University-Industry Research Centers

in the United States

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Executive Summary

University-industry research centers (UIRCs) have attracted considerable attention over the past two decades. In the 1970s and 1980s, the federal and state governments established programs to stimulate the formation of UIRCs, and UIRCs have proliferated throughout the nation. Still, very little is known about the magnitude and scope of UIRCs, their efforts and activities, and their effects on technological change and university research.

This report summarizes the findings from a national study that examined the extent, characteristics and activities of UIRCs. The research examined the role of UIRCs in technological innovation and technology transfer, and the effect of industrial funding on the university's research mission. A comprehensive survey of universities and of UIRCs themselves was conducted in 1991 both to identify the population of UIRCs in the United States and to obtain detailed information on them. All 437 universities and colleges that were recipients of industrially-sponsored research between 1981 and 1988 were contacted, and more than 1,000 UIRCs were surveyed. Responses were received from 511 UIRCs nationwide, yielding a response rate of 48.4 percent. Site visits and personal interviews were conducted at selected UIRCs.

The main findings of the study are:

• Both the number of UIRCs and the magnitude of R&D effort associated with them are quite large. An estimated 1,056 UIRCs were located at more than 200 American campuses as of 1990, with more than half of these established in the 1980s. UIRCs spent an estimated $4.12 billion on research and related activities in 1990. Of this total, we estimate that approximately $2.53 billion was devoted to research and development. UIRCs devoted two-thirds of their effort to R&D and almost one-fifth to education and training. Their R&D effort was divided roughly equally between basic and applied research, with slightly more than 40 percent going to each.

• A significant number of university faculty, research scientists and graduate students nationwide are exposed to UIRC activities. We estimate that in 1990 approximately 12,000 university faculty members and 22,300 doctoral-level researchers were involved in UIRCs. We further estimate that approximately 16,800 graduate students were exposed to UIRCs. Indeed, UIRCs make an important contribution to the economy and society through their education and training effort, producing an average of more than four Ph.D.s and seven master's degrees per year as of 1990. UIRCs also play an especially important role in providing trained employees to industry. On average, 5.70 students from each UIRC received permanent employment from participating companies in the two year period, 1989-1990.

• Government is the major source of support for UIRCs, providing nearly half of their total funding. Eighty-six percent of UIRCs receive government funding. More than 70 percent of UIRCs reported that they were established either wholly or partly based upon funding from federal or state governments. The federal government provided 34 percent of the funding for UIRCs and state governments provided 12 percent. Industry contributed 31 percent, while universities themselves contributed 18 percent.

• UIRCs have become the principal vehicle for direct industry support of academic science and engineering R&D. In 1990, UIRCs accounted for almost 70 percent of industry's support for academic R&D. In addition to their direct funding, participating companies provided benefits to UIRCs and universities more generally in the form of equipment, access to industrial facilities and practical experience for students.

• UIRCs are associated with a broad range of traditional and high-technology industries and span numerous scientific and engineering disciplines. UIRCs also differ importantly in terms of their goals. For example, about one-quarter of UIRCs view improving industry's products and processes as very important, while others pursue more traditional academic objectives removed from commercial objectives.

• Universities—and university faculty members in particular—provided the primary, direct impetus behind the formation of almost three-quarters of UIRCs. Government provided the primary impetus for 10.9 percent, and industry provided the primary impetus for 10.7 percent of UIRCs. These findings suggest that

UIRC relationships are not the result of industry's entreaties. Rather, the primary impetus for UIRCs has come from the entrepreneurial activities of universities. Our findings also suggest that these entrepreneurial efforts have been stimulated by perceived shortfalls in federal research support, and even actively encouraged by government programs that tie university research support to industry participation. This suggests that government funding—both its level and its character—constitutes an important policy tool affecting the relationship between universities and industry.

• The UIRCs in our survey reported 211 patents, which is equivalent to almost 20 percent of the total 1,174 patents granted to universities in 1990. UIRC patent productivity per million dollars of R&D spending was at least comparable to university science and engineering research as a whole. UIRC patent production per million dollars of spending was roughly one-third that of industrial R&D laboratories. UIRCs generated research papers at a rate that is comparable to that for university science and engineering R&D generally.

