

The Creative Enterprise

Managing Innovative
Organizations and People

STRATEGY

VOLUME 1

Edited by
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and
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Praeger Perspectives

PRAEGER

**Westport, Connecticut
London**

Library of Congress Cataloging-in-Publication Data

The creative enterprise : managing innovative organizations and people / edited by Tony Davila, Marc J. Epstein, and Robert Shelton.

p. cm.

Includes bibliographical references and index.

ISBN 0-275-98685-3 (set : alk. paper) — ISBN 0-275-98686-1 (vol. 1 : alk. paper) — ISBN 0-275-98687-X (vol. 2 : alk. paper) — ISBN 0-275-98688-8 (vol. 3 : alk. paper)

1. Organizational change—Management. 2. Technological innovations—Management. 3. Creative ability in business—Management. 4. Industrial management. I. Davila, Tony. II. Epstein, Marc J. III. Shelton, Robert D.

HD58.8.C727 2007

658.4'063—dc22 2006030628

British Library Cataloguing in Publication Data is available.

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Library of Congress Catalog Card Number: 2006030628

ISBN: 0-275-98685-3 (set)

0-275-98686-1 (vol. 1)

0-275-98687-X (vol. 2)

0-275-98688-8 (vol. 3)

First published in 2007

Praeger Publishers, 88 Post Road West, Westport, CT 06881

An imprint of Greenwood Publishing Group, Inc.

www.praeger.com

Printed in the United States of America



The paper used in this book complies with the Permanent Paper Standard issued by the National Information Standards Organization (Z39.48-1984).

10 9 8 7 6 5 4 3 2 1

The Pipeline from University Laboratory to New Commercial Product: An Organizational Framework Regarding Technology Commercialization in Multidisciplinary Research Centers

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In the twenty-five years since the Bayh-Dole Act of 1980, commercialization of academic research has increased significantly (Graff, Heiman, and Zilberman 2002). As a result, academic research has become more intertwined with industry. Participation by industry ranges from sponsoring specific research projects to affiliate membership in research centers such as National Science Foundation (NSF)-funded Engineering Research Centers (ERCs). Indeed, many government-funded research initiatives, such as the ERC program, are founded on the premise that multidisciplinary university and industry collaboration will enhance research productivity and foster technological advances that otherwise would not be possible.

Despite the success of the United States government's science and engineering funding initiatives, a topic that remains poorly understood is the interface between universities and industry. Often, industry leaders misunderstand how to work with universities, which, relative to for-profit companies, operate on longer timelines and can have vastly different organizational cultures, norms, and incentives. Likewise, university researchers often struggle to understand

This material is based upon work supported by the National Science Foundation under Grant No. EEC-0345195. We thank Lynn Preston and Linda Parker of the National Science Foundation for support and guidance of this research. We wish to thank Mary Sommers Pyne and Timmie Wang at the Rice Alliance for Technology and Entrepreneurship at Rice University for their assistance.

the needs of industry and the benefits corporations expect to receive from partnerships involving technology transfer (Steenhuis and Gray 2005; Thursby and Thursby 2003).

Technology transfer refers to a broad category of activities involving the translation of academic science and engineering discoveries into information that can be used by for-profit or nonprofit organizations. This may include non-commercial activities such as information dissemination through publications or research seminars. We refer to technology commercialization as the transformation of science or engineering discoveries into intellectual property, which then serves as the basis for creating new commercial products and processes (Dudley and Rood 1989). The technology commercialization concept encompasses the full process (i.e., “pipeline”) of commercial activities, including invention disclosures, patent filings, licensing, and/or formation of spin-off companies.

The purpose of this chapter is to explicate the technology commercialization pipeline occurring inside multidisciplinary university research centers. The chapter is intended for two audiences. First, technology commercialization scholars can use our analysis of ERCs to supplement the field’s knowledge base of the predictors of success in university technology commercialization. Second, the chapter provides insight for leaders of corporate research and development (R&D) programs concerning how to partner with universities to commercialize new technologies.

The chapter is organized into five sections. First, we provide an overview of the NSF ERC program. Next, we describe the qualitative and quantitative data collection process we used. Third, we describe general characteristics of the ERCs, including their structure, history, and organizational functioning. Fourth, we explain organizational sources of heterogeneity concerning how ERCs pursue technology commercialization. We conclude with implications for scholars of university technology transfer and implications for corporate R&D executives.

OVERVIEW OF THE NATIONAL SCIENCE FOUNDATION-FUNDED ENGINEERING RESEARCH CENTER PROGRAM

Academic research centers that involve industrial collaborations and emphasize communication across the boundaries of academic disciplines have emerged as a result of entrepreneurial awareness and a shift to applied research in universities during the past twenty years (Smilor, Dietrich, and Gibson 1993). By 1994, over 1,000 industry-university research centers had been formed in the U.S. (Roessner et al. 1998). In 1985, the National Science Foundation (NSF) launched the Engineering Research Center (ERC) program, which is the flagship scheme for federally funded support of engineering research in American universities. The program’s mission is to foster national well-being and economic competitiveness by promoting university-industry collaboration to maintain and advance the nation’s technological leadership.

The ERC program also focuses on educating students via interdisciplinary research opportunities and close contact with industry (Feller, Ailes, and Roessner 2002). The focus on both basic and applied research as well as their combined educational focus makes the ERC program unique among funding programs by the federal government.

