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4

ON THE MEASUREMENT OF UNIVERSITY
RESEARCH CONTRIBUTIONS TO ECONOMIC
GROWTH AND INNOVATION

MARYANN P. FELDMAN, ALLAN M. FREYER,
AND LAUREN LANAHAN

ABSTRACT

The increasing complexity of university scientific research and the
increasing pressure for accountability in public expenditures cre-
ates a challenging environment for the measurement of scientific pro-
ductivity. Of course, the choices of metrics employed create different
incentives for institutional actors at the federal, state, and university
levels. This chapter uses the example of the Center for Environment-
ally Responsible Solvents and Processes, an NSF-funded science and
technology center over its ten-year span to assess economic impact,
research outcomes, and public benefit. First, we conduct an economic
impact assessment using the IMPLAN methodology for input-output
analysis. Next, we analyze conventional knowledge and technology
transfer metrics. Our third analysis attempts to consider the social,
cultural, and educational public benefits from the research center.
Then we employ ex post thought experiments to compare the center
with other modes of federal research funding. We advocate a broad,
holistic, and case-specific approach to the evaluation of multidisci-
plinary research centers, combining traditional research outcome
and knowledge transfer metrics with social, cultural, and educational measures.

INTRODUCTION

The mission of universities has become more complex, encompassing commercialization goals and economic development along with the traditional goals of educational and research excellence. Rather than constituting the model of a single-investigator project, the nature of university research practice has come to encompass a range of organizational forms, such as multidisciplinary and interdisciplinary collaborative research endeavors that span across universities, government labs, and industry (Aboelela et al., 2007). The motivation is that the applications with the greatest potential for economic growth often exist at the intersection of disciplines and require the integration of diverse forms of knowledge (Metzger & Zare, 1999). To increase the practical impact of university research, many state and federal programs require university research projects to involve industrial actors, which may include large firms, industry consortium, and new start-ups firms (Hagedoorn, 2002). Increasing in both scale and scope, the university research enterprise not only supports fundamental research but also delivers results in the form of economic outcomes and societal impacts (Mallon & Bunton, 2005). The result is that the academic research enterprise has evolved substantially to develop new multifaceted capabilities.

Alongside these formative changes, state and federal funding agencies have come to demand greater accountability of the results of public investments in academic research. These demands for accountability to political authority, especially to the U.S. Congress—building on the 1993 Government Performance and Results Act (GPRA)—have remained central over the past decade. The Office of Management and Budget’s recent 2009 memorandum, “Increased Emphasis on Program Evaluations,” is one recent example of pressure for research evaluation and accountability (Chubin et al., 2009). These requirements, however, present particular challenges for the evaluation of multidisciplinary and interdisciplinary collaborative university research programs (Bozeman & Boardman, 2004). Traditional measurements of research outcomes have relied on assessments of economic impact, such as the multiplier effects associated with expenditures, or focused on metrics of knowledge creation and technology transfer, such as publications, patents, and spinoff companies. These metrics capture the more tangible outcomes that result from university research; however these measures alone fail to capture the spectrum of results (Cozzens & Melkers, 1997; Ruegg & Feller, 2003; Wagner et al., 2011). A given university research project has the potential to span many years, leveraging additional resources—both public and private, training and education, knowledge generation and transfer, dissemination via publications, technology transfer products, job creation, and greater societal gains. Moreover, traditional performance indicators limited to economic impact assessments and technology transfer may underestimate the total outcomes of the research project (Wagner et al., 2011). This formative change and evolution in university research practices demands new evaluation metrics that look beyond the direct tangible outcomes (Wagner et al., 2011; Kahnis, 2011; Chubin et al., 2009).

The choice and use of metrics are critical as they will subsequently influence the conduct of scientific research and define the nature of the research that is undertaken and may even delimit the resulting contributions. A focus on easily measurable outputs may skew attention toward less risky and more immediately realized countable metrics. The nature of large-scale university research projects inherently incorporates learning and adaptation as it proceeds. A lack of immediate results may indicate the identification of new and relevant problems or some intervening serendipity that suggests a new approach. Moreover, the conduct of research, and the search for solutions, often generates significant positive externalities that, while difficult to measure, may be its most significant impact.

To more completely assess a research investment, this chapter compares various methods and suggests a broader scope of analysis to include a greater range of social, cultural, and educational benefits. We present a framework for capturing the totality of the university activity produced by extending beyond immediate and traditional quantifiable benefits to consider and include less quantifiable impacts. To guide our investigation, we trace one university research program, UNC Chapel Hill’s Center for Environmentally Responsible Solvents
and Processes (CERP), a National Science Foundation University Research Center (URC), which serves as an exemplar of the emerging organizational form that has come to characterize the evolving university research enterprise (Slaughter & Hearn, 2009; Bozeman & Crow, 1990). Section 2 provides our theoretical framework, highlighting the limits of the traditional methods used to evaluate research outcomes. Section 3 uses CERP as a case study to show how broadening the evaluation approach to include an economic impact assessment, research metrics, and public benefit analysis allows for a more comprehensive understanding of the university’s contributions. In addition to presenting the conventional knowledge and technology transfer metrics and social, cultural, and educational public benefits from the research center, we employ ex post thought experiments to compare the center with other modes of federal research funding. We advocate a broad, holistic, and case-specific approach to the evaluation of the evolving university research enterprise by combining traditional research outcome and knowledge transfer metrics with social, cultural, and educational measures. Section 4 concludes by extending this discussion to university research evaluation metrics more generally.