• The nature and level of UIRC performance varies by size, technology field and funding source, and is closely related to whether the UIRC's mission is to develop commercial technology or conduct more traditional academic research. An important source of productivity differences among UIRCs is associated with the different objectives they pursue. UIRCs whose main mission is the improvement of industry's products and processes exhibit the greatest immediate impact on commercial technology. These commercially oriented UIRCs generate substantially more inventions, prototypes and licenses than those pursuing more academic goals. The fields of technology in which UIRCs focus their effort also affect the magnitude and types of their outputs. Among the six most heavily represented fields of technology in our sample, UIRCs in the fields of advanced materials and biotechnology lead in the production of patents. UIRCs in biotechnology lead in the development of new products, while UIRCs in computer software lead in the development of new processes. UIRCs conducting research in the fields of computer software and manufacturing are the top performers in prototypes. Size is another important dimension along which UIRCs differ. Small UIRCs appear to outperform large ones across every dimension of output and performance. However, this finding should not be used as a basis for public policy because the factors which underlie the size effect are still unknown. It is also important to note that our findings on output and performance reflect responses from UIRC directors and not from the industrial participants in UIRCs.

• The closer integration of industry and university research reflected in UIRC formation poses a tradeoff for society. This tradeoff is between an industrial orientation of some UIRCs that appears to promote technical advance in the short run, versus a commitment to the traditional academic norms regarding the public disclosure of research findings. In their promotion of UIRCs, universities have weakened their long-held commitment to the free flow of information and the full public disclosure of their findings in order to obtain industry funding. For example, industrial participants in UIRCs are often able to restrict communication flow and information sharing and cause publication delays or deletions of certain findings. More than 40 percent of respondents reported that information sharing between UIRC faculty and the general public is at times restricted. Almost 35 percent of UIRCs reported that participating companies can require that information be deleted from research papers prior to submission for publication. Nearly one-half of UIRCs reported that participating companies can delay the publication of UIRC findings. Our data also suggest, however, that the weakening of the traditional academic norm of free disclosure is to some extent offset by the benefits of more effective mechanisms for advancing commercial technology. As UIRCs embrace industry's goals, they tend to have a greater immediate impact on the advance of commercial technology.

Introduction

University-industry research relationships are of great interest to the academic, business and policy communities. In recent years, increasing attention has focused on whether the traditional post-war relationships among government, universities and industry require change, particularly with regard to the appropriate level and nature of federal government involvement in university research (see Branscomb 1993; Brooks 1993; Rosenberg and Nelson 1994; President's Council of Advisors on Science and Technology 1992; Government-University-Industry Research Roundtable 1991). While universities continue to play a vital role in the conduct of basic research, concerns have been raised both by the industrial community and Congress that federal support for university research should strengthen commercial technology and improve industrial performance. The perception of mounting international economic pressure on American industry has led to calls for greater research relevance and skepticism about the value of university research conducted in isolation from industrial concerns and priorities.

This report summarizes the findings of a national study of university-industry research centers (UIRCs). The research examined the extent, characteristics and activities of UIRCs, and addressed questions concerning the effects of UIRCs on innovation and the relationship between universities and industry. This report presents new data on the extent of UIRCs, the magnitude and scope of their activities, their sources of financial support, the role of government in their development, their goals, their productivity and performance, and their effects on university research.

University-industry research relationships date back to the rise of modern technology-intensive business during the late 19th and early 20th centuries (Geiger 1986; Etzkowitz 1988). Indeed, significant corporate funding of university research originated in the late 19th century with the rise of the modern vertically-integrated corporation (see Samber 1990; Rosenberg and Nelson 1994). In 1903, MIT established a research laboratory in physical chemistry and followed in 1908 with its research lab in applied chemistry. By 1920, MIT established the Division of Industrial Cooperation and Research to coordinate its interactions with industry. In 1911, the Mellon Institute was established with close links to the University of Pittsburgh and later to Carnegie Mellon University to conduct applied research in physical chemistry and chemical engineering for the steel, coal and petroleum industries of Pittsburgh and the surrounding region. During the inter-war years, university-industry linkages waned, at least until government took a more active role in coordinating such relationships with the onset of World War II.

The period immediately following World War II saw the establishment of a new "social contract" among universities, the federal government and industry (Brooks 1993)—as reflected in the rise of the National Science Foundation and massively expanded Defense Department funding of both university and industrial research. During this period, new links were also forged between university and industry (Rosenberg and Nelson 1994), evident for example in the close connections between MIT's Lincoln Laboratories and the Boston-Route 128 complex (Etzkowitz 1988, 1990; Leslie 1990) and the Stanford Research Park and Silicon Valley (Leslie 1987, 1993).