An ERC provides an organizational structure that functions to systematize widely dispersed teams of collaborating researchers (Bozeman and Boardman 2003). The NSF expects an ERC to initiate broad institutional and cultural change in their host universities. Research pursued within the ERC is not simply a compilation of independent research projects; rather, it is a large, coordinated effort. Therefore, research in the ERC requires interactions among multiple disciplines and researchers. Faculty members in ERCs are encouraged to collaborate with other faculty members, disciplines, and industry researchers to accomplish their research goals. Scholars in ERCs also sometimes pursue other forms of professional activity that increase collaborations with industry, such as consulting (Mowery 1998; Smilor, Dietrich, and Gibson 1993).

Impact of ERCs

Currently there are twenty-two active ERCs. Between 1985 and 2002, the NSF funded a total of thirty-seven ERCs. The level of support from the NSF is sizeable; for example, in 2002 (the most recent data summary compiled by the NSF), the NSF allocated over \$60 million to its ERCs (\$2 million to \$3.7 million per year per ERC). Table 5.1 presents a summary of average yearly funding inputs. The first three columns in Table 5.1 provide overall funding statistics for all ERCs and all years, such that each observation is an ERC-year (i.e., ERC #1 in 2001, ERC #1 in 2002, etc.). The remaining columns provide the averages and measures of dispersion for all ERCs during the period of our data collection, namely 2001–2005.

The outputs produced by ERCs have also been substantial. Data from 1985 to 2002 show that ERC researchers produced a total of 10,922 peer-reviewed journal articles and 9,260 peer-reviewed conference proceedings. ERCs also have produced significant intellectual property; 908 inventions were disclosed and 391 patents awarded to ERC researchers. In addition, ERCs have been the origin of ninety spin-off companies that employ 927 persons (*Engineering Research Centers Program Performance Indicators Data* 2002). Table 5.2 presents a summary of average yearly research outputs for the currently active ERCs from 2001 through 2005. As in the first table, the first three columns in Table 5.2 provide overall research output statistics for all ERCs and all years, while the remaining columns provide the averages and standard deviations for all ERCs.

As reflected in the standard deviation statistics in Tables Table 5.1 and Table 5.2, a great deal of heterogeneity, or dispersion, exists among ERCs.

TABLE 5.1. Average ERC Funding Inputs by Funding Source: 2001–2005

| Source of Funding | M <i>all</i> ERCs, <i>all</i> years; N=99* | SD (<i>all</i> ERCs, <i>all</i> years; N=99)* | Min/Max (<i>all</i> ERCs, <i>all</i> years; N=99)* | 2001 M(SD) (N=18) | 2002 M(SD) (N=19) | 2003 M(SD) (N=19) | 2004 M(SD) (N=23) | 2005 M(SD) (N=20) |
|--|--|--|---|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Total Funding Received (All Sources) | \$6,860,830 | \$3,144,802 | \$1,594,328/ \$19,373,405 | \$6,561,499 (\$3,353,263) | \$7,330,731 (\$4,006,959) | \$6,856,865 (\$3,145,618) | \$6,325,762 (\$2,711,211) | \$7,302,916 (\$2,644,913) |
| NSF ERC Program | \$2,899,165 | \$944,740 | \$577,331/ \$5,232,401 | \$2,449,302 (\$714,941) | \$2,953,921 (\$812,311) | \$3,002,693 (\$962,087) | \$2,802,812 (\$979,105) | \$3,264,479 (\$1,084,927) |
| Other NSF Sources | \$133,416 | \$285,632 | \$0/ \$1,162,435 | \$148,136 (\$315,029) | \$166,345 (\$301,924) | \$134,009 (\$299,669) | \$141,537 (\$299,392) | \$78,985 (\$228,694) |
| Industry (US and Foreign) | \$605,788 | \$856,538 | \$0/ \$6,266,183 | \$929,236 (\$1,472,483) | \$724,010 (\$971,422) | \$501,722 (\$516,562) | \$433,293 (\$521,887) | \$499,605 (\$458,467) |
| Federal Government (US and Foreign) | \$305,942 | \$838,053 | \$0/ \$6,984,500 | \$238,750 (\$431,859) | \$589,629 (\$1,637,085) | \$210,281 (\$375,323) | \$199,992 (\$406,262) | \$309,635 (\$696,148) |
| State Government | \$502,082 | \$878,486 | \$0/ \$4,464,225 | \$771,325 (\$1,226,710) | \$566,610 (\$1,122,385) | \$433,617 (\$643,458) | \$371,866 (\$625,650) | \$413,253 (\$699,164) |
| Universities (US and Foreign) | \$1,068,950 | \$1,079,488 | \$0/ \$6,641,388 | \$1,381,213 (\$1,575,616) | \$1,054,778 (\$970,974) | \$932,011 (\$899,545) | \$955,873 (\$880,881) | \$1,061,508 (\$1,050,775) |
| Other | \$42,822 | \$172,016 | \$0/ \$1,300,000 | \$78,996 (\$305,414) | \$63,242 (\$207,338) | \$24,185 (\$100,067) | \$30,415 (\$93,210) | \$22,839 (\$79,228) |

Note: *In the first three columns, the mean and standard deviation were calculated using 99 observations, of which each observation was an ERC-Year (e.g., ERC #1 in 2001 and ERC #1 in 2002 are separate observations).

