializations

University-based Cluster	R&D Performing Sectors		
	National Leaders	*High Performance Sectors*	*Emerging National Leaders*
Electronics-related	office, computing, and accounting machines; communications equipment	communications services; computer programming, data processing, etc.; electronic components; radio and TV receiving equipment	office, computing, and accounting machines; radio and TV receiving equipment
Life sciences and related	drugs and medicines	drugs and medicines; hospitals and medical and dental labs	drugs and medicines
Other chemical-related	industrial chemicals		industrial chemicals
Environmental-related		R&D and testing services	

TABLE 15: High-Technology Spin-Offs from North Carolina Universities, 1972-1997

Company	Product	Year Founded	Originating University	Status	Current Employees
Wedd Food Labs		1972	NCSU	Out of Business	n.a.
SAS Institute	Software	1972	NCSU	In Production	3,300
Family Health International	Pharmaceuticals	1973	UNC-CH		150
Mycosearch	Biotechnology	1979	UNC-CH		10
Quintiles (Quintiles Transnational)	Contract Research	1982	UNC-CH	In Production	2,000
Enzyme Technology Research (now AndCare)	Medical Technology	1985	Duke	In Production	11
Piedmont Research		1985	Duke	Out of Business	n.a.
Embrex	Biotechnology	1985	NCSU	In Production	104
Boron Biologics	Biotechnology	1986	Duke	In Production	8
Biosponge Aquaculture Products	Biotechnology	1986	Duke	Out of Business Since 1991	n.a.
Sphinx Pharmaceutical	Pharmaceuticals	1987	Duke	In Production	96
Cree Research	Semiconductors	1987	NCSU	In Production	100
Probiologics	Biotechnology	1987	NCSU	Out of Business Since 1989	n.a.
Gentra Systems		1988	NCSU	Out of Business Since 1997	n.a.
Pathogene Biologics	Biotechnology	1989	NCSU	Out of Business Since 1991	n.a.
Macronex	Biotechnology	1990	Duke	Out of Business Since 1996	n.a.
Leadcare (now AndCare)	Medical Technology	1991	Duke	In Production	9
3D Ultrasound	Medical Diagnostic	1991	Duke	In Production	19
Trimeris	Biotechnology	1993	Duke	In Production	37
LipoMed	Medical	1994	NCSU	In Production	9
EpiGenesis	Pharmaceuticals	1995	ECU	Not Yet in Production	5
Aeolus	Pharmaceuticals	1995	Duke		20
ClinEffect Systems	Medical Software	1995	Duke	In Production	10
Inspire Pharmaceuticals	Pharmaceuticals	1995	UNC-CH	Not Yet in Production	19
Triangle Pharmaceuticals	Pharmaceuticals	1995	Duke		53
Novalon Pharmaceutical	Pharmaceuticals	1996	UNC-CH		18
Xanthon	Biotechnology	1996	UNC-CH	Not Yet in Production	8
MiCell Technologies	Chemicals	1996	UNC-CH	Not Yet in Production	8
Zymotech	Biotechnology	1996	NCSU	In Production	2
Renaissance Cell Technologies	Pharmaceuticals	1996	UNC-CH		5
3 Tex	Textiles	1996	NCSU	Not Yet in Production	1
Telemedicine Technolgies	Telecommunications	1997	ECU	Not Yet in Production	3

Source: "The Incidence of High-Technology Start-Ups and Spin-Offs in a Technology-Oriented Branch Plant Complex," by S. Ko, Ph.D. dissertation, University of North Carolina at Chapel Hill, 1993; and authors' estimates. List may not be comprehensive. n.a.=not applicable. Piedmont Research and Wedd Food Labs are presumed out of business (not confirmed).

Federal R&D Spending and North Carolina

The federal government is an important source of R&D funding for industry, universities, and non-profit institutes. Which R&D performers in the state depend on federal sources of funds? What is the impact of federal spending, in the aggregate, on the state's economy? Most important, how would potential changes in federal spending affect North Carolina's R&D effort and economic growth, given the state's unique set of industry and university strengths? To answer these questions, we examined the distribution of federal spending in the state by performer, developed seven possible scenarios for future patterns of federal spending, traced the impact of those patterns on R&D activity in the state, and used an input-output multiplier model to trace the effect of changing R&D on economic growth. The results paint an optimistic picture of the state's position vis-a-vis future federal R&D spending. At the same time, each dollar of federal R&D money has a smaller impact on North Carolina's economy than it otherwise might if the economy were more knowledge-intensive.

The Federal Government Role in R&D.

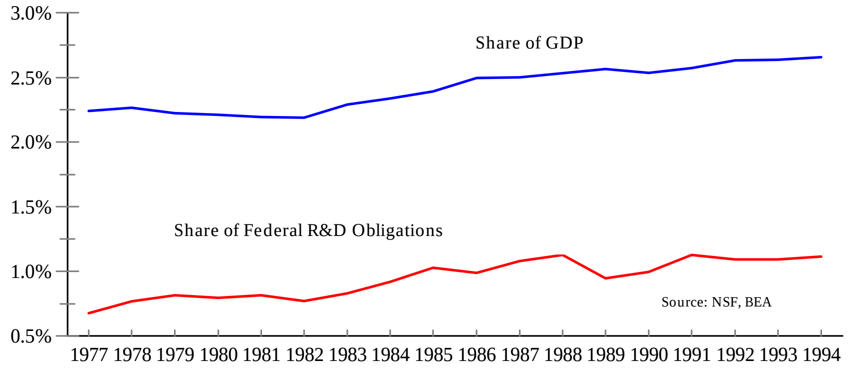
While industry is now providing the largest share of the nation's total research and development budget (both internally and through support to universities and research institutes), the centrality of the federal government to the country's R&D effort cannot be over-emphasized. The U.S. Government's response to national challenges following World War II (e.g., developments in space exploration, atomic weaponry, and energy) built a national science and technology complex that is the envy of the world.[17] Federal initiatives continue to contribute mightily to the direction of science and technology trends in universities and the private sector. The federal government is the most important underwriter of basic research in academia, much of which would not be supported by businesses. Industry is naturally interested primarily in technologies that contribute to the development of goods and services in the near term. The federal government is also able to support research—in academia and industry—that is a clearly in the national interest even though its commercial potential is either minimal or uncertain enough to preclude private sector leadership. Such research, in turn, contributes to the base of scientific knowledge and may end up leading to the creation of critical new technologies and products, the profitability and significance of which are not easily foreseeable.

