TECHNICAL APPENDIX

At the Crossroads: North Carolina's Place in the Knowledge Economy of the Twenty-First Century

prepared for

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Technical Appendix

General Data Sources

Academic Research and Development Expenditures. Data on research and development expenditures were obtained through the National Science Foundation's CASPAR and WebCASPAR Database Systems. R&D data were drawn from the *Survey of Scientific and Engineering Expenditures at Universities and Colleges*, a survey conducted annually since fiscal year 1972. All science and engineering doctorate-granting institutions and/or all other institutions conducting at least $50,000 annually in separately budgeted R&D are included in the survey. Over the years, approximately 97 percent of more than 500 institutions nationwide participate in the survey. Moreover, NSF estimates that this survey accounts for approximately 98 percent of all academic R&D expenditures in the United States. In 1988 and 1993, NSF surveyed the full universe of institutions. In all other years between 1984 and 1994, NSF surveyed all doctorate-granting science and engineering institutions and historically black institutions, and a sample of non-doctorate institutions. The FY 1994 survey had a response rate of 99.6 percent.

For this study, fiscal year 1985 served as the base year and annual data were collected through fiscal year 1994. Growth rates in expenditures over this time period were calculated in real terms (1987 dollars) using preset deflators available in CASPAR. Nominal dollars were also reported where appropriate.

While this source is widely considered to be the most comprehensive available for measuring trends in national academic R&D expenditures, some limitations do exist. Data were not available for all North Carolina institutions and all years, for example. NSF attempts to estimate information for non-respondents using various techniques including imputation using previous years' data and extrapolating from comparable institutions. Despite these efforts, some institutions still had reported R&D totals of zero for some years. Most other traditional sources of error, including sampling, coverage, unit non-response, item non-response and measurement, are quite small.

Graduate Student Enrollment. Graduate science and engineering student enrollment data were obtained from the WebCASPAR Database System. The underlying source is NSF's *Graduate Students and Postdoctorates in Science and Engineering (GSS)* survey. Conducted annually since 1975, the GSS survey collects data from close to 100 percent of all institutions granting masters or higher level degrees in science and engineering disciplines. Estimates for non-reporting programs are imputed using either previous year's data or that of peer institutions.

Three documents contain the findings from this study. The document, *At the Crossroads: Report Summary*, provides a synopsis of the findings and policy implications. The full report, *At the Crossroads: North Carolina's Place in the Knowledge Economy of the Twenty-First Century*, contains the main report findings and methodology. This document, *At the Crossroads: Technical Appendix*, provides extensive technical notes and a set of tables with detailed supporting information. Copies of all documents are available from the North Carolina Board of Science and Technology. ■

Faculty Quality, Publications per Faculty Member, and Total Citations. Data for these measures were obtained from the National Research Council's 1993 report, *Research-Doctorate Programs in the United States: Continuity and Change.* This report draws from three primary sources for its information. Faculty quality ratings were obtained from the 1993 National Survey of Graduate Faculty. Publications and citations data were gathered for the period 1988–92 from the Institute for Scientific Information and were normalized by the number of full-time equivalent faculty using data reported by the Institutional Coordinator at each participating institution.

Although widely considered the most reliable and the only relatively comprehensive source of graduate program ratings in existence, any attempt to capture qualitative program characteristics using quantitative measures will have its faults. The NRC data suffers from three primary limitations. First, the report was generated in an attempt to measure the effectiveness of graduate programs in preparing students for careers in research and scholarship. The needs of students that pursue careers beyond these two fields may not be adequately captured by NRC measures. Second, because no one measure can adequately capture overall program quality, NRC uses numerous indices that, when used in combination, tell a story about overall program quality. Somehow these different measures must be reconciled in a report such as this. Third, reputational measures such as those used to determine faculty quality, are inherently subjective and tend to change only very slowly. The NRC notes, however, that pooling raters' responses generates strong consensus on both the strongest and weakest programs, though considerably less agreement exists on programs in the middle range. Further, the NRC recognizes that, "differences in ranked order between two programs may reflect very small, unreliable, or insignificant differences in the actual quality of a program, and should be regarded by readers with great caution."

In utilizing NRC data for this report, the analysis was carefully crafted to minimize limitations associated with the data. We do not rely exclusively on any single measure of program characteristics. Instead, we use multiple measures of program strength in a weighted index. Each metric was selected after considering both its potential for capturing at least one important aspect of program "strength" and the overall availability and limitations of the data. Moreover, we minimize the effect of the ranked-order limitations (described above) by scoring each program based on decile position within their own discipline nationwide.

University Technology Transfer Activity. All data on university patents, licenses, invention disclosures, royalties and start-up companies were obtained through the *AUTM Licensing Survey, FY 1991–FY 1995,* published in 1996 by the Association of University Technology Managers, Inc. The AUTM survey has been conducted annually since 1993 and covers activity from FY 1991 through FY 1995. Participants in the survey include U.S. universities, hospitals and research institutes, Canadian institutions, and third-party patent management firms. Of the nearly 196 universities surveyed in FY 1995, approximately 62 percent responded. Among the top 100 research institutions (as measured by total federal dollar support), 87 percent responded.