TABLE 5.2. ERC Technology and Knowledge Transfer Outputs: 2001–2005

| | M (all ERCs, all years; N=99) | SD (all ERCs, all years; N=99) | Min/Max (all ERCs, all years; N=99) | 2001 M(SD) (N=18) | 2002 M (SD) (N=19) | 2003 M(SD) (N=19) | 2004 M(SD) (N=23) | 2005 M(SD) (N=20)* |
|--|-------------------------------------|---|--|----------------------|-----------------------|----------------------|----------------------|-----------------------|
| Research Output | 30.99 | 23.99 | 0/11 | 31.00 (25.23) | 26.63 (17.55) | 30.11 (16.73) | 30.39 (27.48) | 36.65 (30.21) |
| Peer-Reviewed Journal Publications | | | | | | | | |
| Invention Disclosures | 6.45 | 7.84 | 0/33 | 6.78 (8.02) | 6.32 (8.65) | 6.26 (6.86) | 6.83 (7.57) | 6.05 (8.79) |
| Patent Applications | 4.67 | 5.70 | 0/24 | 5.28 (7.19) | 4.32 (7.17) | 4.95 (5.15) | 4.52 (4.76) | 4.35 (4.53) |
| Patents Awarded | 1.37 | 2.38 | 0/11 | 1.06 (2.01) | 1.26 (1.76) | 1.05 (1.93) | 1.22 (2.63) | 2.25 (3.19) |
| Licenses Issued | 2.55 | 6.67 | 0/44 | 2.39 (4.80) | 1.58 (4.45) | 2.37 (3.29) | 2.61 (8.42) | 3.70 (9.75) |
| Spin-off Companies | 0.33 | 0.67 | 0/3 | .39 (.78) | .37 (.76) | .47 (.77) | .22 (.52) | .25 (.55) |
| Spin-off Company Employees | 5.2 | 15.09 | 0/73 | 4.50 (12.49) | 5.0 (15.30) | 7.16 (16.54) | 5.04 (15.86) | 4.35 (16.07) |
| Technical Codes and Standards Impacts | 0.17 | 0.86 | 0/6 | —* | —* | —* | .35 (1.11) | .45 (1.47) |

Note: *At time of publication, we had 2005 data from twenty ERCs of the twenty-two active ERCs, due to reporting time differences. †indicates missing data as a result of changing reporting requirements (i.e., from 2001 to 2003, these values were not reported).

These statistics provide evidence reinforcing our view that ERCs vary widely in the way they organize themselves. These differences may be reflected in varying technological opportunity or general organizational issues; we posit they are due largely to the organizational factors discussed in the third and fourth sections of this chapter. We believe that these organizational factors explain much of the variance in research productivity among ERCs, as well as their commercialization success.

DATA COLLECTION METHODS

Our research is part of a large project funded by the NSF that is aimed at discovering best practices regarding technology commercialization occurring within ERCs. The information we present in this chapter is a result of in-depth qualitative interviews with sixty personnel from the twenty-two existing ERCs, survey data from over 800 personnel, and archival data from ERC annual reports for 2001 through 2005.

We used both quantitative and qualitative data collection methods, which can be interwoven to maximize the knowledge yield (McCall and Bobko 1990) of a research endeavor (Currall et al. 1999). “Typically, ‘qualitative observation’ identifies the presence or absence of something, in contrast to ‘quantitative observation,’ which involves measuring the degree to which some feature is present” (Kirk and Miller 1986). Qualitative methods are particularly well suited for developing a grasp of organizational phenomena where a well-established body of research literature does not exist, as is the case with organizational analyses of ERCs. Accordingly, we utilized a “two-phase” design (Creswell 2002) whereby we used qualitative methods to deepen our understanding of the organizational phenomenon under study, and to develop an accurate conceptualization of how ERCs are organized and how they operate. Subsequently, during the quantitative phase, we made use of the information generated by interviews to develop survey instruments, which were administered in November 2005. Surveys yielded quantitative perceptual and attitudinal data. We will restrict our discussion mainly to our interview and archival data; survey data will be used in our future research.

In-depth interviews with ERC personnel took place in 2005. Between January and May 2005, we visited eleven ERCs and spent at least one hour with several representatives from each ERC, including directors, industrial liaison officers (ILOs), administrative directors, education/outreach officers, and research thrust leaders. Additionally, we also spoke with faculty members and students who did not hold formal leadership positions in their ERC. We followed a semi-structured interviewing process. We used a common pool of questions and varied the order of questions depending on the answers we received and the role held by the interviewee. When granted permission from the interviewee, we recorded interviews and referred to the tape to complete our notes for each interview. Additionally, in most cases, at least two

researchers participated in every interview, with one research assistant attending every interview to maintain comparability across interviews. This procedure resulted in notes from at least two perspectives, in addition to the actual audiotapes. We ensured that our interpretations from each interview were accurate and consistent across the interviewers.

We also conducted phone interviews between January and November 2005, with directors and/or ILOs in each ERC we did not visit. Therefore, using the combination of on-site and phone interviews, we spoke with at least one representative from every ERC. This thorough interview process allowed us to grasp the diversity of the ERCs and the context in which different ERCs operate. Indeed, as we will discuss later, we found that ERCs varied substantially due to different technology foci, geographic locations, and host universities.