In North Carolina, strong federal support of university R&D and active federal laboratories such as the Environmental Protection Agency and the National Institute of Environmental Health Sciences, undergird the state's science and technology enterprise, strengthening mutually-reinforcing ties between public, non-profit, and private sector R&D performers. Through federal R&D support, universities are able not only to make new scientific and technological discoveries, but also to provide critical research experience to generations of students that eventually assume positions in the state's federal labs, R&D-performing businesses, and non-profit research houses. Demand for skilled and creative R&D personnel feeds supply and vice versa as the North Carolina R&D infrastructure evolves and grows. Knowledge spillovers–informal exchanges of information, expertise, and ideas between industry, academic, and public sector actors–contribute further strength to the state's R&D enterprise. Federal government support is central to these dynamics. ■

Trends in Federally-Supported R&D in North Carolina

In 1995, North Carolina scientists garnered $825.4 million in federal R&D obligations, up from $485.7 million in 1985 and $116.9 million in 1975.[18] While the state's share of the total federal R&D budget doubled from 0.6 to 1.2 percent between 1975 and 1995, it remains well below its share of U.S. gross domestic product (Figure 3). Moreover, the ratios are not converging; North Carolina's share of GDP grew from 2.5 to 2.7 over the five year period between 1988 and 1994 while its share of the federal R&D budget remained essentially unchanged. The state's allocation of the federal R&D budget is therefore well below what might be expected given the size of its economy. While that is another indication of the lower technology-intensiveness of North Carolina industry, it may also suggest that industry R&D per-

FIGURE 3: North Carolina's Share of Federal R&D versus its Share of GDP



Source: NSF, BEA

formers are less successful in attracting federal R&D dollars. (In contrast to industry, non-profit and academic performers in the state have garnered above average shares of federal R&D funds.)[19]

Over 53 percent of total federal R&D dollars spent in North Carolina in 1995 went to universities, colleges and teaching hospitals (Table 16). Another 27 percent were earmarked for federal labs. Industry's share of the state's federal R&D dollars is both low and declining. Between 1992 and 1995, universities, federal labs, and non-profits increased their share of federal dollars while industry's declined by nearly one-half. A majority (53 percent) of the state's federal R&D funds in 1995 were provided by the Department of Health and Human Services (HHS), followed by Defense (17 percent), the Environmental Protection Agency (EPA; 14 percent), and the National Science Foundation (NSF; 6 percent). Yet that distribution of funds differs widely across the different types of performers (industry, federal, universities, non-profits). In 1995, industry received the bulk of its support from Defense, while the vast majority of federal funds to universities and other non-profits were granted by HHS. Federal labs in North Carolina were fairly evenly split between EPA, Defense, and HHS (Figure 4).

TABLE 16: Federal R&D Spending in North Carolina

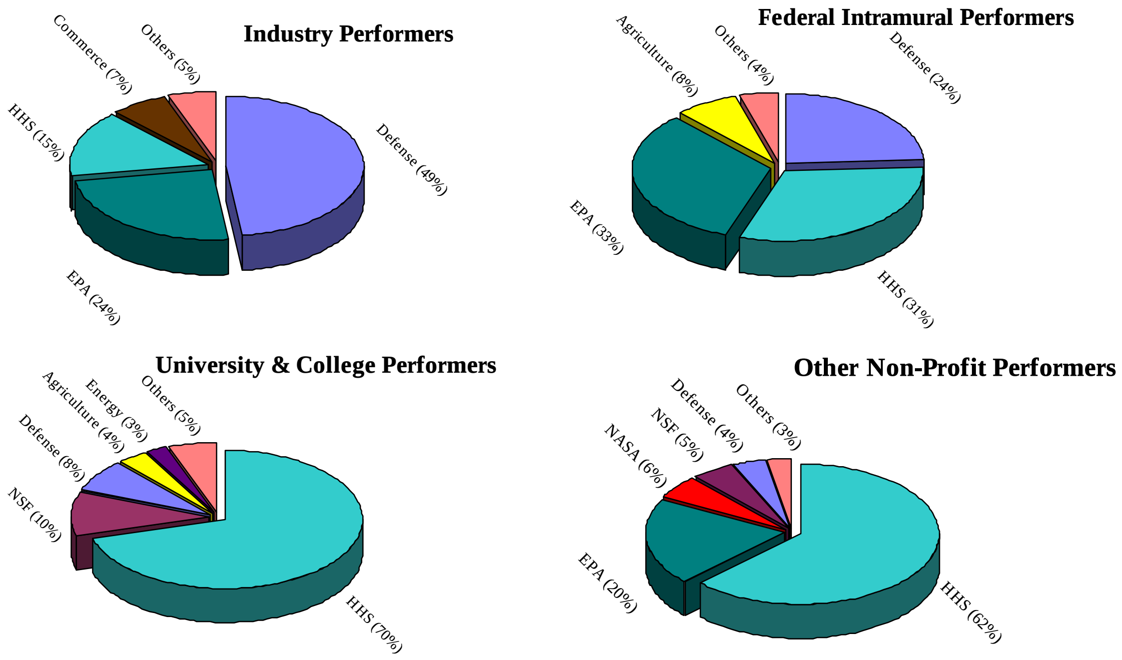
By Agency and Performer, Fiscal Year 1995 (Dollars in Thousands)

Agency	Federal Intramural	Industry	Univ & Colleges	Other Non-Profits	State & Loc Govt	TOTAL	*Percent Share*
Agriculture	16,903	80	15,574	19	10	32,586	3.9
Commerce	5,387	6,796	5,680	74	478	18,415	2.2
Defense	53,262	48,037	33,218	2,231	0	136,748	16.6
Energy	844	50	11,296	1,314	0	13,504	1.6
HHS	68,595	15,207	310,668	37,036	3,225	434,731	52.7
Interior	3,265	95	285	0	0	3,645	0.4
Transportation	0	1,654	2,438	250	2,076	6,418	0.8
EPA	71,885	24,401	8,169	11,752	0	116,207	14.1
NASA	16	877	7,484	3,361	0	11,738	1.4
NSF	22	2,716	45,653	2,965	85	51,441	6.2
TOTAL	220,179	99,913	440,465	59,002	5,874	825,433	
Percent Share	26.7	12.1	53.4	7.1	0.7		

Source: National Science Foundation, *Federal Funds Survey, Early Release Tables*. Only ten major R&D funding agencies included; does not include R&D plant.

FIGURE 4: Federal Obligations for R&D in North Carolina

By Agency and Type of Performer, Fiscal Year 1995



Source: National Science Foundation, Federal Funds Survey, Early Release Tables.