ON THE FOLLIE OF REWARDING ECONOMIC OUTCOMES WHILE HOPING FOR PUBLIC BENEFIT

In his influential article “On the Folly of Rewarding A, While Hoping for B,” Steven Kerr (1975, p. 769) highlights discrepancies within the reward system that lead to suboptimal outcomes. Using the example of orphanage practices, he argues that directors are often faced with a dilemma between the societal goal of placing children in suitable homes and programmatic budget incentives to maintain enrollment. As Kerr notes, “[T]o the extent that staff size, total budget, and personal prestige are valued by the orphanage’s executive personnel, it becomes rational for them to make it difficult for children to be adopted” (p. 772). Thus, what is immediately rewarded may act against society’s longer-term interest.

We argue that Kerr’s theory may also occur with scientific research and development, if a limited range of concrete, traditional outcome metrics at the expense of the less tangible goals that include broader public benefit drives the university research enterprise. When evaluators measure specific activities they incentivize those activities. While society desires technological progress and economic growth, increasingly there are pressures to celebrate the number of companies started, reward faculty for taking out patents, or count the number of jobs that result from research activities.

This emphasis on economic impact and research metrics, by Kerr’s logic, would lead scientists to align their research and results with metrics rather than with the less tangible goal of public benefit. Moreover, by defining the performance indicators by these metrics, a significant portion of the research outcomes important to society may be overlooked. Fundamental research projects are likely to simultaneously serve multiple educational, technical and industrial objectives. Thus, there is a need to calibrate the metrics used in rewarding resources to ensure the integrity of the larger research enterprise. The desired outcomes of economic growth and technological progress will be enhanced if the science policy community and university officials expand their assessment metrics to include social, cultural, and educational measures as well.

One issue is that motivations vary among stakeholders. Given the range of demands, research outcomes are often measured from multiple perspectives using disjointed frameworks. University officials are often most interested in demonstrating the regional economic impact of research, providing a justification for more funding, and satisfying economic development concerns. Moreover, the dollar amount of research funding figures prominently in university rankings. State and local economic development officials have incentives to garner the greatest impact for their jurisdiction, even if nationally the impact is a zero sum. Federal officials, especially at funding agencies, on the other hand, have an interest in broader contributions to education and research, but still face the need to justify their programs. The data available from the Association of University Technology Managers (AUTM) has focused attention on invention disclosures, patents, licenses, and new firms; some academic scholars focused on research productivity have made use of these existing measures while other scholars have taken in-depth qualitative approaches that are not scalable to the assessment of large national funding programs. University research officials, especially those affiliated with state-funded institutions, are asked to provide economic impact statements for research projects similar to those produced for sporting events or a new office park. nationally, though, the assessment of economic
impact should reflect productivity gains in terms of economic and societal outcomes rather than simply reflect distributional impacts. From a national perspective, any incentive to increase funding to any one locality where the largest local impact might be anticipated rather than where the best science could be conducted would result in suboptimal allocation.

It is both possible and necessary to define and measure the productivity of multidisciplinary university research projects in a way that motivates university scientists to seek private gain through publication records and management of intellectual property and to maximize societal benefit. Ensuring this range of outcomes, however, demands concerted efforts from researchers themselves, and from the evaluators who define, frame, and assess the central research missions. If we only promote traditional research outcomes, then we overlook the great potential of public benefit that results from university research. Evaluators not only have a role in tracing programmatic impacts, they also serve a guiding role in defining and promoting the range of possible societal outcomes delivered by the university research enterprise.

UNIVERSITY RESEARCH CENTERS

Hailed as the most significant institutional innovation in science policy in the past thirty years (Bozeman & Boardman, 2004), URCs have demonstrated great promise and are believed to promote innovation and technological change. Nevertheless, they are plagued by high levels of uncertainty, long-term horizons, and complex causal paths requiring multiple inputs and integrating industrial actors; this in turn presents difficulties in reconciling with political needs for accountability. In an effort to present a set of evaluation metrics that captures the evolving university enterprise's contributions to academic audiences, economic growth, and public benefit, we trace one university research program, CERSP, as an exemplar.

Broadly defined, URCs extend beyond the boundaries of a single disciplinary department, receive financial support independent of departmental allocations, and demonstrate strong ties to industry and commerce (Miller, 2010). Sustainability is a major concern for these centers due to the absence of tuition revenue; however, centers often enjoy more flexibility in terms of their organizational structures and their research agendas. These features offer a unique research environment for producing outcomes distinct from their departmental counterparts. Specifically, given the multidisciplinary nature of both the topic and research team, centers produce spillover effects across departmental lines and between the university and industry. Regardless of how the research project evolves, the facilitation of communication across disciplines and beyond the bounds of the university has considerable implications for those involved with the URC. If the efforts of a collaborative multidisciplinary team of researchers transform a scientific discipline, we argue that research becomes richer, thus producing public benefits. Each center represents an experiment in the conduct of university research, requiring significant investment but having the potential to generate transformative scientific breakthroughs and broad societal impact.