Our conceptualization of technology commercialization outcome metrics and antecedents was informed by our qualitative data. We advocate a multifaceted approach for operationalizing commercialization effectiveness (Banner and Gagné 1995). Thus, commercialization effectiveness data were collected in terms of quantitative archival data on the number of technology transfer outputs, including invention disclosures, patent applications, patents awarded, and spin-off companies. Likewise, we took a multidimensional approach to conceptualizing the antecedents of commercialization success and their measures. The antecedents we uncovered during the interviews provided insights into the ways in which ERCs vary in their commercialization practices and success. Organizational variables were the primary determinants we found to explain variation across ERCs. We explicate these variables later in this chapter. First, however, we describe our general observations about characteristics of ERCs and how they function as organizations.

CHARACTERISTICS OF ERCs

Pipeline to Commercialization

Traditionally, academic research was viewed as a linear process, progressing from basic science to applied science to product development (Cohen, Nelson, and Walsh 2002; Croissant, Rhoades, and Slaughter 2001). Universities historically focused on the basic science component. More recently, this viewpoint has shifted as the focus to commercialization has shifted. Universities no longer restrict themselves to basic science. Further, universities now contribute to both sustaining (i.e., incremental) innovations and disruptive innovations (Rice, Leifer, and Colarelli-O'Connor 2002). Therefore, collaboration among university researchers and companies may help companies stay competitive by making incremental improvements to existing products or by leveraging technical discoveries to create completely new products. This is becoming increasingly common as universities contribute to development of new products (Cohen, Nelson, and Walsh 2002; Croissant, Rhoades, and Slaughter 2001).

Throughout their history, ERCs have emphasized both sustaining and disruptive technologies. In recent years, the ERC program management has placed an increasing emphasis on awarding grants to ERCs engaged in “pre-paradigmatic” or “transformational” research. These ERCs attempt to create new science and engineering paradigms, which can result in revolutionary technologies in new or existing industries. In line with NSF terminology, we use the term “pre-paradigmatic” to describe the technology of these ERCs. “Paradigmatic” or “next generation” research centers, on the other hand, build upon existing science and engineering models; they are focused on producing incremental technological improvements to sustain existing product lines and processes. We refer to these as “paradigmatic” technologies. Table 5.3 lists the ERCs, their demographic information, and their technology categorization as pre-paradigmatic or paradigmatic.

ERCs typically restrict themselves to activities designed to prove a technological concept or establish a limited application of the technology. These are two of the three well-defined stages of disruptive technologies (Myers et al. 2002). Proof of concept is the first stage; it shows viability of the research idea. The second stage involves establishing a limited application, which supplies the rationale for the new technology’s use over the conventional approach. This is the stage at which ERCs may push the technology toward commercialization via the university’s Office of Technology Transfer (OTT) or another commercialization avenue. The final stage of technological maturity, widespread commercial application, is not part of the ERC charter.

Extensive further investment must be made to bring an ERC-based technology to a stage that is ready for commercial application. Even if the university is accommodating by lowering the cost of licensure, a company licensing the technology still takes a considerable risk. According to one study, only 12 percent of development projects become commercial products, and two-thirds of those 12 percent succeed (Raine and Beukman 2002). Another study reports that 46 percent of all licensed inventions fail before product development, while 72 percent of inventions licensed at the proof of concept stage fail (Thursby and Thursby 2003).

The risk in licensing new technology is high. Typically, more funding is necessary for the technology before it can succeed as a commercial product. The ERC model does not have a built-in mechanism to advance this transition from immature technology to mature product. This is one explanation for why ERCs have varying levels of success in commercialization. In the next section, we delineate the organizational factors we believe to be central in determining the rate of transition from university research to commercial products. Scholars who study university technology commercialization can use these factors in theorizing about the determinants of commercialization effectiveness. Industry executives and leaders of agencies can use these factors to better enable collaboration and commercialization success.

TABLE 5.3. ERC Technology Descriptions and Categorizations

| ERC | Founding Year | Host University | Technology Area | Pre-Paradigmatic or Paradigmatic Technology |
|--|---------------|---------------------------------------|---|---|
| ERC for Environmentally Benign Semiconductor Manufacturing | 1997 | Univ. of Arizona | Manufacturing and Processing | Paradigmatic |
| ERC for Extreme Ultraviolet Science and Technology | 2004 | Colorado State Univ. | Microelectronic Systems and Information | Pre-Paradigmatic |
| Center for Neuromorphic Systems Engineering | 1995 | California Institute of Technology | Microelectronic Systems and Information | Pre-Paradigmatic |
| Mid-America Earthquake Center | 1998 | Univ. of Illinois | Earthquake Engineering | Paradigmatic |
| The Center for Environmentally Beneficial Catalysis | 2004 | Univ. of Kansas | Manufacturing and Processing | Paradigmatic |
| ERC for Collaborative Adaptive Sensing of the Atmosphere | 2004 | Univ. of Massachusetts | Manufacturing and Processing | Pre-Paradigmatic |
| ERC for Biomimetic MicroElectronic Systems | 2004 | Univ. of Southern California | Bioengineering | Paradigmatic |
| Particle Engineering Research Center | 1995 | Univ. of Florida | Manufacturing and Processing | Paradigmatic |
| Center for Low Cost Electronic Packaging | 1995 | Georgia Institute of Technology | Manufacturing and Processing | Paradigmatic |
| Biotechnology Process Engineering Center | 1995 | Massachusetts Institute of Technology | Bioengineering | Pre-Paradigmatic |