The particular mix of federal funding by agency is an important means of gauging the possible impact of changing federal R&D trends and priorities on the state's economy. The budget agreement between congress and the president signed in mid-1997 calls for the protection of environmental and health-related research efforts. Other areas, however, are slated for decline, with defense research the most significant of these. Between 1992 and 1995, the agencies with the largest real dollar increases in obligations to North Carolina performers were HHS, EPA, NSF, and Commerce (Table 17). By contrast, defense obligations in the state—which are granted primarily to industry—fell considerably, consistent with national R&D priorities. Over this period at the national level, NSF, NASA, EPA, and the Department of Transportation (DOT), Commerce, and HHS all increased their shares of the total federal R&D budget, while the shares of the Departments of Interior, Energy, Defense, and Agriculture (USDA) all declined. With the bulk of North Carolina's federal R&D funding coming from NSF, EPA, and HHS, the state is well positioned given these trends. Overall, federal R&D support in North Carolina increased by 11.5 percent in real terms between 1992 and 1995, compared with a real decline of 3.9 percent in the U.S. as a whole.

The largest individual performers of federal R&D in the state are UNC-Chapel Hill, Duke University, private industry, EPA, HHS (primarily the National Institute of Environmental Health Sciences—NIEHS), NC State University, the Department of Defense, Wake Forest University, and Research Triangle Institute.[20] Some of those performers are likely to fare

TABLE 17: Federal R&D Obligations by Agency in North Carolina, 1992-1995

(Thousands of 1997 Dollars)

Agency	1992	1995	Percent Change	Percent Change U.S.
Department of Agriculture	40,327	36,813	-8.7	-5.4
Department of Commerce	11,382	19,188	68.6	67.4
Department of Defense	195,819	142,561	-27.2	-12.6
Department of Energy	12,999	14,397	10.8	-14.8
Health and Human Services	383,085	471,601	23.1	19.5
Department of Interior	5,665	3,798	-33.0	-16.1
Department of Transportation	4,759	6,688	40.5	49.0
Environmental Protection Agency	84,623	123,172	45.6	6.6
NASA	11,377	12,322	8.3	5.4
National Science Foundation	45,178	56,430	24.9	14.8
Total	795,213	886,969	11.5	-3.9

Source: *NSF Early Release Tables, Federal Funds Survey*. Includes funds for expenditures and plant.

better than others in coming years given their present mix of agency funding. UNC-CH and Duke, for example, receive over 80 percent of their federal R&D support from HHS and a relatively small share from Defense. By contrast, in 1995, Defense and USDA provided 38 percent of NC State's federal support; present indication is that the R&D budgets of both of these agencies will face among the most significant real declines through 2002. Indeed, USDA is one of only two major federal agencies to see its R&D budget fall in real terms between fiscal years 1997 and 1998 (the other is DOT). And FY 1998 is slated to bring real increases for most other agencies (including Defense).

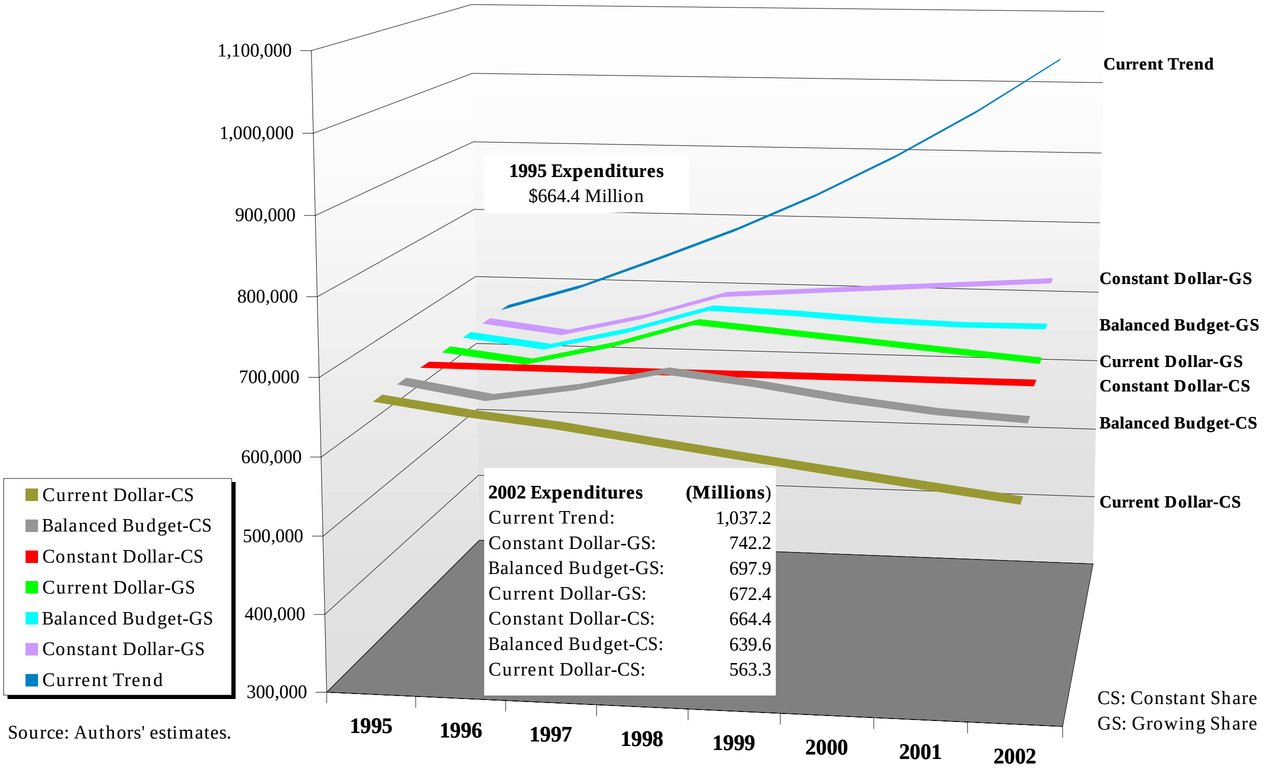
Recent shifting patterns of federal R&D expenditures in North Carolina may be summarized in the following way. In *current dollar* terms, federal R&D spending in the state increased by over 20 percent between 1992 and 1995, versus 3.6 percent nationally. The difference in the rates is a combination of several factors. First, if we hold constant the quality of performers, skills in garnering funds, the effectiveness of lobbyists and elected officials, and other unique local circumstances, growth and decline in the aggregate national federal R&D budget affects North Carolina performers in the same way as performers elsewhere. That simply means that, to some extent, the rate of growth observed in North Carolina is purely the result of aggregate funding trends at the national level. If the U.S. budget increases, North Carolina's budget is likely to increase, other things equal. Second, North Carolina's mix of funding by agency in 1992 (and, by extension, areas of research focus) also partly determined its rate of increase over the subsequent three years; some agencies fared better than others at the national level and these trends were passed on to the performers at the state-level. Finally, North Carolina R&D performers may have been especially meritorious relative to performers in other places, elected officials may have been more effective in lobbying for funds than their counterparts elsewhere, or some other local circumstances may have affected the rate of growth we observed.[21]

Projected Federal R&D Spending in North Carolina

We constructed several scenarios based on different assumptions about the growth or decline of federal R&D spending, and the state's ability to capture a growing share of the pie. Our most optimistic scenario is simply an extrapolation of the current trend. We then specify three alternatives—one in which the federal government keeps R&D spending constant in real dollars, another in which R&D spending is constant in nominal dollars, and a third in which R&D is cut to achieve a balanced budget by 2001. In each of those cases, we assume, in turn, that the state maintains its share of R&D dollars and is able to increase its share, due to a favorable mix of industries.