One limitation of the survey is the small number universities participating in all five years of the survey. There are only seventy-eight such "five-year recurrent respondents." Also, all data compiled are self-reported by the institutions and remain unverified. While university coverage by this survey is in no way comprehensive nor guaranteed free of errors, it is the most complete and detailed report of its kind.

Technical Notes

North Carolina Industry at the Millennium

Identifying and characterizing specific core areas of research and development in the private sector at the level of U.S. states is a difficult exercise. Regional data on R&D activity by detailed sector are not available. National Science Foundation surveys, the primary source of R&D expenditure information, collect data from only enough respondents to describe industrial R&D trends (disaggregated by sector) for the nation as a whole. As a result, in the absence of an involved primary data collection effort, any analysis of state-level industrial R&D trends must necessarily be indirect.

With national-level information, it is possible to isolate those specific sectors that, on average, conduct a relatively greater volume of research and development. Trends in size and performance of these industries within a given state can then be described, under the assumption that the state's private sector conforms—at least roughly—to the national-level profile in terms of R&D activity. With these assumptions it is possible to get some sense of the likely general growth of a state's private sector "R&D enterprise," as well as the areas of emphasis or strength within that enterprise. Nevertheless, any analysis on these lines must be mindful of the fact that without primary data collection, very little is known about the actual amount of R&D undertaken by industry in the different U.S. states and regions.[1]

This study is subject to these same problems. A full-scale survey of North Carolina industry and its pattern of R&D expenditure was beyond the scope of the project. However, through a combination of a variety of data and other information, we attempted to construct a reasonably accurate picture of R&D activity and the technology-intensiveness of the state's private sector industries. This permits us to identify existing and emerging industrial specializations and strengths, as well as to assess the likely relative R&D intensity of the different specializations. The findings here could serve usefully as the basis for a full-scale study of research and development activity in North Carolina industry.

We describe and analyze three types of information. First, we profile North Carolina industries that are likely to be *R&D intensive* based on national-level industrial trends (where R&D intensity is defined as the ratio of national-level R&D expenditures to U.S. sales). The sectoral breakdown we use is determined by the maximum amount of sectoral disaggregation available in the National Science Foundation's *Survey of Industrial R&D*. The profile includes measures of size, specialization, and performance, including projected national growth rates to the year 2005. We compare trends across multiple data series, including current industrial specialization, potential degrees of R&D intensity, and future performance.

Second, we use U.S. Patent and Trademark Office data to compare innovative activity in the state, by *technology area*, with patenting activity elsewhere in the nation. Patent data are disaggregated into categories that conform roughly to the Standard Industrial Classification (SIC) system, even though the patents themselves may be granted to private, public, or non-profit institutions. Because the vast majority of patents are obtained by industry, patenting trends one rare piece of hard information on what is largely private sector innovative activity. Even given the limitations of patent activity as a measure of innovation, they provide some insight into changing industrial R&D trends in the state.

Third, we examine recent trends in size and performance for North Carolina industries defined as *technology-intensive*.[2] Although a number of sectors may conduct comparatively little research and development (measured in terms of R&D intensity), they may still depend to a significant degree on basic and applied R&D conducted by public, private, and non-profit institutions. Technology-intensive businesses are defined as those that either produce high technology goods and/or utilize high technology manufacturing processes. These sectors are more likely to depend on, and therefore conduct, research and development. We use an accepted classification scheme of technology-intensive industries to identify and describe the largest and fastest growing technology-intensive sectors.[3] Trends are described to the four-digit SIC level of industrial detail, which permits us to isolate very specific areas of growth and decline in the state.

R&D Intensity. The National Science Foundation reports research and development expenditures for 34 disaggregated industries and an "all other industries" category. Together, the 34 sectors accounted for nearly 94 percent of all U.S. private industry R&D activity in 1992, the date of the most recent data available at the time of this writing (*Technical Appendix* Table 20). The sectors performing the largest share of industry R&D include aircraft and missiles (14.4 percent), office computing and accounting machines (9.6 percent), motor vehicles and motor vehicles equipment (8.4 percent), and research and development and testing services (7.7 percent). The latter—R&D and testing services—also conducts the most significant volume of R&D relative to sales. Other highly R&D intensive industries include office, computing, and accounting machines, computer programming and data processing, aircraft and missiles, communication equipment, scientific and mechanical measuring instruments, and drugs and medicines. *Technical Appendix* Table 20 also reports the federal share of total R&D expenditures by sector. These data provide an indication of the significance of federal R&D dollars for specific industries. Sectors such as aircraft and missiles, computer programming and data processing, and scientific and mechanical measuring instruments conduct significantly more federally funded R&D in relative terms than is the national average.

Patenting Trends. The use of patent data to document trends in innovative activity is fraught with difficulties. As a legal means of financially protecting the output of particular creative activities, patents can only provide an incomplete measure of technological change. As one analyst notes: "Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in quality."[4] Much R&D and innovation will never result in goods that can or need to be patented. Like publication rates by discipline in academia, patent rates also differ significantly by sector. Comparing patenting rates in textiles and apparel to those in computer programming and software, for example, will be misleading at best.