TABLE 5.3 (CONTINUED)

| ERC | Founding Year | Host University | Technology Area | Pre-Paradigmatic or Paradigmatic Technology |
|--|---------------|----------------------------------|---|---|
| ERC for Reconfigurable Manufacturing Systems | 1996 | Univ. of Michigan | Manufacturing and Processing | Paradigmatic |
| Integrated Media Systems Center | 1997 | Univ. of Southern California | Microelectronic Systems and Information | Pre-Paradigmatic |
| Engineered Biomaterials ERC | 1997 | Univ. of Washington | Bioengineering | Pre-Paradigmatic |
| Center for Advanced Engineering Fibers and Films | 1999 | Clemson Univ. | Manufacturing and Processing | Pre-Paradigmatic |
| ERC for Engineering of Living Tissues | 1999 | Georgia Institute of Technology | Bioengineering | Pre-Paradigmatic |
| Center for Computer-Integrated Surgical Systems and Technology | 1999 | Johns Hopkins Univ. | Bioengineering | Pre-Paradigmatic |
| Center for Power Electronics Systems | 1999 | Virginia Institute of Technology | Microelectronic Systems and Information | Paradigmatic |
| Marine Bioproducts Engineering Center | 1998 | Univ. of Hawaii | Bioengineering | Paradigmatic |
| VaNTH ERC for Bioengineering Education Technologies | 2000 | Vanderbilt Univ. | Bioengineering | Pre-Paradigmatic |
| Center for Wireless Integrated MicroSystems | 2001 | Univ. of Michigan | Microelectronic Systems and Information | Paradigmatic |
| Center for Subsurface Sensing and Imaging Systems | 2001 | Northeastern Univ. | Microelectronic Systems and Information | Paradigmatic |

TABLE 5.3 (CONTINUED)

| ERC | Founding Year | Host University | Technology Area | Pre-Paradigmatic or Paradigmatic Technology |
|--|---------------|------------------------------|------------------------|---|
| Pacific Earthquake Engineering Research Center | 1998 | Univ. of California–Berkeley | Earthquake Engineering | Paradigmatic |
| Multidisciplinary Center for Earthquake Engineering Research | 1997 | Univ. at Buffalo | Earthquake Engineering | Paradigmatic |

Strategic Planning

NSF funding of ERCs is typically awarded in approximately two five-year terms, up to a maximum of eleven years. The NSF requires that long-term strategic goals and plans be reevaluated frequently. Additionally, short-term goals and action plans help ERCs achieve their long-term goals. To facilitate this goal setting and strategic planning, the NSF introduced a tool in 1997 called the three-plane framework (see Figure 5.1).

The three-plane framework is used to align long-term and short-term planning and organizational resource allocation. The NSF requires ERCs to use the three-plane framework in all strategic planning activities. It consists of three levels, which represent the advancement of research from basic to applied. The first plane focuses on fundamental, or “basic science.” The NSF expects the majority of ERC research to fall into this category. The middle plane is “enabling technologies.” The research in this plane reflects the middle ground between basic research and commercial products. It brings together basic research outputs and assembles them into components that can be used to form a substantive output. The third plane is the “engineered systems” plane. This plane reflects applied research aimed at developing commercializable products or processes. Engineered systems assemble the research from the lower two planes into technologies that may be commercializable.

ERC research is oriented toward the engineered systems plane. This is fundamentally different from the traditional university research paradigm, which is more driven by curiosity than focused on translational research and engineered system deliverables. Research thrusts (i.e., groups of researchers) inside the ERC are often formed according to the three-plane framework. Sometimes a thrust maps vertically and conducts research in all three planes. Other times, thrusts are horizontal and focus on only one plane. Often,

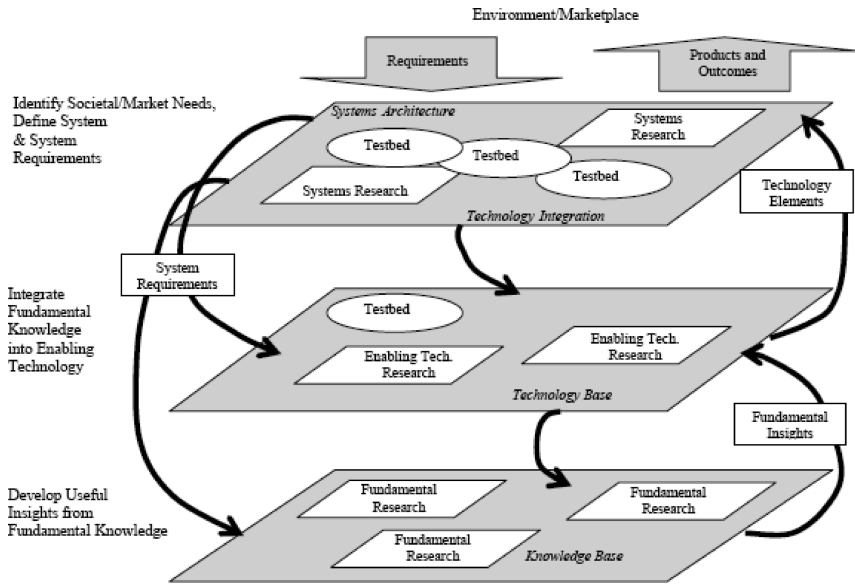


FIGURE 5.1 Three-Plane Framework

testbeds are formed as a mechanism for integrating the work of all the thrusts; testbeds most often reside in the third plane. Although ERCs vary in their implementation and interpretation of NSF mandates, the three-plane framework provides a template to which ERCs generally adhere. The framework has implications for the organizational structure of ERCs.