The scenarios are summarized in Figure 5. They are referred to as current trend, constant dollar-constant share, constant dollar-growing share, current dollar-constant share, current dollar-growing share, balanced budget-constant share, and balanced budget-growing share. Estimated expenditures in 1995 are $664.4 million in 1994 dollars. In four of the seven scenarios, we project real federal R&D expenditures to increase in North Carolina between 1995 and 2002. In the case of balanced budget-growing share, for example, the favorable research mix (in health and the environment) in North Carolina outweighs the expected decline in the state due

FIGURE 5: Projected Federal R&D Expenditures in North Carolina 1995-2002 (1994 Dollars)



2002 Expenditures	(Millions)
Current Trend:	1,037.2
Constant Dollar-GS:	742.2
Balanced Budget-GS:	697.9
Current Dollar-GS:	672.4
Constant Dollar-CS:	664.4
Balanced Budget-CS:	639.6
Current Dollar-CS:	563.3

Source: Authors' estimates.

to the anticipated fall in real spending at the national level. Put another way, even though the total R&D budget may fall at the national level, federal R&D in North Carolina may increase because of the state's emphasis in the two protected research areas: environment and health. That is not to say that federal R&D spending in the state would not have grown even faster in the absence of balanced budget pressures. The current trend provides one possible scenario along those lines. It also indicates how dramatic the recent trends in federal spending in the state have been, at least between 1992 and 1995. It is most reasonable to view the current trend as the extreme upper bound in the range of possible federal spending sce-

Gauging the Impact of Federal Spending

Federal research and development money spent in North Carolina affects the state in two fundamental ways. First, each dollar generates more than a dollar of economic activity through successive rounds of spending (termed multiplier or ripple effects). After earning a federal research contract, R&D performers such as universities, businesses, and non-profits purchase goods and services from North Carolina vendors and hire personnel to carry out the work. That spending constitutes the *direct effect* of each dollar of federal money committed to the state. Direct expenditures are less than total expenditures because some purchases are made from vendors located out of state (that out-of-state spending constitutes *leakage* of federal R&D spending). In-state vendors themselves purchase goods and services from other North Carolina vendors, who, in turn, also purchase goods and services, and so on. The result of all successive rounds of purchases for goods and services are termed *indirect effects*. Finally, the workers and families of the R&D performers and vendors make purchases with income paid (directly or indirectly) from the federal funds. Those also generate multiplier effects (termed *induced effects*). The sum of total direct, indirect, and induced effects exceeds the initial amount that R&D performers expend within the state. The ratio of this sum to the direct expenditures constitutes the multiplier, the dollar value increase in activity generated with each dollar of federal expenditure.

The second fundamental way in which federal research and development money affects the state is more difficult to quantify. Federal R&D money generates *spillovers*, which are essentially new technologies, knowledge, and information that is exploited by the private sector to develop new products or processes.[22] A recent study of federal spending in Massachusetts identified two means by which a reduction in spillovers adversely affects the economy.[23] First, as noted above, federal R&D generates much basic research that the private sector relies upon in conducting its own basic and applied research and development. Reductions in federal R&D spending harm public sector agencies and universities the most, reducing basic research that these institutions perform and subsequently R&D undertaken by industry. The size of that effect may potentially be large, since industry is the largest overall R&D performer in the economy.[24]

Second, reductions in R&D both directly through federal R&D reductions as well as indirectly through induced reductions in industry R&D result in fewer new products, services, and technologies, eventually reducing economic growth and possibly damaging the long-term competitiveness of local businesses. There is growing hard evidence that for-profit firms rely heavily on basic science to develop new goods and services. One recent study has found, for example, that U.S.-invented patents typically include many citations to basic scientific papers, most of which are authored by scientists at universities and laboratories supported by major agencies such as the National Science Foundation and the National Institutes of Health.[25] In fact, the study found that "more than 70 percent of the scientific papers cited on the front pages of U.S. industry patents came from public science—science performed at universities, government labs, and other public agencies."[26] Reductions in federal R&D, then, may act to: reduce R&D directly in the state via immediate reductions in financial support to public, private and non-profit R&D performers; reduce R&D indirectly in the state via subsequent additional reductions in private sector R&D induced by the initial direct decline in R&D; and reduce the development and introduction of new goods and services that sustain growth and maintain competitiveness. Note that we only quantify the first type of effect, though we note the possible significance of the others.[27] ■

narios. The extreme lower bound is represented by the current dollar-constant share projection.

Given the current health of the economy, and the nature of the president's FY 1999 budget proposal which would balance the budget sooner than we forecast, we believe that the actual trend is likely to lie somewhere between balanced budget-growing share and the current trend. In general, North Carolina's outlook is optimistic even in the face of federal cutbacks in discretionary spending aimed at balancing the budget. Of course, the outcome will not be as favorable for North Carolina if congress and the president renege on their commitment to protect environmental and health-related research. In addition, wide swings in federal R&D support are unlikely because of the mix of spending in the state. The health and environmental R&D budgets have been relatively stable over time, particularly in comparison to smaller agencies and the Department of Defense.

The Impact of Federal R&D Dollars

Our analysis indicates that each dollar of federal R&D money now spent in North Carolina generates approximately 75 cents of additional economic activity (Table 18). Of the total $664.4 million in federal R&D expenditures in North Carolina in 1995, $328.3 million (or 49.4 percent) represents direct in-state spending either as purchases of goods and services from North Carolina vendors by R&D performers or as expenditures by R&D employees made within the state. The $328.3 million in direct expenditures generated an additional $249.5 million in indirect and induced spending, for a total impact of $577.8 million. The ratio of direct in-state spending to total impacts is the aggregate multiplier. FY 1995 federal spending accounted for $216.2 million in income, nearly 9,000 jobs, and $340.7 million in value added (or gross state product).[28]

The expenditure impacts represent about 0.18 percent of total state output, 0.16 percent of income, 0.21 percent of employment, and 0.19 percent value-added. Those figures demonstrate the limited nature of multiplier effects associated with federal R&D and serve to emphasize that the most important influence of federal spending in the state is probably related to indirect spillover effects. Put differently, if federal R&D spending fell to zero tomorrow, the immediate impact on the state in terms of reduced jobs, income, and gross state product would be slight. In time, however, the absence of federal funds would almost certainly severely limit the R&D capacity of the state's economy and thereby eventually limit additional growth and development.