Used carefully and with the associated caveats in mind, however, patent statistics can reveal some useful information about innovation rates. They are perhaps the only direct measure of innovative output available at the state level. Here we use fractional counts over the period 1963 to 1995 from the U.S. Patent and Trademark Office (USPTO) to compare patenting rates in specific sectors in North Carolina to the rates *in comparable sectors* in the rest of the U.S. If we assume that a given North Carolina industry has the same propensity to patent inventions as the same industry in other states, then *relative* patent counts provide a reasonable measure of changes in level of innovative activity in the state.

To make sure that such comparisons are meaningful, we must also assume that the method by which USPTO determines the location of the innovative activity is valid. USPTO assigns patents to states based on the residence of the first-named inventor, under the assumption that this represents the individual or institution that took a primary role in creating the invention. How reasonable is this? Certainly some inventions are developed in multiple places while others are developed in one particular place before they are subsequently patented by another person or institution in a different location. Assigning location based on first-named inventor is therefore potentially misleading. However, for the purposes of this report, USPTO's methodology is satisfactory if we assume that there is no reason why the error associated with the location assignment varies significantly across U.S. states. For these reasons we restrict our analysis to comparisons between states, within the same sectors.

Total patents granted to North Carolina first-named inventors over the 1986 to 1995 period are provided in *Technical Appendix* Table 21. Twelve percent of all patents granted in the state fell under industries not classified specifically by USPTO (the "all other SICs" category). Many of these may represent innovative activity in higher technology nonmanufacturing sectors (e.g., programming and software) that are not well represented in the Standard Industrial Classification system that USPTO uses as the basis of its patent class concordance.[5] Sectors granted the most patents over the period include electronic components and communications equipment, professional and scientific instruments, special industry machinery, and fabricated metal products. *Technical Appendix* Table 21 does not indicate differences in patenting activity across sectors, however. Some industries simply patent more of their inventions than others. The table provides only a snapshot of the mix of patenting activity in the state over the period.

Current and Emerging Industrial Technology Strengths. We base the categorization of sectors primarily on the National Science Foundation's industrial classification scheme, and then use the more disaggregated R&D intensity data to characterize the makeup of the broader industries. Patent statistics provide the only direct measure of innovative activity. And though they are reported by product area rather than industry, they can provide some insight into the likely degree of innovative activity in each broad sector.

One alternative to our approach is to simply identify the largest of the R&D intensive sectors as the state's core industrial strengths in the state's R&D enterprise. This is similar to the approach we use for the academic sector, where we identify those disciplines that are most nationally competitive in terms of research prowess. However, the relationship between industrial performance and research and development is fundamentally different than that between economic growth and academic R&D. Many industries conduct very little R&D, but rather depend on off-the-shelf technologies or R&D performed in other institutions. Indeed, North Carolina's economy is dominated by sectors such as these (including textiles and apparel, tobacco, and furniture).

Additional detail on R&D performing sectors defined as high performance, emerging leaders, and current leaders is provided in *Technical Appendix* Tables 26-28. The high performance sectors are comprised of five non-manufacturing and five manufacturing industries. These are industries that posted above average rates of employment growth between 1989 and 1994 and/or that are projected to grow significantly between 1994 and 2005. The tables also list four-digit SIC level technology-intensive industries within each R&D performing sector that achieved the highest rates of employment growth over the seven-year 1989–96 period. For example, the key growth industry in the high-growth communications services sector in recent years has been the radiotelephone communications industry.

The column "Dynamic Patent Fields" lists product areas in which the state's rank among all U.S. patents between 1986 and 1995 significantly improved. To evaluate a given entry, read across the columns. For example, drugs and medicines ranks among the fastest growing sectors in the state, driven by strong growth in pharmaceutical preparations. The patenting of drugs and medicines-related products has also increased in recent years, such that North Carolina accounted for a significantly greater share of U.S. drugs and medicines patents in 1995 than it did in 1986.[6]

Emerging national leaders were identified on the basis of improvements in North Carolina's employment ranking versus all other states, while current national leaders are those industries with an employment location quotient exceeding 1.3 and with a U.S. employment ranking of tenth or better.[7]

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

The identification of the competitive strengths of North Carolina's academic infrastructure to support and stimulate R&D activity throughout the state is both subjective and complex. It is subjective because while there are a number of criteria and indicators available, there is no agreement on how these indicators should be weighted. That is, even among experts, there can be substantial differences in what are considered the most important and valid indicators, as well as different concepts of "competitive strength." And it is complex because the data available do not always match the concept of competitive strength that is most pertinent, even when there is agreement on the latter.

The methodology used here is based on several concepts, assumptions, and data limitations. First, to fulfill the principal purposes of this study we are interested in identifying those particular technology areas within North Carolina's academic institutions for which the state has comparative strengths compared to the nation. Thus, we use indicators of the ranking of academic programs in North Carolina's academic institutions within their respective disciplines nationally.

Second, we consider only those disciplines that are within the (natural) sciences and engineering. While the presence in the state of distinguished academic programs in other fields, including the social sciences, humanities, law, and business, for example, may be factors in stimulating and supporting total R&D activity within the state, the linkages are indirect and not easily measured.

Third, data available from standard sources that assess and rank academic programs nationally use what some might consider excessively broad categories of disciplines. For example, measures and rankings are available for academic chemistry departments, but not for organic chemistry, inorganic chemistry, textile chemistry, etc. Thus, the data may "hide" strengths of specific programs in particular specializations.