Organizational Structure

The strategic planning requirement is one aspect of ERCs that makes them operate as more formal organizations than academic departments, which only rarely engage in formal strategic planning. ERCs also have several leadership teams: a core leadership board, an industrial advisory board, and a scientific advisory board. The core leadership board consists of the internal ERC leadership roles: a director, an assistant director, an administrative director, an industry liaison officer (ILO), an education/outreach officer, and two to five research thrust leaders. The director and the research thrust leaders are usually faculty members, while persons with corporate and/or administrative backgrounds often hold the other positions. The industrial and scientific advisory boards are in place to provide input on the direction of research. Most member companies send one representative to serve on the industrial advisory board. This is an important role for industry partners because it allows them to provide input as well as gain access to the latest research knowledge and discoveries. Indeed, companies that maintain close ties report receiving the most benefits from their participation with the ERC (Feller, Ailes, and

Roessner 2002). Finally, the scientific advisory board is made up of key experts in the areas in which an ERC conducts research.

ERCs are hosted by one lead university and partner with several other universities. The administrative function of leadership resides at the lead university. Collaborations are often geographically dispersed around the U.S. The ERC educational programs also focus on diversity and outreach, which encourages collaboration with historically minority-oriented universities. ERCs also give early exposure to elementary- and high school-aged students, in an effort to recruit the next generation of scientists and engineers.

In addition to providing general requirements for the basic organizational structure, the NSF closely oversees the organizational functioning of ERCs. Each year, an NSF review panel visits each ERC for several days to provide feedback on successes and areas requiring improvement. ERCs hold one or more retreats per year to plan for the site visit, engage in strategic planning, and revisit their overall goals. Advisory boards and faculty attend these retreats. The leadership teams and students from every ERC also attend the annual ERC conference in Washington, D.C., hosted by NSF, at which they consult with other ERCs to share best ERC practices and receive from NSF the strategic focus of the overall ERC program for the upcoming year. In addition to the formal gatherings, each ERC holds informal events such as consulting days where lawyers or entrepreneurs provide information on commercialization activities, students present their research to industry representatives, lunches are held to share research progress, and other opportunities are provided for the parties to share information.

In sum, ERCs are organizational entities themselves. They are usually dispersed over large geographic areas and function as virtual research organizations. Because of their unique features, ERCs make ideal candidates for study by organizational researchers, especially in the area of technology commercialization and industry-university collaboration.

Industry Relationships

A hallmark of the ERC program is significant involvement by industry. This is reflected in the following statement regarding the ERC Program management's vision for ERCs: "Thus, ERCs provide the intellectual foundation for industry to collaborate with faculty and students on resolving generic, long-range challenges, producing the knowledge needed to ensure steady advances in technology and speed their transition to the marketplace, while training graduates who are more effective in industry" (*Engineering Education and Centers Division, document 00-137a* 2003). ERCs are similar to other academic research centers funded by the NSF, yet they are unique because of their focus on development of engineered systems rather than solely on basic research. They are also unique in their focus on collaboration with multiple disciplines, universities, and industrial partners.

Feller and colleagues (Feller, Ailes, and Roessner 2002; Feller and Roessner 1995; Roessner et al. 1998) have extensively studied the industry partner perspective in ERCs. They have found that industry receives many benefits from participation in ERCs, especially when they are closely engaged and maintain frequent contact. Perhaps surprisingly, partner firms do not place the greatest value on the acquisition of intellectual property but, rather, place most value on the knowledge transfer outputs from an ERC in the form of students graduating and access to cutting-edge science. One interviewee attributed this to the fact that, if the university maintains intellectual property rights, then no other competitor can own it, and the university can fight the battle of ownership with others instead of the industry partner fighting that same battle with its competitors.

From the industry perspective, the benefits of an affiliation with an ERC are made possible because substantial NSF funding helps establish a successful research infrastructure without requiring large investments from industry. The research infrastructure brings key faculty together and provides a forum for collaboration on a common integrative theme that spans departments, disciplines, and institutions. Because of these benefits, companies often pay membership dues and participate without requiring detailed economic justification for their participation. Most feel they receive many benefits, but those benefits are not easy to translate into bottom-line figures; often they are intangible and hard to quantify (Feller, Ailes, and Roessner 2002).

Herein lies a significant challenge for ERC sustainability after the NSF funding ends. When government funding ends, ERCs often look to industry for financial sustainability. However, because industry cannot easily quantify the payoffs of their participation, they may not invest more than nominal fees in an ERC. Sponsored research is easier to justify because it is tied to a specific deliverable. But sponsored research income alone cannot fund an ERC and the overhead associated with it. Indeed, membership dues for an ERC are unlikely to financially sustain an ERC. Therefore, Feller and colleagues argue that the ERC is a financially fragile organization because, without continued government support, it cannot maintain its industry partnering model and success (Feller, Ailes, and Roessner 2002).

In our examination of ERCs, we uncovered this pattern, which may reflect the lack of sustainability know-how on the part of government leaders. Some ERCs have begun demonstrating success at self-sufficiency, but the current ERC model itself is not conducive to successful sustainability through industry funding. This is one of the biggest topics of concern among ERC personnel today. Our research indicates that the most successful ERCs tend to view themselves as start-up companies or enterprises. However, often ERC leaders have academic roots, not entrepreneurial roots, which make them unfamiliar with managing the ERC as an enterprise. The NSF paradigm for sustainability advocates income from government, university, and industry sources. The government's emphasis on industry funding, however, is often overly optimistic. Another perspective

worthy of consideration is the inclusion of endowments (private donors) as a category of financial support for ERCs. Adding private donors to the list of possible funding sources is a promising possibility. Overall, it seems that the ERC organization may indeed be fragile when the time comes for financial self-sustainability.