We can also examine how the several R&D spending projections translate into different impacts on the state's economy by calculating the ratio of the 1995 total output impact to the 2002 total output impact for each scenario (Figure 6). The output impact of federal spending in 2002 is 56 percent higher (in real terms) than in 1995 under the rosiest scenario (a 'gain' of 5,022 jobs). By contrast, the total expenditure impact of federal spending under the worst case scenario would fall by 15 percent in 2002 (a 'loss' of 1,300 jobs). and 7,588 jobs, a real decrease of 15 percent. As noted above, however, we believe that the former is more likely than the latter.[29]

To conduct the impact analysis, we constructed estimates of two types of expenditures by all R&D performers in the state: detailed purchases of commodities per R&D dollar (e.g., computers, instruments, measuring devices, chemicals, rental cars, hotels and other travel expenses, etc.); and expenditures for personnel. These data were then incorporated in an input-output model (IMPLAN Pro) to calculate the total economic impacts of alternative levels of federal R&D spending. See *At the Crossroads: Technical Appendix* for additional detail. ■

TABLE 18: Summary of Results of Impact Estimation

Fiscal Year 1995 (Output, Income and Value-Added in Millions, 1994 Dollars)

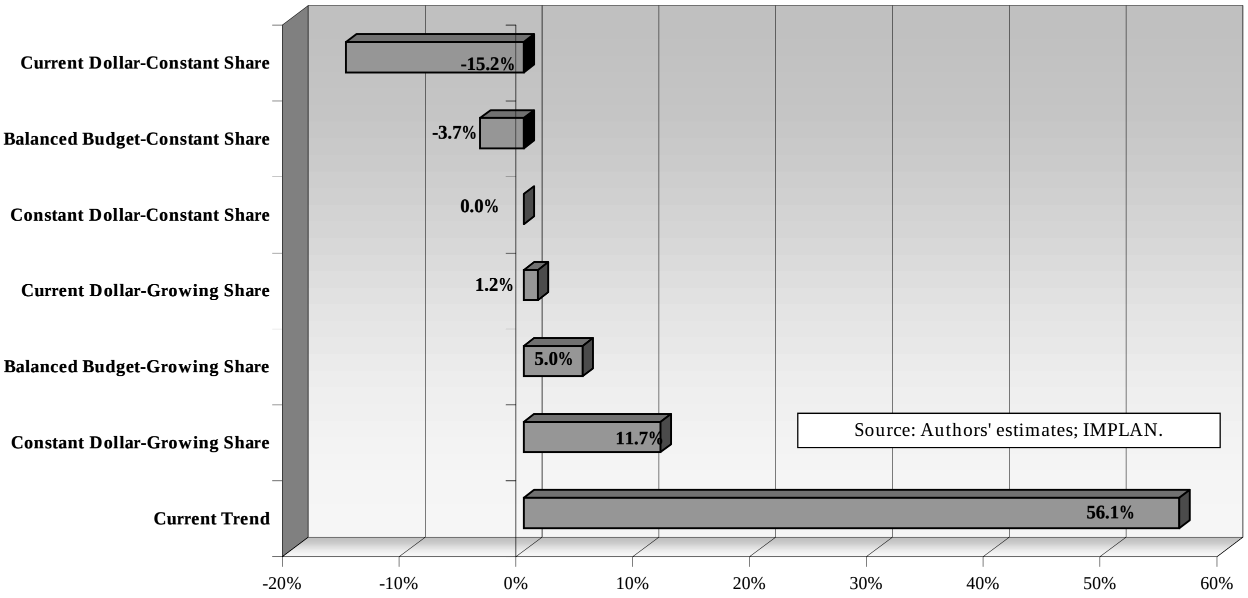
Estimated Federal R&D Expenditures in North Carolina	664.4
Direct In-State Expenditures	328.3
Indirect Expenditures	99.5
Induced Expenditures	150.0
Total Expenditures	577.8
Aggregate Output Multiplier	1.76
Total Income Impact	216.2
Total Employment Impact	8,950
Total Value-Added Impact	340.7
Relative Impact	
Share of 1994 Total NC Output	0.18%
Share of 1994 Total NC Income	0.16%
Share of 1994 Total NC Employment	0.21%
Share of 1994 Total NC Value-Added	0.19%

Note: Aggregate multiplier assuming 25 percent higher local purchases is 1.77.

Source: Authors' estimates; IMPLAN.

FIGURE 6: Total Relative Output Impact from Alternative Projected Changes in Federal In-State R&D Expenditures, 1995-2002

(2002 Output Impact over 1995 Output Impact, Constant Dollars)



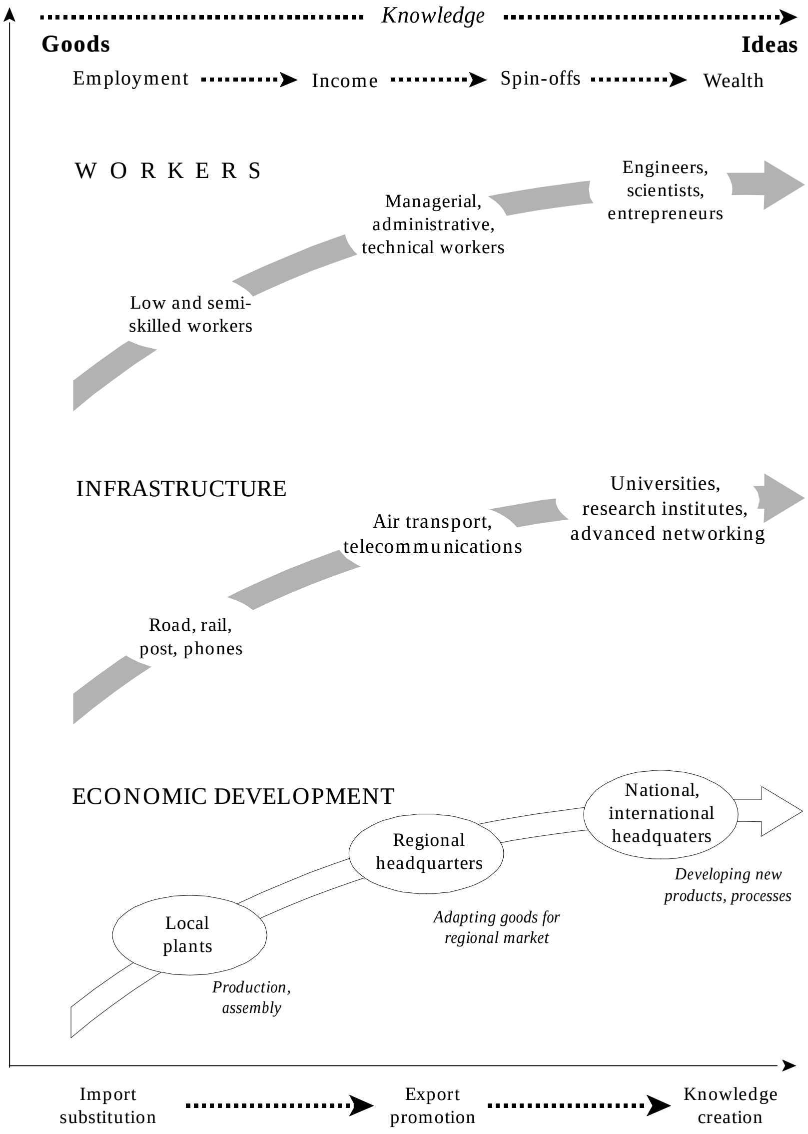
Source: Authors' estimates; IMPLAN.