Fourth, we are attempting to identify not only the academic programs in North Carolina that currently have the greatest competitive strengths, but also those programs that hold the most promise of being the highest ranked programs nationally in the future. To do this requires somewhat different indicators.

Finally, our ultimate goal is to identify areas of competitive strength in North Carolina's academic R&D infrastructure that can be compared to the state's primary industrial strengths. To do this requires aggregating across academic institutions, within a given discipline, where the "rules" for aggregating are somewhat arbitrary. For example, in one discipline, there may be one top five program within North Carolina, but no other program ranked in the top 40 among U.S. universities. In another discipline there may be four programs from four universities that are all ranked between 30th and 40th. Which discipline should be ranked higher in terms of relative strength nationally? In other words, how important is breadth of academic strength across universities and implicitly, across regions of the state? There is no correct answer, but clearly there are different spatial implications.

Matching of NRC and NSF Disciplines. In order to combine data from the NRC and NSF for constructing program and discipline scores, it was necessary to match discipline categories. Although most of the discipline categories from the two sources are the same or substantially similar, there were a few that were more difficult to match. We used judgement to match disciplines that are most closely aligned. For example, when matching R&D funding data supplied by NSF to faculty quality, publications and citations data from the NRC, the NRC discipline "Statistics/Biostatistics" was matched with the NSF discipline, "Mathematics and Statistics." Similarly, the NRC discipline "Mathematics" was matched to the same NSF discipline "Mathematics and Statistics." The full set of matched disciplines is as follows (NRC discipline/NSF discipline): aerospace engineering/aerospace engineering; biochemistry and molecular biology/biological sciences; biomedical engineering/biological sciences; cell and development biology/biological sciences; chemical engineering/chemical engineering; chemistry/chemistry; civil engineering/civil engineering; computer sciences/computer sciences; ecology, evolution and behavior/other life sciences; electrical engineering/electrical engineering; geosciences/earth sciences; industrial engineering/industrial engineering; materials engineering/materials engineering; mathematics/mathematics and statistics; mechanical engineering/mechanical engineering; molecular and genetic sciences/medical sciences; neurosciences/medical sciences; oceanography/oceanography; pharmacology/medical sciences; physics/physics; physiology/medical sciences; and statistics/biostatistics/mathematics and statistics.

Program-Level R&D Strengths. The results of scoring individual programs in the state according to R&D funding, perceived faculty quality, total publications per faculty member, and citations are provided in *Technical Appendix* 29-33. Data sources for these indicators are the National Science Foundation's annual *Survey of Scientific and Engineering Expenditures at Universities and Colleges*, the National Research Council's *National Survey of Graduate Faculty*, and the *AUTM (Association of University Technology Managers) Licensing Survey*. Extensive descriptions of these sources (and their associated limitations) are provided in the *Technical Appendix*.

External Funding. A number of academic programs in North Carolina rank in the top twenty nationally in terms of the level of R&D funding within their respective disciplines (*Technical Appendix* Table 29), including seven programs at NC State, four programs at Duke, and five programs at UNC Chapel Hill. The state's universities boast top money-winning programs in five of eight engineering disciplines (NCSU materials, NCSU civil, NCSU chemical, UNC-CH biomedical, and NCSU electrical) and seven of seven bioscience-related disciplines (Duke molecular and genetic sciences, Duke neurosciences, Duke pharmacology, Duke physiology, UNC-CH biochemistry and molecular biology, and UNC-CH cell and development biology). Other highly ranked programs in terms of R&D funding are UNC-CH ecology, UNC-CH geosciences, NCSU mathematics, NCSU statistics, and NCSU oceanography. Programs not ranked in the national top twenty at any university or college in the state include aerospace, industrial, and mechanical engineering, and astrophysics/astronomy, chemistry, computer science, and physics. Many of these latter programs rank highly in terms of other indicators however.

Faculty Quality. Twenty-one North Carolina programs rank in their respective disciplines' national top twenty in terms of perceived faculty quality. The faculty quality indicator is derived from the National Research Council's (NRC) periodic survey of leading scholars. Individuals are asked to rate—on a 0-5 scale—the faculty quality and program effectiveness for all doctoral-granting departments within their disciplines. NRC averages the ratings across all respondents and ranks programs according to their means. *Technical Appendix* Table 30 summarizes NRC's latest findings with respect to North Carolina institutions.

Several programs that fail to make the national top twenty in terms of R&D funding have achieved a top twenty ranking in terms of faculty quality: Duke ecology, Duke biomedical engineering, UNC-CH pharmacology, NCSU industrial engineering, UNC-CH statistics, Duke and UNC-CH oceanography, Duke cell and development biology, Duke biochemistry and molecular biology, UNC-CH civil engineering (environmental sciences and engineering), NCSU aerospace engineering, UNC-CH pharmacology (interdisciplinary program), UNC-CH chemistry, UNC-CH biostatistics, UNC-CH molecular and genetic sciences. Interestingly, only five of sixteen programs in the national top twenty in R&D funding also achieve a national top twenty ranking in faculty quality (Duke molecular and genetic sciences, neurosciences, and pharmacology, UNC-CH biomedical engineering, and NCSU oceanography). For shifts in rankings, see *Technical Appendix* Table 31.