While URCs are generally time-limited, their contributions extend well into the future. Annual and final reports are only able to account for the short-term contributions, yet studies have found that research continues to have an impact by way of spillover and demonstration effects beyond the term of funding. Mansfield (1998) found in his analysis of seventy-seven industries that there is a time delay of roughly seven years between academic research and industrial practice. Applying this to the maximum ten-year NSF funding period for some of its major centers programs, at most 30 percent of a center's industrial and economic benefits are likely to be realized during its existence. As we proceed in this attempt to account for the total impact of a university research center, it is important to acknowledge the likelihood of as-yet-unrealized future outcomes.

CERSP AS AN EXEMPLAR—BACKGROUND, METHODOLOGY, AND DATA

We examine the Center for Environmentally Responsible Solvents and Processes (CERSP), which completed its tenth year of funding as a National Science Foundation (NSF) Science and Technology Center (STC) in 2009. CERSP was awarded roughly $36 million by NSF
for the collaborative effort between The University of North Carolina at Chapel Hill (UNC), North Carolina State University (NCSU), University of Texas at Austin, Georgia Institute of Technology, and North Carolina A&T State University. When awarded in 1998, it was the single largest grant received by researchers in the UNC system.

To robustly assess the performance of CERSP, we employ multiple methodologies. Evaluating a complex center with myriad objectives that span K-12 education, higher education, industry extension, and technology transfer activities— including infrastructure, start-up, and consulting services—provides an interesting and challenging opportunity. Previous efforts to measure outcomes of STCs against their triple mission of knowledge transfer to industrial partners while advancing research frontiers and the quality of science education have been criticized for taking an overly quantitative approach (Fitzsimmons, Grad, & Lal, 1996), though recent work by Chubin et al. (2009) has begun employing a more robust approach.

Arundel asserts that science policy is hampered by “a lack of indicators and analyses that are relevant to policy needs” (2006, p. 11). By using CERSP as a case study, we will illustrate the limits of the traditional outcome metrics and try to show how scholars, university officials, and the public can account for additional educational and cultural impacts. Our approach represents a combination of what Helper (2000) has described as learning “just by watching,” and appreciative theorizing, or what Weick (1995, p. 385) has defined as “an interim struggle in which people intentionally inch towards stronger theories.” This is in the tradition of Yin (2003), who advocates for the use of field research and case study analysis to question existing theory and empirical findings. Edmondson and McManus (2007) similarly argue that the appropriate methodological fit for a study of this nature, which resides in a relatively nascent field, requires a greater degree of qualitative and observational analysis.

As we attempt to account for the contributions of the evolving university research enterprise, we recognize that this evaluation of CERSP serves as an exercise in exploring possible measures as well as in building a stronger foundation with which to account for university research outcomes. With significant variation among staffing structures, connections to universities, core activities, and funding allocations, it would be unrealistic to implement a one-size-fits-all approach to evaluating the contributions of a center. We argue that it is the unique nature of each URC that presents the primary methodological challenge in defining and evaluating a research program’s outcomes. While comparative analysis between two or more centers is one possible method for measuring impact, we argue that the selection of only the most promising centers and the wide variation among centers make this approach generally unworkable. As emphasized by Roessner (2000), URCs, and other competitive university research programs lack a counterfactual, given that they are subject to peer review before being awarded funding. Only the most competitive proposals receive funding, which leads to a selection bias in comparative analyses. Moreover, those that do receive funding vary considerably from one another, thus making it exceptionally difficult to do a comparative analysis.

Ideally, we would employ a comprehensive list of evaluation indicators to capture the totality of a center’s impact. However, the unique design of URCs, university research projects more generally, and limitations of standard outcome metrics make this unrealistic. Thus, such an effort to evaluate the contributions of a URC necessitates extensive observation and creativity. Rather than limiting an analysis to the traditional evaluation metrics, we take a slightly different approach. We follow one NSF STC over time, utilizing various methods to assess research outcomes in terms of its economic impact, research outcomes, and public benefit. Then we contextualize the center’s performance using a number of ex post thought experiments comparing the center with other modes of federal research funding.

The data we use include approximately three thousand pages of documentation, including the original proposal to NSF, the center’s annual reports, and its final report. We also have data on formal technology transfer outcomes available from UNC’s Office of Technology Development. These data are supplemented with interviews with program participants. Two of the authors attended center meetings, including an NSF site visit, as participant-observers. We reviewed other published and unpublished social science research and journalistic accounts of CERSP’s economic impact. In the thought experiments, we use publicly available information on NSF funding patterns, provided by NSF and the Academy of Arts and Sciences.

Dr. Joseph M. DeSimone, William R. Kenan Jr. Distinguished Professor of Chemistry at UNC and Professor of Chemical Engineering at NCSU, served as the PI and director for CERSP. The center’s
co-director was Dr. Ruben G. Carbonell, now the Frank Hawkins Kenan Distinguished Professor of Chemical Engineering at NCSU and the chairman of the Department of Chemical Engineering. These two researchers led a team of more than six hundred students, staff, and researchers at the five affiliated research universities during a ten-year period. With a vision to "enable a revolution in sustainable technology" and a mission to support multidisciplinary, fundamental research that would yield sustainable processes, products, and broad societal benefit, the researchers affiliated with CERSP deliberately undertook the type of high risk/high reward research that is often avoided by universities and industry (CERSP final report, 2009). It was the unique long-term, high investment structure of the NSF STC program that allowed researchers at the Center flexibility to undertake an endeavor of this magnitude. The potential contribution of the technology was clear from the proposal: the researchers aimed to develop sustainable technology for processes to manufacture high value products based on environmentally friendly solvents. This technology would provide substantial public benefit by developing manufacturing processes that would be more sustainable due to decreased emission of chemicals harmful to human health and greater energy efficiency.