Implications and Guides to Policy

The report raises some old and difficult questions for policy makers: what can be done to ensure a smooth transition from a traditional manufacturing to a knowledge-based economy? And, how can we help expand knowledge resources more broadly in geographic terms, so that R&D can occur in non-metropolitan counties with small and medium sized manufacturing establishments? Accomplishing those two tasks will help prevent chronic displaced worker problems, and will help increase incomes in the state.

Our analysis of the impact of possible changes in federal R&D spending suggests that the state is well poised to capitalize on projected shifts in federal research priorities toward health and the environment. That is particularly encouraging since the current budget picture suggests a growth in federal R&D spending in North Carolina even with a balanced budget. However, federal R&D dollars that come into North Carolina do not have as large a ripple effect as they could because of the state's relatively modest concentration of high technology industry. Much R&D-related spending leaks out of the state (as North Carolina R&D performers purchase inputs and services from high technology firms located elsewhere in the U.S.). As the knowledge intensiveness of the economy grows, a greater share of such spending will remain inside the state's borders.

Figure 7: The Evolution of Knowledge along Economic Development Continuum



The challenge facing decision makers may be cast in terms of the trajectory on along which economies move as they develop (see Figure 7).[30] Less developed economies (or regions) produce goods, primarily to ensure that local needs are met (import substitution). The measure of their success is employment growth. Those economies require a healthy number of low and semi-skilled workers as well as roads, rail lines, postal service, and telephones. At the next stage of development, economies produce for export and to generate income for the region. They may develop regional headquarters. They require technical, managerial, and administrative workers, and more rapid communications. The most mature economies produce knowledge and generate wealth. As loci of control, they develop into national or international headquarters locations. Their personnel needs are skewed toward knowledge workers while their infrastructure needs are tilted toward knowledge resources.

We can consider North Carolina to be moving up this trajectory. Table 19 translates the trajectory into specific business requirements. In the early stages of development (the lower part of the trajectory), businesses need worker and managerial training, technical assistance, and help establishing buyer-supplier networks. As the businesses become more mature, their needs change. Those at the top of the trajectory require specialized equipment, a good work environment, and connections with knowledge resources around the world. This table also shows an intermediate point along the trajectory where businesses commercialize either applied or basic research. For that, licensing and patenting assistance is needed, as well as incubator space, marketing assistance, entrepreneurial training, and financing.

The state can help move the economy up the trajectory by providing the appropriate services. Indeed, many of the state's efforts over the past two decades fit into this matrix. The development of MCNC and the Biotechnology Center, for example, are consistent with later-stage development. The development of the information superhighway similarly allows businesses to connect with knowledge resources around the world.

Table 19: Appropriate Services Along Economic Development Continuum

Improving production techniques and inputs →	**Conducting applied research** →	**Commercializing outputs of basic and applied research** ←	**Conducting basic research**
• Provide worker training	• Provide technical training	• Provide licensing and patenting assistance	• Provide/operate specialized equipment and facilities
• Provide managerial training	• Provide/operate testing and calibration equipment	• Provide incubator space	• Provide a good work environment
• Offer technical assistance to help solve problems	• Help organizations link to local universities/ institutes	• Help organizations obtain financing for start-up or expansion	• Help organizations connect to appropriate knowledge resources around the world
• Build/operate a pilot plant	• Provide crunch space	• Provide marketing assistance	
• Help establish buyer-supplier networks		• Provide entrepreneurial training	
Lower level of economic development	→	→	*Higher level of economic development*

In terms of assistance for commercializing the results of applied and basic research, the state already provides some of the needed services through the university system. In addition, the Technology Development Authority identifies targets for start-up capital. But the relevant question is what more can be done? The report provides a few principles:

■ *Put resources where there is likely to be a payoff because of existing critical mass.*

The report identifies where industrial and university strengths coincide. Efforts are already underway in some of those sectors (the Biotechnology Center with pharmaceuticals; MCNC with telecommunications and electronics). Further efforts could be made toward other clusters, e.g., industrial chemicals and environmental technologies.

■ *Identify industries that are likely to be winners.*

The limitation of any type of industrial policy is in being able to pick winners and avoid losers. Indeed, the market does that reasonably well. But, to pull the economy up the trajectory, the state needs to be proactive. Our analysis has identified some good business development targets. For example, twenty-five industries are technology-intensive and growing in terms of jobs and wages.

■ *Develop home grown businesses that may emerge as headquarters and/or research centers.*

The payoff from successful start-ups and spin-offs is substantial—the creation of quality jobs and income growth at SAS, Sphinx, Emrex, and Quintiles are cases in point. The North Carolina economy is much riper for entrepreneurial development today than it has ever been.

■ *Invest in knowledge infrastructure.*

The old mindset among industrial developers was that roads needed to be built to ensure that jobs would come, especially in non-metropolitan areas. As we move into the 21st century, knowledge infrastructure plays that role. To get growth into regions that need it, we need to consider the strategic use of telecommunication links, business parks, institutions of higher education (and training), in addition to transportation nodes. The Global TransPark is one model for that.

■ *Invest in people.*

As traditional industries continue to downsize and new businesses start-up and expand, our workforce needs to be upgraded so that employees can make the transition. Similarly, entry-level workers (in high school) need to be prepared for work that requires computation and a higher level of skills than in the past. This suggests a host of school-to-work and displaced worker programs. It also implies a rethinking of traditional methods of training and education delivery, as well as a better meshing of the needs of industry with the missions' of the state's universities and community colleges.