Publications and Citations. More objective measures of academic quality than perceived faculty quality, collected and published in the NRC study, are publication productivity of the faculty and the number of citations (in scholarly journals) of faculty publications. Sixteen programs across North Carolina academic institutions rank in the national top twenty within their respective disciplines for total publications (*Technical Appendix* Table 32). Particularly notable among these is pharmacology at Duke, a program also ranked in the top twenty in R&D funding and faculty quality. Programs achieving top twenty rankings for publications but not R&D funding or faculty quality include NCSU physics, NCSU ecology, UNC-CH neurosciences, and NCSU mechanical engineering.

The total number of citations of faculty publications are a measure of academic quality and strength in that they are one indicator of the significance (as well as volume) of published research. Seventeen North Carolina are ranked in the top twenty of their respective disciplines along this indicator (*Technical Appendix* Table 33). Duke's pharmacology is among these, making it the only program in the state to achieve a top twenty ranking along all four of our performance measures.

Composite Rankings of Programs. By combining the four individual measures of academic program strength—total R&D funding, faculty quality, publications per faculty member, and total citations—we produced a composite index of the most nationally competitive academic programs in North Carolina. As outlined in the text, the first two measures were assigned a weight of 0.3, while the last two were given weights of 0.2 each. Table 10 is the result. Here, scores correspond to the decile of national ranking within each program's respective discipline, where a ten means ranked in the top 10 percent, a nine ranked in the second 10 percent, an eight ranked in the third 10 percent, and so on. The overall composite score is therefore the weighted average of the scores on each of the four measures.[8] Only programs ranked in the top third of their disciplines are listed in Table 10. The full list of North Carolina programs with their scores on each indicator are provided in *Technical Appendix* Table 34. Table 11 is the result of combining three indicators of academic performance, including the level of R&D funding, change in faculty rank, and total publications per faculty member (scores for all North Carolina programs are provided in *Technical Appendix* Table 35.

Federal R&D and North Carolina

Time Trends. We base much of the analysis of the North Carolina federal R&D patterns on 1992–95 trends. This is because federal spending priorities can shift significantly as party control of congress or the presidency changes hands. Defense-focused R&D during the Reagan era gave way to more non-defense research under President Bush, a trend strengthened during the Clinton era (even under Republican control of Congress). Pressure to balance the federal budget took on greater urgency in the early 1990s, while R&D priorities shifted to a greater degree toward environmental and health issues. Most analyses of political priorities and the nation's science and technology enterprise expect these broad trends to continue at least into the foreseeable future. See "On the Allocation of Federal R&D Funds," by C. T. Hill, Institute of Public Policy, George Mason University, background paper prepared for the Committee on Criteria for Federal Support of Research and Development, January 1995.

Scenario Construction. Evaluating the quantifiable ripple effects of changes in federal R&D spending in the state requires two types of projections. First, we need to project federal spending in the state in the absence of balanced-budget pressures (a "no-change" case). This projection becomes the counter-factual against which alternative potential reductions in spending are evaluated against. Second, we need to project what the federal R&D budget in North Carolina will look like as the federal government moves toward a balanced budget between 1998 and 2002. This is extremely difficult to do, since it depends on the mix of current spending in the state, the relative success of North Carolina R&D performers in obtaining federal funds, the performance of the national economy (which dictates, in part, the volume of discretionary expenditures), shifting federal R&D priorities, and the adherence of both parties to the 1997 balanced budget agreement. In light of these difficulties, we constructed seven alternative federal spending scenarios, two of which we select as potential base ("no-change" cases). We also provide the potential range of impacts across alternative scenarios in order to better illustrate the potential magnitude of the impacts.

The seven alternative scenarios are constructed from four basic data sources: 1) federal obligations by agency in North Carolina (available from the National Science Foundation through fiscal year 1995); 2) national federal obligations by agency (available from NSF through 1997); 3) the most recent information on federal budget actions for fiscal year 1998; and 4) initial American Association for the Advancement of Science (AAAS) estimates of the Clinton Administration's balanced budget plan on federal research and development expenditures through the year 2002. These four sets of data mean that 1998 represents the latest year for which at least some information on federal spending patterns (by agency) is available; 1995 is the latest year for which information on North Carolina federal spending (by agency) is available.

With the exception of Constant Dollar-Constant Share and Current Dollar-Constant Share, each scenario was constructed by first employing alternative assumptions to generate projections of federal R&D expenditures for the U.S. as a whole between 1999 and 2002. Additional assumptions were then introduced to allocate a share of national R&D expenditures to North Carolina between 1996 and 2002. Therefore, the scenarios account for the differing availability of R&D spending data at the national and state level. Note that the underlying data used to identify state and national spending trends are budget obligations rather than outlays or expenditures. This is dictated by data constraints. We assume a constant relationship between obligations and expenditures that is based on limited available historical series of the two variables for North Carolina.

As noted above, in constructing trend estimates (extrapolation-based projections of overall levels of spending and mix by agency source), we considered state historical trends only from the year 1992. This is most reasonable given that the early 1990s represented the beginning of serious national political interest in achieving a balanced budget. In addition, focusing on recent years reduces the "small number problem," i.e., that part of the significant growth in federal R&D spending in the North Carolina over the last fifteen to twenty years is partly a function of the small size of federal R&D expenditures in the state early in this period. The following sections provide detailed descriptions of the logic and methodology behind the individual scenarios.