ORGANIZATIONAL FACTORS IMPACTING COMMERCIALIZATION OF UNIVERSITY TECHNOLOGIES

In this section, we use preliminary findings from our study of ERCs to shed light on sources of heterogeneity across ERCs with respect to technology commercialization.

Organizational Porosity

Porosity describes the flow of resources (information, people) across organizational boundaries. A research organization can be porous in two ways: intraorganizational porosity and extraorganizational porosity. Intra-ERC porosity is the collaboration that occurs within the ERC, among individual investigators and research teams, and across academic disciplines. Many people we interviewed emphasized the importance of *interdependent* research teams in collaboration across these boundaries. Also mentioned was the important role of testbeds in integrating research teams toward a common goal, which therefore facilitates collaboration. A higher level of collaboration appears to encourage more commercialization productivity because of the ability to tackle complicated applied problems that require input from various research thrusts and different academic disciplines.

Extra-ERC porosity involves the collaboration and communication between the ERC and its affiliates, such as its industry partners and other universities. Again, the importance of frequent communication with industry partners was emphasized throughout our interviews. More interaction between the ERC and the industry appears to lead to more commercialization productivity because of input about market demand from industry experts or entrepreneurs (Feller, Ailes, and Roessner 2002).

An important antecedent of intra- and extra-ERC porosity is the level of trust among the parties. Indeed, trust has been suggested as an important indicator of the degree to which universities commercialize technology (Gopalakrishnan and Santoro 2004). Intra-ERC trust involves trust among researchers, within and across research teams and across the boundaries of traditional academic disciplines. Extra-ERC trust reflects the level of trust ERC personnel have with industry partners, and vice versa. In the ERC context, increased trust likely leads to more porosity because of enhanced information flow, more cooperative contractual agreements, and decreased transaction costs (Inkpen and Currall 2004), all of which are expected to lead to more commercialization activity.

We view porosity as a central consideration when analyzing commercialization effectiveness. By the nature of collaboration, a high level of communication is required among researchers and between industry and universities. Therefore, trust formation must be an important requirement in enhancing collaboration. From our interview results, we believe that ERCs that have high levels of communication and collaboration across boundaries are most successful in terms of shorter commercialization timelines and success in commercialization activities.

ERCs' Managerial Structure

Managerial structure is defined by three facets: hierarchical levels, centralization, and formalization. Some authors posit that because technological innovations must start with those people with technical competency, technology commercialization occurs most successfully when a research organization is organic (i.e., flatter structure, decentralized, and informal). Yet, the question of structure is complex because the mere existence of a multi-disciplinary research center such as an ERC demands a certain degree of centralization, formalization, and hierarchy (Bozeman and Boardman 2003).

Bozeman and Boardman (2003) make several recommendations for organizing research centers, such as aligning reporting lines to the unique culture of the university, delineating responsibilities between an administrative director and research director, fostering creative competition by offering seed money for promising grant proposals, and cultivating center-wide relationships through gatherings and communications that include faculty and industrial partners. These efforts can be challenging to implement when a research center attempts to partner with multiple universities, especially when they involve the work of researchers who have little visibility with their respective university leaders. Leadership buy-in from all universities involved is very important; this may be harder to achieve if organizational structures and processes are mismatched among the universities and the ERC.

ERCs unavoidably introduce some degree of bureaucracy. In our interviews, many faculty members complained about the administrative burdens of ERC involvement. However, most acknowledged that the benefits of involvement in an ERC outweigh the burdens. Nevertheless, it is important to recognize the added pressures ERC researchers must endure to pursue ERC-related research. To foster first-rate academic research, as well as technology commercialization activities, ERC leaders must minimize the administrative load experienced by ERC faculty members.

Reputation of an ERC's Host University

ERCs based in universities with favorable reputations are more likely to commercialize successfully and more frequently. This may be because industrial

partners gravitate toward relationships with universities perceived to produce relevant research for markets (Bradshaw, Munroe, and Westwind 2005; Di Gregorio and Shane 2003; Sine, Shane, and Di Gregorio 2003; Stuart 2000). Further, universities with strong reputations attract faculty with successful track records in cutting-edge research and industry collaboration. Often these faculty members secure industry contacts that greatly benefit the ERC. Therefore, both the university's reputation and the reputation of its faculty members mutually reinforce an ERC's ability to succeed with commercialization efforts.

Commercialization Infrastructure of an ERC's Host University

Support systems are an important aspect of commercialization activity. Reasonable patent protection, ownership, and licensing policies are crucial to success in commercialization (Gopalakrishnan and Santoro 2004). Office of Technology Transfer (OTT) policies should encourage commercialization by reducing risk to the licensing companies and reducing risk to the inventors. The ILO role is a featured role in ERCs that gives further infrastructure support to faculty interested in commercializing. The ILO acts as an important boundary person who can negotiate relationships between universities and industry, as well as personally market technologies to company contacts. The ILO also may act as a liaison to the OTT to ease the burden of the commercialization process on faculty. We found that ERCs with active, marketing-oriented ILOs tended to be more successful than ERCs whose ILOs focused primarily on industrial membership recruitment and partnering. Moreover, if the ILO is successful, his or her work can further drive the entrepreneurial culture that supports commercialization (Kassicieh, Radosevich, and Umbarger 1996).