TRADITIONAL METRICS AND BROADER BENEFITS

Accurately capturing the impact of a university research center requires a holistic approach in order to identify the full range of outcomes created and to measure the spillover effects in the local community and beyond. In this chapter, we use a set of mixed and varied methods to capture the total set of impacts. First, we conduct an economic impact assessment using the IMPLAN methodology for input-output analysis. We then analyze conventional knowledge and technology transfer metrics. Our third analysis considers social, cultural, and educational public benefits from the research center. Using calculations from the center's final report, Table 4.1 presents a comprehensive list of the economic impacts, research metrics, and public benefits. We review the metrics and discuss the results of each analysis in turn.

<p>| Table 4.1. Evaluation of the Center for Environmental Solvents and Processes (CERSP) |
|---------------------------------|-----------------|-----------------|-----------------|
| <strong>Outcome</strong>                     | <strong>Economic impact</strong> | <strong>Research metrics</strong> | <strong>Public benefit</strong> |
| Jobs created                    | $66/year        |                  |                 |
| Income effect                   | $3.35M/year, in constant 2007 dollars |                  |                 |
| Impact on NC state industries   | $13.51M/year, in constant 2007 dollars |                  |                 |
| Research investment             | $30M in research; $6M in education |                  |                 |
| Licenses                        | 14              |                  |                 |
| Start up firms                  | 8               |                  |                 |
| Leveraged funding               | $145M in supplemental funds reported by all PIs |                  |                 |
| Start up centers                | 5 new centers* and an additional $310M budgeted by state of NC |                  |                 |
| Patents and applications        |                  | 90              |                 |
| Networks: PI external collaboration |                  | 297 total (110 with universities, 20 with government, 67 with industry) |                 |
| Networks: Students co-authoring with researchers outside of CERSP | 208 total (8 undergraduates, 143 graduates, 57 postdocs) |                  |                 |
| Students supported via CERSP    |                  | 554 total (235 undergraduates, 235 graduates, 84 postdocs) 345 students were from underrepresented groups |                 |</p>
<table>
<thead>
<tr>
<th>Outcome</th>
<th>Economic impact</th>
<th>Research metrics</th>
<th>Public benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students recruited to industry and research institutes</td>
<td>26 postdocs and 41 graduate students</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Conference presentations</td>
<td>750 total (330 invited lectures and 200 abroad)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Student conference presentations</td>
<td>266 students gave 431 presentations</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Publications</td>
<td>511 peer reviewed papers, 54 chapter, 1 textbook</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Citations</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Workshops</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>K-12 education contribution to teachers</td>
<td>11,000 teachers trained with environmental science laboratory workbooks</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>K-12 education contributions to students</td>
<td>1.2M students in grades 7-12 reached in classrooms via certified workbooks and CERSP trained teachers, mentoring program for high-risk students, two kits used by more than 25,000 K-12 students</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CERSP students who continued academic training</td>
<td>141 undergraduates, 45 graduates, 3 postdocs</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Student outreach</td>
<td>200 students involved with K-12 outreach</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>K-12 education diversity</td>
<td>Reached 20,000 K-12 students in underrepresented groups via demos and presentations, reached 1M grade 7-12 students in underrepresented groups via workbooks</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cultural shifts in research practice</td>
<td>Shift from disciplinary research practices towards more diverse interdisciplinary and translational research environment, demonstration effect</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CERSP Web site</td>
<td>More than 2M hits</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Dashes represent metrics that are applicable in the holistic assessment model where data are unavailable or not reported. Blank cells represent metrics that are not applicable.

*Triangle National Lithography Center at North Carolina State University (NC State), Clean room and 600 MHz NMR facilities at University of North Carolina (UNC), $35M for Engineering Research Centers at NC State and North Carolina Agricultural and Technical State University, and $55M for University of Texas and UNC for Energy Frontiers.
ECONOMIC IMPACT ASSESSMENT

Economic impact assessments frequently use input-output analyses to estimate the impacts of specified economic events. This technique examines the repeated rounds of spending among industries, households, and governmental institutions that result from specific events within a specified study region. In this case, we studied these interactions using IMPLAN Professional Software, an input-output modeling program. Input-output analysis examines business-to-business and business-to-consumer relationships, capturing market transactions for a given period of time (Minnesota IMPLAN Group, Inc., 2004). We estimated the projected effects of CERSP as an exogenous increase in demand from the infusion of federal funds into the state of North Carolina.