Balanced Budget-Constant Share. The Balanced Budget I scenario first estimates federal agency R&D spending nationwide for 1998 through 2002. The FY 1998 estimates are from AAAS, which based its figures on the most recent congressional R&D budget actions.[9] The FY 1999-2002 projections apply an estimated growth rate in agency spending over this period to the 1998 estimates. The projected change in agency spending between 1999 and 2002 was initially prepared by AAAS in June 1997 based on an analysis of the president's budget, well before the somewhat unexpected Congressional fiscal decisions of the late summer and fall resulted in significant real increases in FY 1998 R&D spending for most federal agencies. Therefore, the Balanced Budget-Constant Share scenario effectively assumes that federal R&D spending experiences a real increase in 1998 (for most agencies and overall), followed by steady real decreases (for most agencies) to 2002. The reasonableness of this assumption depends on the overall performance in the economy as well as the accuracy of AAAS analyses of future Congressional and Executive R&D spending priorities. The scenario is plausible in the sense that it assumes decreases in federal discretionary spending in the later years of the balanced budget horizon (as per the balanced budget agreement). Of course, it is difficult to predict what impact the real increase in agency R&D spending in FY 1998 will have on subsequent expenditure patterns, given the balanced budget requirements. Overall, given present economic trends, the Balanced Budget-Constant Share scenario is likely a conservative estimate of short-term federal R&D resources.

Given projected federal by-agency R&D expenditures for the U.S. as a whole, it is necessary to employ an assumption about the share of each agency's spending that will be allocated to R&D performers in North Carolina. On the one hand, North Carolina has been relatively successful in obtaining greater shares of a federal R&D budget that has been declining in real terms in recent years. We might assume that this success will continue in the future, particularly since North Carolina's ratio of overall federal R&D spending to gross state product is still well below average among the largest manufacturing states. This means that North Carolina less likely to become target in any efforts to effect a more even geographical distribution of a shrinking federal R&D budget. On the other hand, such an assumption generates moderately optimistic federal spending trends for the state relative to trends nationwide. Therefore, in the context of some uncertainty about projected national economic performance as well as the continued relative success of North Carolina R&D performers in obtaining federal funds, we assumed that the share of federal R&D funds for each agency provided to performers in the state will remain constant between 1996 and 2002 under the Balanced Budget-Constant Share scenario. Additional scenarios (Balanced Budget-Growing Share, Constant-Growing Share, and Current Trend) alter this assumption and are based on extrapolation of recent trends in the state's share of each federal agency's R&D dollars.

Balanced Budget-Growing Share Scenario. In contrast to Balanced Budget-Constant Share, which assumes that the state's share of each federal agency's R&D spending will remain constant between 1995 and 2002, under Balanced Budget-Growing Share we allow changes in the mix of R&D spending by agency in the state based on trends between 1992 and 1995. For example, over this three year period, U.S. Department of Agriculture spending in North Carolina as a share of total Federal spending in the state fell from 2.41 to 2.32 percent (.028 percentage points annually). Likewise, the shares of Departments of Defense, Interior and Transportation all fell, while the shares of Energy, Health and Human Services, Environmental Protection Agency, and the National Science Foundation all gained. Department of Commerce and NASA spending as shares of the North Carolina total were virtually unchanged.

As discussed earlier, these trends indicate a favorable R&D mix relative to recent historical as well as projected short-term shifts in R&D priorities at the national level. The strong positive mix effect found in the shift-share analysis of recent Federal agency spending trends in North Carolina (reported above) indicates that between 1992 and 1995, the state's strong performance in garnering federal R&D dollars was largely a function of its profile of R&D spending by agency in 1992. Specifically, federal R&D funding in 1992 came primarily from agencies that saw the most significant increases in their R&D budgets over the three year period. In terms of the future, AAAS projections indicate that the agencies likely to experience the strongest nominal dollar increases in R&D spending are Commerce, EPA, and NASA; those likely facing current dollar declines, according to AAAS, are Defense and Energy. The R&D budget of Health and Human Services may grow only slightly in relative nominal terms. Nevertheless, the size of the HHS budget (relative to Commerce and EPA, for example) means that it will remain an important driver of total R&D spending nationally and in North Carolina. HHS accounted for nearly 52 percent of Federal R&D dollars in the state in 1995, compared with under 17 percent nationally.

The Balanced Budget-Growing Share scenario accepts the national level agency-specific projections under Balanced Budget-Constant Share. However, since the scenario permits the agency-specific mix of federal spending in the state to change, it results in a more optimistic scenario than under Balanced Budget-Constant Share.

Constant Dollar-Constant Share, Constant Dollar-Growing Share. The two Constant Dollar scenarios simply assume that federal R&D expenditures (either in North Carolina or the U.S. as a whole) will grow only with inflation. Under Constant Dollar-Constant Share we assumed that the level of federal R&D in the state would remain constant at its 1995 level in real terms. Under Constant Dollar-Growing Share we assumed that the federal R&D budget for the U.S. as a whole would remain constant at its 1998 level in real terms. We then allowed the mix of agency-specific funding in North Carolina to shift between 1996 and 2002 based on 1992-1995 trends.