Notes

1. Stough, R., "Introduction," *Annals of Regional Science* 32 (1), 1-5, 1998. See also Lucas, R. E., "On the Mechanics of Economic Development," *Journal of Monetary Economics* 22 (1), 3-42, 1988.

2. See *Technical Appendix* Tables 1 and 2.

3. Data are from the National Science Foundation. See *Technical Appendix* Table 3.

4. The data are from the National Science Foundation (NSF) and should be interpreted cautiously. Determining the source of industrial R&D dollars is more difficult than identifying total R&D expenditures. Although NSF's *Survey of Industrial R&D* solicits expenditure source information from U.S. businesses, significant under-reporting of some questionnaire items is common. There is evidence, for example, that responding firms may have a tendency to incorrectly identify the source of their R&D funds, either as a result of poor internal information or confidentiality concerns. Moreover, in some states (including North Carolina) the sample of responding firms is relatively small. The problem is compounded by lower item response rates typical on expenditure source questions.

   We compared early release expenditure data from the most recent *Survey of Industrial R&D* to federal obligations data from the *NSF Federal Funds Survey* (see *Technical Appendix* Table 4). While the former survey is targeted to businesses, the latter is completed by federal agencies. It may be a more reliable indicator of the volume of federal funds distributed to the state's industries. In fact, the ratio of federal obligations to industry to total expenditures by industry hovered near 5 percent in North Carolina between 1993 and 1995, a figure that is among the lowest in the country. The national average over the period exceeded 24 percent. By all available data, there is thus reasonably strong evidence that North Carolina industry's dependence on federal R&D funding is substantially below average.

5. For university R&D spending and science student enrollment data, see *Technical Appendix* Tables 5-8; data are from the National Science Foundation.

6. *Technical Appendix* Tables 9-19 report detailed Association of University Technology Managers *AUTM Licensing Survey* data for patent applications, patent issues, licensing, royalties, invention disclosures, and start-up companies data for North Carolina universities and their comparable institutions in California, Georgia, Massachusetts, Michigan, Texas, and Virginia.

7. In 1994, the average wage for the ten most R&D intensive industries in North Carolina was 54 percent higher than the wage for the ten least R&D intensive sectors. In the same period, R&D intensive sectors in the state also paid higher wages relative to comparable sectors in other states than did North Carolina's non-R&D intensive sectors. While the state ranked tenth in overall employment in the U.S. in 1994, it ranked thirtieth in average wages. The average wage rank for the ten least R&D intensive sectors in the state in 1994 was 25 (ranging from second in the tobacco products sector to forty-second in the food and kindred products industry). By contrast, the average wage rank for the 10 most R&D intensive industries was 19 (ranging from sixth in communication equipment to thirtieth in aircraft and missiles). With the continued growth of R&D intensive industries, average absolute and relative wages in the state are likely to increase.

8. The trends described in Tables 3 and 4 and Figure 2 warrant a degree of caution. North Carolina's economy has consistently outperformed the national average in recent years and may do so through 2005. Moreover, some sectors (e.g., textiles) have enjoyed strong growth in output at the same time reducing employment. Unfortunately, state-level employment or output projections were not available at the degree of sectoral disaggregation necessary to replicate NSF industry categories. (Output or gross state product projections were not available at an appropriate level of disaggregation at the national level either.) This prevented us from making a direct comparison between specializations and projected growth while also accounting for average R&D intensity. However, if national projections provide at least some indication of the relative performance of specific industries, the basic findings are reasonable. The economy will still undergo a shift from traditional to more knowledge intensive activities. The management or facilitation of this transition is likely to become a major issue as the state's R&D enterprise continues to evolve.

9. "The U.S. Textile Industry," Office of the Chief Economist, American Textile Manufacturers Institute, Washington, DC, 1996.

10. See *Technical Appendix* Table 22.

11. See *Technical Appendix* Tables 24 and 25.

12. See *Technical Appendix* Table 23. The classification used here is slightly different than the North Carolina Employment Security Commission's (NCESC) original. NCESC's classification was originally a three-digit SIC level system. In expanding it to four digit SIC sectors, a limited number of sectors were added (e.g., oil exploration services) or deleted (e.g., architectural services) to ensure that it distinguished as closely as possible only and all technology intensive businesses.

13. *Technical Appendix* Tables 26-28 provide additional detail (including SIC classification) for each of the R&D performing industries. The tables also indicate related high growth four-digit SIC sectors for each major R&D performing industry.

14. Note that UNC-Charlotte did not respond to the latest NSF survey thus preventing the inclusion of that university's programs in our study.

15. The measure is similar to a location quotient, with a norm equal to 1.0. That is, a location quotient equal to 1.0 for a given discipline means that

R&D funding for that discipline is exactly proportional to total R&D funding in the state. On the other hand, a location quotient equal to 2.0 would mean that the discipline has double the proportional amount of R&D funding.

16. In 1994, location quotients for biological, medical, and other life sciences all exceeded 1.0, along with materials engineering. Those four fields may be regarded as potential specializations in the state. There is a significant break in the location quotients between agricultural sciences (at 1.0) and all other disciplines (the next highest is oceanography at .8). Observing those measures over time also suggests the erosion of state specializations in agricultural sciences, other physical sciences, and, interestingly, computer sciences between 1985 and 1994, at least in terms of R&D funding. The location quotients for these sectors all dropped significantly over the period.

    The NSF disciplines and their 1994 R&D funding location quotients are aerospace engineering (.01), agricultural sciences (1.0), astronomy (0), atmospheric sciences (.01), biological sciences (1.2), chemical engineering (.6), chemistry (.7), civil engineering (.7), computer science (.6), earth sciences (.6), electrical engineering (.6), materials engineering (1.6), mathematics and statistics (.8), mechanical engineering (.6), medical services (1.4), oceanography (.8), other engineering (.7), other geosciences (.5), other life sciences (1.3), other physical sciences (.2), and physics (.6).

17. *Allocating Federal Funds for Science and Technology*, Committee on Criteria for Federal Support of Research and Development, National Academy Press, Washington, DC, 1995.

18. Data are from the National Science Foundation’s Survey of Federal Funds, which primarily reports data for the following agencies: Agriculture, Commerce, Defense, Energy, Health and Human Services, Interior, Transportation, EPA, NASA, and the National Science Foundation. These agencies account for over 97 percent of federal R&D spending in North Carolina.

19. While North Carolina’s slice of the federal research and development budget has held relatively steady, the distribution of the budget among other states has shifted significantly, with some states’ share of federal R&D declining and others’ increasing. Over the last two decades, Georgia, Missouri, Florida, Colorado, and Texas have experienced increases in their share of the federal R&D budget, while shares held by New Mexico, New York, Massachusetts, and California have all declined. Georgia’s dramatic increase is due specifically to that state’s development of the Air Force’s F-22 fighter aircraft. Once R&D on the F-22 is complete, Georgia’s share is expected to decline. See *The Future of Science and Technology in the South Atlantic: Trends and Indicators*, Center for Science, Technology, and Congress, American Association for the Advancement of Science, Washington, DC, September 1997.