IMPLAN software constructs the two key models used in input-output analysis—the descriptive model and the predictive model. As its name suggests, the descriptive model provides information about local economic interactions in the form of regional economic accounts. These tables describe a local economy in terms of the flow of dollars from purchasers to producers within the region, while also including information about trade flows—the movement of goods and services within a region and between the region and the outside world. Along with these purely economic elements of input-output analysis, IMPLAN also permits the incorporation of social accounting into the descriptive model, a method that allows the analyst to examine nonindustrial transactions within the region, including the payment of taxes by households and businesses and transfer payments from government to households and businesses. For its predictive model, IMPLAN uses the regional economic accounts to construct local-level multipliers, which describe the response of the economy—defined by the descriptive model—to some exogenous change in demand or production.

The implicit assumption in any economic impact assessment is that the direct, indirect, and induced spending attributable to the project would not have occurred without the event of interest. This "but for" assumption on which all impact assessments are based is more applicable for planning purposes and evaluating the impact of alternative investments. The simplifying assumption is that all revenues generated by the university research center are new to the area and are not substitutes for existing research or technology commercialization efforts.

<table>
<thead>
<tr>
<th>Type of impact</th>
<th>Direct</th>
<th>Indirect</th>
<th>Induced</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased industry output (millions of 2007 dollars)</td>
<td>7.97</td>
<td>3.45</td>
<td>2.10</td>
<td>13.51</td>
</tr>
<tr>
<td>Increased employment (implan calculations of job-years)</td>
<td>29</td>
<td>17</td>
<td>20</td>
<td>66</td>
</tr>
<tr>
<td>Increased labor income (millions of 2007 dollars)</td>
<td>1.81</td>
<td>0.88</td>
<td>0.65</td>
<td>3.35</td>
</tr>
</tbody>
</table>

Note: Sum of components may not add up to totals due to rounding.

Economic impact studies separate out spending related to the center's operations, direct NSF funding, and education programming, and model each according to the multipliers associated with that economic activity. We assume that the $36 million in total funding received from NSF was distributed evenly over the center's ten-year existence. Adjusted to 2007 dollars, we estimated that $3.347 million per year were spent on research, $335,000 on operations, and $335,000 on education programming.

The results of the IMPLAN analysis are summarized in the economic impact section of Table 4.1. Table 4.2 provides a breakdown of estimated direct, indirect, and induced effects. We estimate the total impact on North Carolina's economy at $135 million over ten years, an average of $13.51 million per year. We estimate that CERSP has generated $33.5 million in additional income for North Carolina workers and business owners over ten years, an average of $3.35 million per year. These estimates are consistent with the creation of sixty-six person-jobs over the course of the center's existence.

These results represent a significant impact on the state, with the start-up company Liquidia providing the largest share. Due to the region's strong presence in biotechnology and medical product development, the center's activities (including Liquidia) have produced significant economic synergies along these supply and value chains, producing a multiplier of 1.7. A recent review of 138 university economic development studies found that they used multipliers ranging from 1.34 to 2.54, with a median of 1.7 (Siegfried, Sanderson, &
McHenry, 2007). In practice this means that for every dollar invested into the state's economy by the center's activities, IMPLAN's calculations estimate that those activities yield another 1.7 dollars in return. This analysis indicates a significant and positive impact on the state's economy.

In performing this analysis, we encountered several limitations. First, the static nature of the software's modeling introduces a certain level of uncertainty into our efforts to address a dynamic, inherently temporal economic process covering ten years using a single-year model. Second, the difficulty in translating the additional events specified above (licensing, research networking, educational programs, etc.) into concrete investment values or jobs created ensured that while the analysis captures a majority of the center's economic impact, it does not capture everything. Taken together, these limitations introduce a degree of uncertainty into our results. Even those events we can model successfully involve the significant application of assumptions.

More sophisticated economic impact analysts will doubtless point out that we could potentially avoid these shortcomings with refinements to our existing model, the use of more advanced software or the use of a different assessment technique altogether. Indeed, Drucker and Goldstein (2007) provide four refinements to the economic impact modeling of university research activities, noting that each requires subjectivity. It is indeed paradoxical that economic impact models require very subjective assumptions that undermine the motivation for comparable, objective metrics in the first place. If the quest for clearly defined outcomes is intended to replace subjectivity with concrete, comparable metrics, then by their very nature, economic impact assessments cannot provide them. Moreover, the incentives to demonstrate the largest economic impacts allow for overly optimistic assumptions.

TECHNOLOGY AND KNOWLEDGE METRICS

In addition to quantifying the economic impact of a project, there are a number of other outcomes that are simply unaccounted for in an economic impact analysis. Thus, we additionally quantify the center's contributions in terms of technology and knowledge for industrial development, future university research, and science education. As Laursen and Salter (2004) highlight in their paper on university influences on industrial innovation, many studies are finding a deepening relationship between university basic research and industrial development, which is not exclusively attributable to an economic relationship. Using the Carnegie Mellon Survey of 1,500 R&D managers representing multiple sectors, Cohen and his colleagues (1998) found that university research contributes to industrial R&D by producing new ideas for research projects, facilitating the execution of existing R&D projects, and serving as a source of information for competitors, thus stimulating further research. Quantifying this relationship in a comprehensive way, however, presents quite a challenge. Patents, publications, citations, university-initiated start-ups, and licenses are among the most common metrics used to quantify basic research output. While these are relatively straightforward to compute, many scholars argue that they do not accurately capture the total knowledge or technology gained from research. A number of more recent studies on the impact of university research on industry have examined additional factors: informal information exchange, public meetings and conferences, recently hired graduates, joint or cooperative ventures, contract research, consulting, and temporary personnel exchanges (Cohen, Nelson, & Walsh, 2002; Agrawal & Henderson, 2002; Agrawal, 2001; Salter & Martin, 2001). While it is easy to quantify metrics such as the number of recently hired graduates, it is more difficult to evaluate other metrics, such as identifying and evaluating the nature of informal information exchanges. We use a combination of these research measures to provide a comprehensive analysis of impact.