Constant Dollar-Growing Share is optimistic in two respects. First, it assumes a constant real level of overall federal R&D spending out to the year 2002. This is inconsistent with the general downward real trend in national-level federal R&D activity of recent years. It is most plausible if the economy remains strong and there is a renewed commitment to federal R&D in Congress and/or the White House. Second, it assumes the favorable shifts in mix of federal sources in North Carolina over the 1992 to 1995 period continue in like fashion through the year 2002.

Current Dollar-Constant Share, Current Dollar-Growing Share. The Current Dollar scenarios assume that federal R&D expenditures fail to keep pace with inflation by holding steady at their nominal initial period values. Under Current Dollar-Constant Share, federal R&D spending in North Carolina is held constant at its 1995 level in nominal terms. With inflation, this generates a significant decline in real spending through 2002. This scenario is the most pessimistic of the seven scenarios and probably represents a reasonable lower bound for the set of projections.

Current Level-Growing Share holds federal R&D expenditures at the national level constant in nominal terms at their 1998 level. A share of the federal R&D budget is then allocated to North Carolina based on trends in agency-specific spending in the state between 1992 and 1995 (as in Constant Dollar-Growing Share and Balanced Budget-Growing Share). These assumptions generate a projection that is moderate in its degree of optimism regarding federal spending trends in the state.

Current Trend. In the best of all worlds, the recent significant rate of growth in federal R&D expenditures in North Carolina would continue through the year 2002. The Current Trend scenario embodies this assumption by simply extrapolating from the growth in federal R&D spending in the state between 1992 and 1995. The scenario is extremely optimistic in light of the possibility of a slowing of national growth and increased pressures to balance the federal budget. The scenario is most plausible if the national economy continues to expand at its present pace and North Carolina R&D performers are exceptionally successful in competing for federal R&D resources over this period.

Impact Analysis Data Preparation. The requisite data for the impact analysis were gathered and prepared in four stages. In the first stage, we obtained detailed fiscal year 1997 spending data for total sponsored research from UNC-Chapel Hill and NC State University. These data report expenditures for contract research by detailed object code. Since object codes used by NCSU differ in some cases from those at UNC, we first converted NCSU codes to the UNC object code system using accounting manuals from each university. We then split the two universities' spending into three categories: commodities, personnel, and other. Commodity purchases and personnel costs (wages, salaries, stipends, etc.) are self-explanatory; the "other" category includes expenditures on retirement and other fringe benefits, special accounting codes, and intra-university transfers. These expenditures represent direct out-of-state expenditures and intra-university funds. The list of budget object titles and UNC/NCSU spending under each is provided in *Technical Appendix* Table 38.

In the second stage, we converted the object codes under commodity spending to Standard Industrial Classification (SIC) categories using a dictionary of SIC codes, previous research, and judgement.[10] This amounts to identifying the specific commodities that the universities purchased in FY 1997 with each sponsored research dollar. The SIC codes were then matched to IMPLAN Pro software's input-output sectoring scheme (the IMPLAN sector(s) for each object category is also provided in *Technical Appendix* Table 38). Since IMPLAN offers over 500 sector detail, this permitted a fairly close match between the object spending data and commodity purchases. The object code level data were then summed over IMPLAN sectors to derive total UNC/NCSU expenditures for each input-output commodity. The final step in this stage was to identify what the share of these expenditures made within North Carolina. Lacking survey-based or secondary data on in-state spending patterns for UNC and NC State, we assumed—with a few exceptions—that each university's ratio of in-state to total spending for a given commodity was equal to the average regional purchase coefficient (RPC) for the commodity as determined by IMPLAN. In the case of some categories of university expenditure, we adjusted the RPC. For example, the universities report in-state and out-of-state travel separately. Using these figures, we were able to derive a direct estimate of the share of in-state travel purchases to total travel purchases.

An RPC represents the estimated share of total local demand that is met by local production; IMPLAN estimates RPCs for a given area via individual regression equations for each commodity (calibrated with variables constructed from local area data). The use of average RPCs to estimate local spending is a reasonable approach in the absence of better information about local purchasing habits by given institutions. Unfortunately, as averages, they may over- or under-estimate local spending for individual sectors (e.g., universities) in the economy. To test the sensitivity of our findings to the size of the RPC, we also produced impact estimates assuming that local R&D purchases (by universities and other institutions, see below) are 25 percent higher, on average, than the level indicated by IMPLAN's RPCs. As it turns out, this resulted in very little change in the aggregate multiplier.

UNC and NCSU do not account for all federal R&D spending by university in North Carolina. Duke also conducts a considerable volume of federally supported R&D, as do some smaller universities (e.g., Wake Forest). In the third stage, we estimated total spending for each input-output commodity and personnel for all universities in the state based on the patterns observed for UNC and NCSU. Mechanically, this involved summing UNC and NCSU expenditures for each commodity and taking the ratio of commodity spending to total spending to construct an aggregate gross absorption vector. Multiplying this vector by total estimated commodity expenditures for all North Carolina universities, colleges and teaching hospitals in 1995 generated estimates of aggregate university spending by individual commodity (for FY 1995).[11] Total non-commodity expenditures by the state's universities were then allocated to the "other" and personnel categories according to UNC/NCSU averages. These procedures assume that other universities in the state tend to purchase the same mix of goods and services (as well as personnel) as a UNC/NCSU average. We believe this is a plausible assumption since this average represents a mix of health-related, basic scientific and engineering-related R&D, a reasonably accurate characterization of Duke University's R&D profile. Moreover, a significant share of each university's sponsored research budget is expended on personnel. This helps minimize the effect of errors in identifying commodity expenditures, the most difficult part of the impact analysis.