20. See *Technical Appendix* Table 36.

21. Shift-share analysis, a technique usually applied to the study of industry growth, provides one means of quantifying these different influences (see *Technical Appendix* Table 37). The technique simply involves the evaluation of plausible counterfactuals. The national R&D budget grew by 3.6 percent in current dollar terms; other things equal, we would expect North Carolina’s federal R&D budget to grow at the same rate. Call that

the "national growth effect." The remaining 16.7 point difference in growth rates is made up of a "mix effect" and a "local skill" effect. The mix effect assumes that each agency's spending in the state should grow (or decline) at a rate equivalent to its rate of change at the national level. Calculating that effect for the 1992-1995 period suggests that 13.5 points of the 20.3 percent state growth rate resulted from the state's favorable agency mix in 1992; North Carolina's total budget grew partly because most of its R&D funding is granted by agencies that enjoyed increases over the period, some share of which were funneled to North Carolina performers. Finally, the difference between the mix effect and the national growth effect may be attributed to local circumstances or skill in obtaining funds. The analysis, summarized in the bottom of Appendix Table 37, suggests that between 1992 and 1995, the state's federal R&D budget grew by 3.6 percent simply as a result of the rate of increase of the total R&D budget at the national level, by 13.5 percent due to the favorable agency mix and research focus in the state in the beginning of the period, and by 3.2 percent due to unique circumstances, political will, or skill (including research merit) in obtaining federal money.

22. "Real Effects of Academic Research," by A. Jaffe, *American Economic Review* 79 (5), 957-70, 1989. See also "The Search for R&D Spillovers," by Z. Griliches, *Scandinavian Journal of Economics* 94 (Supplement), 29-47, 1992.

23. *Planning for Change/Planning for Growth: Implications of Reduced Federal Research Spending for Massachusetts*, by A. Jaffe, Economic Resources Group, Inc., February 1996.

24. *Planning for Change/Planning for Growth*, p. 31-2.

25. "The increasing linkage between U.S. technology and public science," by F. Narin, K. S. Hamilton, and D. Olivastro, *Research Policy* 26 (3), pp. 317-30, 1997.

26. "Industry Technology Has Strong Roots in Public Science," *CHI Research Newsletter*, Vol. V, No. 1, March 1997. See www.chiresearch.com/nlt_v1.html (viewed 9/12/97).

27. Although some studies have attempted to quantify spillover effects in one form or another (see, for example, *Planning for Change/Planning for Growth, op. cit.*, and *The Impact of Tufts University School of Veterinary Medicine on the Massachusetts Economy*, Nexus Associates, Inc., Belmont, MA, October 1995), we did not for several reasons. First, there is no established and accepted methodology available for quantifying spillovers. Even input-output based analysis of spending multiplier impacts, which is well-accepted, can potentially generate misleading findings. Producing findings that vastly under- or over-state spillover effects will not serve the policy process and may actually be worse, from a policy perspective, than treating them in a qualitative manner.

    Second, there is good reason to believe that any quantitative estimates of spillovers would be subject to a potentially wide range of error, particularly from a state-specific perspective. While private sector R&D performers undoubtedly draw on basic federally-supported science from the universities, federal labs, and non-profits, they do not necessarily draw only or even predominantly on locally-produced science. Scientific findings are published for a global audience and are increasingly available via Internet and other easily accessible sources. Although some research has shown that there is some evidence of localized spillovers (see, for example, “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations,” by A. B. Jaffe, M. Trajtenberg, and R. Henderson, *Quarterly Journal of Economics* 108, pp. 577-98, 1993), it is not yet strong enough to draw many firm conclusions.

Third, fully quantifying the spillover effects would require some estimate of value of downstream goods and services introduced by North Carolina companies indirectly as a result of federally-supported R&D conducted within the state. The information requirements of such an undertaking are well beyond the scope of this study and, in our view, well beyond the present state of knowledge regarding the link between local R&D, innovation, and economic growth. Evidence of the linkages between publically supported R&D and private sector activity may shed some light on the significance of university, government laboratory, and non-profit R&D activity on aggregate economic growth, but this is different than attempting to quantify overall impacts in monetary terms.

In electing not to quantify spillover effects, we are not asserting their insignificance. On the contrary, we find that they are likely the most significant adverse impacts associated with potential reductions in federal R&D activity in North Carolina. Just as linkages between universities and the private sector are beginning to increase through spin-offs and other activity, a reduction in R&D support that hits universities hardest may limit subsequent economic growth in the state. The problem is that the difficulty with placing a number on this impact means that the probability of a misleading finding is very high. Indeed, one recent review of academic studies of spillover effects found that while most analyses are “flawed and subject to a variety of reservations,” “the overall impression remains that R&D spillovers are both prevalent and important” (“The Search for R&D Spillovers,” p. 29). It is for this reason that we have chosen to consider them in qualitative rather than quantitative fashion.

28. At 1.76, the aggregate multiplier is lower than some other similar studies have found. A 1984 study of the impact of UNC-Chapel Hill’s total sponsored research budget on the state’s economy found a multiplier of 2.0, for example. On the one hand, this study uses a highly disaggregated input-output model which is subject to less error than the aggregated models used in most earlier studies. Our multiplier may simply be more accurate. On the other hand, it is possible that using regional purchase coefficients to estimate local purchases (see *Technical Appendix*) is underestimating in-state expenditures. To test this, we inflated all local spending coefficients by 25 percent (to a maximum of 1.0) and recalculated the impacts. The multiplier under the inflated coefficients increased to only 1.77.

The impact of federal R&D spending differs significantly by sector. Services account for the bulk of the total direct, indirect, and induced expenditure impacts (at 36 percent), followed by finance, insurance, and real estate (19 percent), wholesale trade (18 percent), manufacturing (13 percent), and transportation, communications and utilities (8 percent). The breakdown suggests the relative degree to which each sector would be affected by a reduced federal spending, at least in the short term. In the long term, once spillover effects are taken into account, the distribution of impacts might look different. The manufacturing sector, for example, depends heavily on R&D to continually introduce new products and technologies. Reductions in federal spending might be expected to eventually hit this sector harder than the current distribution of multiplier impacts implies.

29. See *Technical Appendix* Table 40.

30. Figure 7 and Table 19 are from "'Knowledge Parks' and the Economic Development Trajectory," by M. I. Luger, *Proceedings of the Sheffield Regional Technopole Symposium*, Sheffield, England, 1996.