The center has an ambitious vision focused on enabling a revolution in sustainable technology by integrating interdisciplinary and translational research practices. While analyzing some of these outputs presents empirical challenges, it is nonetheless critical to consider the multiple dimensions to provide a comprehensive assessment of the research project.

Patents, university-initiated start-ups, and licenses are among the most prominent metrics used for directly measuring technology transfer between the university and industry (Jaffe, 1989; Henderson, Jaffe, & Trajtenberg, 1998; Jensen & Thursby, 1998; Mowery et al., 2001). Over its ten-year lifespan, CERSP produced ninety
patents and patent applications, fourteen technology licenses, and eight startup firms. While these values do not exhaustively account for the total technological contributions made by the center, these data suggest that the center has been extremely active and has made considerable contributions to industry.

In addition to these technology transfer channels, there are other more indirect channels that facilitate knowledge transfer between the university and industry. These measures are presented in the research outcomes section of Table 4.1. Knowledge and technology transfer measures both suggest that contributions to the academic community and to industry are substantial. The exact nature of these contributions, however, is difficult to determine. For example, while affiliates of CERSP may have presented at more than 750 conferences, we are unable to determine the extent to which those presentations have directly influenced subsequent university research and/or industrial development. Although bibliometric analyses that measure the quality of knowledge outputs are well established within the literature (Wagner et al., 2011), we did not have access to these data for this analysis. Despite the challenge of measuring the precise impact associated with these various knowledge channels, the data nonetheless reflect a significant degree of output produced by the center.

PUBLIC BENEFITS

While many studies (Neal, Smith, & McCormick, 2008) include economic impact assessments, research metrics, or some combination of the two, surprisingly few have addressed public benefit as an outcome (Sarewitz, 1996). In his highly influential report, which served as the impetus for the creation of the National Science Foundation, Bush (1945) highlighted the critical link between basic research and public welfare. Although the path may be circuitous, Bush argued that basic research provides the foundation for applied research, which in turn leads to the development of products and, more importantly, to public benefit. Scholars and policy officials, however, have struggled over defining metrics to account for public benefit. Even though they have not been able to devise a comprehensive methodological toolkit for evaluating this outcome, its importance should not be understated. In light of this obstacle, the common practice used to capture this outcome often takes the form of anecdotes and individual case studies that highlight the impact of a certain scientific discovery. As a step toward developing a framework for evaluating public benefit, we broadly define the public benefit to include widespread educational, cultural, or societal factors. We would be naive to assume that each of these public benefit factors takes on a definitive form; thus, we use this construct as a guiding tool for recognizing these contributions as we evaluate outcomes.

Much of this discussion has focused on CERSP’s contributions to industry and the greater academic research community. However, CERSP has also had an educational impact through improvements in K–12 science teaching, science outreach programs, and higher education. These impacts are summarized in the public benefit section of Table 4.1. CERSP has improved K–12 education in North Carolina, Georgia, and Texas. For example, as a result of the serendipitous adoption of a requirement for all North Carolina schools to teach environmental science, CERSP developed environmental science laboratory workbooks that have been widely disseminated to more than 1.2 million seventh through twelfth grade students. The CERSP research team was also able to provide materials for teacher training. Since that time, over 4,100 teachers have participated in CERSP workshops and received certification. More than seven thousand additional teachers are estimated to have used the CERSP workbooks. All of these numbers reflect calculations as of 2009; however, it is likely that these numbers will continue to grow. While these data do not provide a comprehensive account of the total impact that this center has had on secondary education, they do suggest that the program has made considerable contributions both to scientific pedagogy and to the next generation of scientists and researchers.

Moreover, more than two hundred university students were involved in K–12 outreach activities and viewed these activities as a major benefit of participating in the center’s programs (DeSimone and Roberts, 2009). Not only did they view this activity as a critical social responsibility, but they also found the challenge of explaining complex concepts to fifth graders to be exceptionally valuable.

CERSP has also made significant contributions to education programs for UNC, NC State, University of Texas at Austin, Georgia Institute of Technology, and North Carolina A&T State University, including scholarship support at all levels of higher education. Thirty
that investment in the ten-year, interdisciplinary, multimillion dollar, multi-university center was more effective and productive for CERSP than a comparable investment in multiple smaller NSF centers or in standard awards. The rest of this section explores this notion in greater detail by considering two scenarios: (1) one STC center versus multiple smaller projects; and (2) a flexible program versus a more structured research program.

One STC Center vs. Multiple NSF Projects

While one might presume that $36 M invested in an STC produces a similar level of output as investment in multiple projects, say, twelve $3M awards (totaling $36M); we suggest that this is not the case. We argue that one large center is able to optimize its productivity to a greater degree than can the aggregate of multiple projects. In essence, the total is greater than the sum of its parts. Given that researchers affiliated with one large center are not subject to the same financial and time constraints as those affiliated with smaller and limited duration projects, they are able to focus more of their efforts on the actual research project. Researchers affiliated with shorter-term projects, on the other hand, are subject to the pressures of securing future funding, which consumes considerable time and resources and serves as a distraction from the active project.