Universities, of course, do not account for all federal R&D spending in the state. Federal labs and industries also constitute a significant share. In stage four, since we lacked any data on spending by these non-university sectors, we assumed their spending patterns resembled that of the research, development, and testing services sector (SIC 873, IMPLAN sector 509). We multiplied estimates of total R&D spending by all non-university sectors in the state in FY 1995 by the gross commodity absorption vector for IMPLAN sector 509 to derive estimates of spending by individual commodity, as well as for personnel.

Technical Appendix Table 39 lists total commodity purchases by input-output sector for all North Carolina R&D performers in FY 1995, along with the average RPC or equivalent, the ratio of the spending on each commodity to total R&D expenditures (under the "Estimated Gross Absorption" column), and the ratio of in-state spending on each commodity to total R&D expenditures (under the "Estimated Regional Absorption" column). The table describes the aggregate commodity production function for the state's R&D enterprise. Most commodity purchases (over $100.5 million in 1995) are made for IMPLAN sector 496, colleges, universities, and schools. This "commodity" purchases represents primarily overhead or indirect costs of academic R&D performers. Other major commodity purchases include computer and data processing services, R&D and testing services, real estate, air transportation, other business services, semiconductors and related devices, wholesale trade, personnel supply, chemicals, and so on. Total R&D expenditures less in-state commodity purchases, out-of-state purchases, and intra-university transfers constitute personnel expenditures.

Model Estimation. To estimate the model, we first imported the aggregate R&D spending vector for the state into IMPLAN. Since the vector represents local per commodity expenditures per total R&D dollar, we only needed to introduce the projections of total federal R&D spending in the state to produce estimates of that spending's direct and indirect impact on the North Carolina economy. To estimate induced effects, we first disaggregated total wage and salary payments into those made to high, moderate, and low income households. IMPLAN includes three personal consumption expenditure vectors to account for differing spending patterns by income. We estimated the ratio of disposable to total income using tax and savings rates in the social accounting matrices provided in IMPLAN. The three household income rows and expenditure columns in the input-output accounts are treated as industries for the purposes of generating induced, or household spending, effects.

Notes

1. One alternative piece of information available at the state level is employment by occupation. A comparison of the share of scientists and engineers in each sector in North Carolina could be compared with the same share for the national sector. However, currently data are only published at the two-digit SIC level and contain too many confidentiality suppressions to make such a comparison reliable.

2. Data on technology-intensive industries were first presented in "Technology-Intensive Industries in North Carolina," by E. Feser, Institute for Economic Development, University of North Carolina at Chapel Hill, 1997. The data assembly and report were commissioned by the North Carolina Alliance for Competitive Technologies. The findings here differ slightly from the earlier report, however, since three sectors have been added to the classification of technology-intensive industries (radiotelephone communications, radiotelephone communications except radio, and telegraph and other communications).

3. The classification of technology-intensive businesses was prepared by the North Carolina Employment Security Commission and is comparable to classifications adopted in other states.

4. "Patent Statistics as Economic Indicators: A Survey," by Z. Griliches, *Journal of Economic Literature* 28, p. 1,669.

5. The USPTO patent classification system is based on the 1972 Standard Industrial Classification system.

6. Note that employment change is used as the growth measure. Some industries may have reduced employment while also increasing output or value-added. Although output measures are not available at the necessary degree of disaggregation, we did examine growth in gross state product (value-added) at the two digit level to identify dynamic industries that may not be adding a significant number of workers. Rubber and miscellaneous plastics and electronic components were both added on this basis. We did not add sectors that experienced significant declines in employment coupled with notable growth in value-added (e.g., textiles). This reflects an emphasis on job creation as well as well as income growth in identifying high performance sectors.

7. Specifically, sectors were classified as "emerging national leaders" if the total shift in rank (say, from tenth to fifth, or five points) was at least 25 percent of the sector's base year rank. Note that the relative national position of a given sector in the state may improve as a result of a decline in employment in that sector in other states. "Emerging national leaders" are U.S. industries that appear to be concentrating in North Carolina over time, although the industry as a whole may be growing or declining.

8. While most programs received final scores based on all four indicators, a few were scored based on one fewer variable due to missing research and development expenditure data. In these cases, the variable weights were adjusted accordingly.

9. The latest FY 1998 Congressional budget action information incorporated in the projections are from late November 1997.

10. An earlier study reported commodity expenditures under each object code for UNC in fiscal year 1983. The study helped identify multiple commodity expenditures under single object codes where were commodity spending patterns were not likely to change significantly over the intervening fourteen years (e.g., household supplies). See "The Impact of the UNC Research Budget on the Economy of the State of North Carolina," by H.A. Goldstein and X. M. Mu, Department of City and Regional Planning, University of North Carolina at Chapel Hill, September 1984.

11. Although expenditure data for UNC and NCSU were from 1997, 1995 represents the latest year for which total federal R&D spending in the state is available.