In addition to the industrial liaisons provided by the ERCs, our interviews uncovered other features of ERCs that encourage translation of research into commercialized technologies such as dedicated support staffs, state-of-the-art research facilities, and access to dedicated office equipment. One interviewee called this a "universe of support" and suggested that it is vital to achieving commercialization success.

Industry Targets and Technology Area

The commercialization process differs across industries. Some industries include companies that are more receptive to university technologies (Hanson 1995). Prototypes are required before companies consider licensing; yet in certain industries, such as the life sciences, it takes longer to develop a product for testing (Hsu and Bernstein 1997). Further, life sciences are an example of an industry that must surpass regulatory hurdles before commercialization can occur. Nevertheless, the life sciences are a source of sizeable commercialization activity, accounting for up to two-thirds of total patent activity (Fisher

and Atkinson-Grosjean, 2002; Mowery 1998). Companies in the semiconductor and electronics industries also are very active in commercialization (Mowery 1998). The upshot is that if an ERC is involved in an industry with high commercialization rates, the ERC is expected to have more commercialization success.

In addition to the type of industry and technological focus, other industry factors were discovered in our interviews. Many respondents mentioned the need to manage expectations with industry, and most mentioned the clash of timelines between industry and university research. Other interviewees mentioned the need to maintain close contact with industry in order to receive timely feedback and input; this maintains the commercial relevance of university research. But most ERC personnel also mentioned that restricting industry partners to an advisory role, and not a management role, is a key condition to making collaboration successful.

Many respondents emphasized the concern that ERCs can truly only be the “R” in R&D. In other words, ERCs are only equipped (i.e., in regard to funding, facilities, researchers, timelines, etc.) to do the initial research on technology, but not actual product development. The testbeds of the ERCs seem to be the best place for optimal collaboration, because they conduct applied aspects of the research. Therefore, many interviewees said that a match between the testbeds and the interests of industrial companies leads to successful collaboration. Finally, many interviewees asserted that corporations need to learn how to work with universities and that ERCs need to learn how to work with corporations. This goes back to a fundamental premise of this chapter: an understanding of the interface between industry and university must be achieved to increase commercialization and collaboration success.

In summary, we have observed several antecedents to commercialization effectiveness. We believe that porosity of organizational culture, managerial structure, university reputation, university infrastructure, and industry/technology area are important when explaining commercialization heterogeneity across ERCs. In the next section, we apply these observations to universities more broadly to contribute to scholarly discourse regarding the factors that make universities successful in commercialization. An increased understanding of these issues also will facilitate improved corporate-university collaborations.

IMPLICATIONS FOR TECHNOLOGY TRANSFER SCHOLARS AND CORPORATIONS

ERCs provide an intriguing context in which to study university technology commercialization. They are enterprising and industry-focused; therefore, they reflect trends in many universities toward greater entrepreneurial activity. We have inductively explored the organizational functioning of ERCs, as a specific example of how universities engage in technology commercialization. Our initial findings indicate that heterogeneity exists across ERCs with regard to technology commercialization practices and organizational functioning.

Scholars interested in university-industry technology commercialization can use the variables we uncovered in exploring technology commercialization heterogeneity across ERCs to develop new conceptual models of university technology commercialization. Further, ERCs hold many interesting opportunities for learning about universities, especially entrepreneurial universities, which are committed to technology transfer. The technology commercialization focus of ERCs will be interesting to scholars who study technology transfer because the data available is vast and the record keeping is unsurpassed in other types of academic research organization.

As always, causation is difficult to determine without a complex, controlled, longitudinal study design. Even then, it is often difficult to disentangle cause and effect of organizational phenomena. For instance, do our organizational variables invariably cause technology commercialization, or could the relationship be bi-directional? Although we have made extensive use of longitudinal qualitative and quantitative data, we cannot conclude with certainty the direction of relationships discussed here. These concerns are valid, and we acknowledge this limitation of the present study, especially in these preliminary findings.

Individuals in companies that collaborate with universities should assess where a university falls on the spectrum of each of the organizational variables we discussed above. How encouraging is the university toward faculty members commercializing their research outputs? How bureaucratic, hierarchical, and centralized is the university and/or academic department hosting the research efforts? Is it organic and flexible, allowing the researchers to collaborate freely? What resources are provided in the way of commercialization support, and what policies are in place in the university's OTT? How open are the communication lines between the university and its industry partners? These are important questions to ask about a university with which a company aims to collaborate.

Answers to these questions will assist company executives in understanding barriers and concerns of the university. Partnerships must be positioned in terms of long-term research benefits for the university (e.g., sponsored research funding and access to industry experts), which may motivate the university to relax the terms of licensing demands. If an industrial liaison exists, they can serve as boundary communicators because they understand both university and industry concerns. Therefore, it may be advisable for companies to initiate contact with ILOs rather than university technology transfer professionals or individual faculty members.

Scholars and industry leaders alike can learn from the findings presented in this chapter in regard to how universities participate in technology commercialization. The preliminary findings on ERCs that we presented in this chapter are intended to help scholars better explore commercialization success in universities. We hope that lessons learned from our study of ERCs are useful to industrial R&D executives in building effective commercial relationships with multidisciplinary academic research centers.

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