Thought Experiment 1: Alternative NSF Funding Sources

To highlight this point, we compare CERSP, an MPS (NSF Directorate for Mathematics and Physical Sciences) STC, with other NSF programs that support similar fields of research. In particular, we consider the following programs: standard awards in the chemistry division, Phase I Centers for Chemical Innovation (CCI), and Nanoscale Science and Engineering Centers (NSEC). Table 4.3 highlights the average time span and funding allocations for all chemistry awards made in 2008, all active CCIIs and NSECs, and CERSP. While all of these programs support basic research in the physical sciences, specifically chemistry and nanotechnology, these data illustrate the wide variety of MPS programmatic support in terms of funding expenditures and project lengths.
Table 4.3: Comparison of NSF Chemistry Grants

<table>
<thead>
<tr>
<th>Program</th>
<th>Time span</th>
<th>Annual allocation ($)</th>
<th>Total allocation ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry standard awards (FY08)</td>
<td>3.1 years</td>
<td>$1,450,000</td>
<td>$4,495,000</td>
</tr>
<tr>
<td>CCI (Phase I)</td>
<td>3 years</td>
<td>$486,000</td>
<td>$1,460,000</td>
</tr>
<tr>
<td>NSEC</td>
<td>5 years</td>
<td>$2,387,000</td>
<td>$11,540,000</td>
</tr>
<tr>
<td>CERSP (STC)</td>
<td>10 years</td>
<td>$3,612,000</td>
<td>$36,117,733</td>
</tr>
</tbody>
</table>

The data for CCI (Phase I) and NSEC awards were compiled from the NSF award search database: http://www.nsf.gov/awardsearch/. The data on the Chemistry standard awards was retrieved from AAAS Report (XXXIII).

As already noted, in 1999 UNC, NCSU, University of Texas Austin, Georgia Tech, and North Carolina A&T State University were jointly awarded a ten-year grant of $36,117,733 to support CERSP. How might things have been different if that same amount of money was awarded as multiple chemistry standard grants, CCIs, or NSECs? In that case, the university would have been awarded approximately eighty standard awards, twenty-five CCIs, or three NSECs (Table 4.4, Column I). The cumulative time spent drafting eighty, twenty-five, or even three proposals far outweigh the time spent drafting one proposal for the STC. Thus, if the university had received the same amount of funding for multiple projects, greater administrative time would have been devoted to drafting and submitting proposals, rather than in conducting the research. Compared to the eighty different standard projects that might have been awarded, CERSP was in fact able to fund 139 separate projects with roughly forty active on an annual basis. This far exceeds the amount of research that would have been conducted via the standard grant mechanism and is partially reflective of time not wasted in securing additional funding.

Thought Experiment 2: Funding Success Rates

What if the same group of CERSP investigators conducted research through one of the other three avenues? Over the course of ten years, at best the investigators would only be able to conduct research for three standard awards, three CCIs, or two NSECs (Table 4.4, Column II). As noted above, in each of these scenarios, the researchers would have needed to spend additional time drafting proposals for funds that would not come close to the $36M allocated for the STC. Furthermore, with the funding rate as low as 26 percent (Scott & Smith, 2008), the chances that the same researcher could secure constant support over the course of a ten-year period are slim. CERSP’s NSF funding expired in 2010, however, the center’s investigators were able to secure more than $430M in supplemental funds for the continuation of various projects that began under the STC grant. While we make no claims regarding the ideal length of time needed to conduct research and secure additional funding, we do suggest that the ten-year period allowed the investigators sufficient time to focus on conducting research and producing results, which helped them secure future funds. We suggest that three to five years would not have been sufficient for the investigators to conduct the research and sustain the project.

Thought Experiment 3: Time to Conduct Research under Multiple Programs

On another note, what if the same group of researchers conducted $36M worth of research through these three different programs? Considering the time-span data in Table 4.4, Column III, it would take the research team 250 years to conduct $36M worth of research via standard grants, seventy-five years via CCI, or sixteen years via NSECs. Only the third scenario is plausible, and even in this case it would take an additional six years to conduct research with the same level of investment. These numbers highlight the large scale of CERSP and the limits of securing this level of funding through other NSF programmatic avenues.

Basic research clearly takes a variety of forms, ranging from lab-based experiments to computer-simulated analyses, and these different projects require various modes of support. For a multi-university, interdisciplinary, physical science center, however, we suggest that the ten-year $36M allocation was much more effective than other possible modes of funding available through the MPS Directorate. STCs are surely not optimal programs for all avenues of basic research, but we argue that CERSP’s productivity was optimized through being funded as an STC.
Table 4.4. Comparison of NSF Chemistry Programs (II)

<table>
<thead>
<tr>
<th>Program</th>
<th>(I) No. of awards &gt; $36M</th>
<th>(II) No. of projects completed in ten year period</th>
<th>(III) No. of years for one research team to conduct $36M worth of research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry standard awards (FY08)</td>
<td>80</td>
<td>3</td>
<td>250</td>
</tr>
<tr>
<td>CCI (Phase I)</td>
<td>25</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>NSEC</td>
<td>3</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>CERSP (STC)</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Research Program: Flexible vs. More Structured

CERSP’s overarching aims to revolutionize sustainable technology and support multidisciplinary fundamental research for broad societal benefit remained integral components of CERSP, the center’s objective, goals, domains, and/or performance measures evolved over the decade and reflected a number of significant shifts in the investigators’ research directions. CERSP benefited from its unique structure as an STC through a greater degree of flexibility compared with other more structured and inflexible programs. Moreover, we suggest that the ten-year, multi-university, multidisciplinary center afforded the participating universities a research environment conducive to significant and surprisingly unexpected returns. We explore this in greater detail by highlighting the evolution of the research objectives over the tenure of the center and by noting the subsequent shifts in the internal funding allocations.

In 1999, CERSP focused 100 percent of its research efforts on fundamentals and microelectronics related to CO₂ processes. As noted in their final 2009 report, this trend of research continued over the first few years of the project when the investigators focused much of their attention on surfactants, polymerization, and reaction kinetics and mechanisms in both continuous and batch regimes. They predicted that this research would lead toward improved techniques in the fermentation processes and possible transformative discoveries in biotechnology. By 2004, however, they realized that industry giants were too heavily invested in existing technologies to support the revolutionary research to which CERSP aspired. Even if the CO₂ processes continued to evolve from the research, the underlying technology and existing manufacturing facilities were too firmly embedded to allow for much change (CERSP final report, 2009). Thus, in 2005 with the approval of NSF, CERSP broadened its research from microelectronics to include CO₂-related areas on nanostructures. Figure 4.1 highlights this shift in research focus by tracing the number of new, active, and total projects over the ten-year period. In 2005, we notice a significant shift in the number of new projects, which reflects a redirection of research from fundamentals and microelectronics toward nanotechnology. Furthermore, Figure 4.2 illustrates the distribution of funds by project over the formative, transition, and legacy phases of the project. Research on fundamentals and microelectronics was a priority for the first half of the project. However, the redistribution of funds toward energy and nanotechnology reflects a substantial shift in research priorities for the second half. By refocusing their efforts on freeing nanostructures from silicon wafers, the investigators were able to cultivate new industrial affiliations and become more active in entrepreneurial activities. Given the inherent time lag in realizing benefits from academic work, the benefits of the center’s research is likely to be realized only in the coming years (Mansfield, 1998).

Had CERSP not had the flexibility to evolve and redirect its research over the span of the project, we suggest that its contributions would have been significantly curtailed. The unique structure of a multi-university interdisciplinary research environment afforded CERSP’s investigators a fortuitous environment to explore new avenues of research. If the center had been more narrowly focused on one specific discipline or field, or if the length of the project had been limited to the standard three to five years, we suggest that these discoveries in nanostructures would not have been realized.

This shift in research focus illustrates that the investigators were able to adhere to the strategic plan yet remain flexible in its implementation. As the investigators noted in their final report, the ultimate distribution of funds and research priorities were not what they had envisioned. Although they did not originally anticipate this shift in research, they describe a cross-disciplinary migration of technology that may have contributed to greater creativity and productivity. We argue that less significant advances would have been made had the research been conducted through a more structured program, namely, one that was either shorter in length or more restricted by
a certain field of research. It was the unique structure of the STC that allowed considerable new discoveries and technology to come to fruition.

CONCLUSIONS

Economic impact assessments frequently use input-output analyses to derive the estimated impacts of specified economic events. This technique examines the repeated rounds of spending among industries, households, and government that result from a specified event within a study region considering direct, indirect, and induced effects.

Limitations include reliance on a host of embedded subjective assumptions and a tendency to characterize distributional effects as productivity gains. While more sophisticated input-output models might overcome these techniques, we would continue to produce answers that may disguise complex assumptions under a simplistic veneer of objectivity. If the quest for clearly defined outcomes is intended to replace subjectivity with concrete, comparable metrics, then even the most sophisticated economic impact assessments fail to deliver.

We therefore propose a broader array of metrics to measure the impacts of complex interdisciplinary research. Research outcome measures, augmented by emerging bibliometric, social network, and geospatial analysis techniques, will continue to play an important role in the assessment of these projects. However, we argue for advancing the boundaries of assessment farther into the realm of public benefit to encompass holistically the full impact of research in social, cultural educational progress.

ACKNOWLEDGMENTS

This material is based upon work supported by the Science and Technology Centers (STC) Program of the National Science Foundation under Agreement No. CHE-9876674. Additional funding was provided by the U.S. National Science Foundation SciSIP 0947814. Authors are at the University of North Carolina, Chapel Hill, and are listed alphabetically. The authors acknowledge Jennifer Miller’s research assistance.

NOTES

1. Direct effects represent the changes for a given industry resulting from the increase in final demand for that same industry on, for example, payroll; indirect effects include the impacts on all local industries resulting from industries purchasing from industries
in multiple iterations as a consequence of this increase in final demand; and induced effects result from the increases in spending by households that were caused by both the direct and indirect effects. The total effect of the new investments from the proposed projects is represented by the sum of all three of these effects.

2. $145M in additional research funds leveraged by principal investigators (see Table 4.1) are not included in this analysis.

REFERENCES