The past fifteen years have seen a resurgence in formal relationships between universities and industry, precipitated to some extent by perceived declines in federal funding for various types of academic research. University-industry research relationships have also been stimulated at least in part by changes in science and technology policy at both the federal and the state levels (Government-University-Industry Research Roundtable 1991). In the early 1970s, the National Science Foundation (NSF) created the University-Industry Research Center experiments and the Innovation Center experiments; and in 1978, the NSF added the University-Industry Cooperative Research Projects program (U.S. National Science Foundation 1982). During the mid-1980s, the NSF established two programs to encourage the formation of university-industry research centers: the Engineering Research Centers and Science and Technology Centers (U.S. General Accounting Office 1988). State-sponsored UIRCs began to proliferate in the early 1980s (Osborne 1988; Fosler 1988; Watkins 1985a and 1985b; Wyckoff and Tornatzky 1988; Watkins and Wills 1986; National Governors' Association 1983; Feller 1990, 1991). According to a study of state science and technology programs, 43 states had science and technology initiatives with expenditures totaling $563 million as of 1988 (Minnesota Department of Trade and Economic Development 1988).

The long history of university-industry relationships and the recent proliferation of government programs designed to foster such relationships have spawned a diversity of types of UIRCs. The NSF alone has provided funding for a number of distinct center programs designed to stimulate the formation of UIRCs, including Materials Research Centers, Industry-University Cooperative Centers, State Industry-University Centers, Supercomputer Centers, Engineering Research Centers, and Science and Technology Centers. UIRCs also vary by academic discipline or field, the technologies they choose to focus on and the industries with which they choose to interact and associate. Most important, UIRCs are distinguished by their missions and objectives; some UIRCs focus on advancing commercial technology, while others focus on more traditional academic pursuits that are removed from the more practical concerns of the firms that contribute to their support.

Given these trends, it is not surprising that university-industry research relationships have attracted increasing attention from scholars and other experts in recent years. Indeed, a number of recent studies have examined the influence of university research on industrial innovation. A detailed survey of industrial R&D laboratories (Nelson 1986; Levin et al. 1987; Klevorick et al. 1993) found that the relationship between university science and industrial R&D varies greatly by scientific and technological field as well as by industry. Two recent studies looked specifically at the relationship between university and industry R&D. Jaffe (1989) found that (at the state level) industrial R&D tended to locate in proximity to and be stimulated by university R&D. Mansfield (1991) explored the "social rate of return" to university R&D. Based on a survey of 76 firms drawn largely from R&D-intensive industries, Mansfield found that about one-tenth of new products and processes commercialized between 1975 and 1985 would not have been developed without recent university R&D.[1]

The most widely cited micro-level studies of university-industry research relationships are those conducted on the biotechnology industry by Blumenthal and colleagues (Blumenthal et al. 1986a; Blumenthal et al. 1986b; Gluck et al. 1987). These studies surveyed both industry and university participants about their involvement in university-industry relationships. They found that such relationships benefit industry participants by increasing their access to university research, reducing the costs of engaging in R&D in new fields, and providing training and staff development for company scientists. They also found that industry participants fear a loss of proprietary information.

University research may also be affected by ties with industry. Building on the classic work of Merton (1973), Dasgupta and David (1987, 1992) suggest that deepening relationships between university and industry may compromise fundamental tenets governing academic research, including the free flow of ideas and the commitment to generating knowledge for public benefit. Dasgupta and David (1992) further suggest that the strengthening of ties between university and industry may ultimately generate social costs by drawing resources away from basic research. Mitigating this latter concern, research on the history of the interaction between science and technology (Rosenberg 1982) and universities and industry (Rosenberg and Nelson 1994) suggests that since advances in commercial technology often stimulate basic science, an immediate shift in resources toward more applied research and development may not undermine basic research in the long run.

A number of studies have attempted to evaluate government sponsored university-industry centers. The NSF university-industry center programs, in particular, spawned a series of evaluations (e.g. Gray et al. 1986). These evaluations examined factors such as the inter-disciplinary nature of research, the role of corporate sponsors, involvement of large and small companies, leadership, participation of junior and senior faculty, research linkages and communication channels (Gray et al. 1986; Shapira 1989). These evaluations came to two primary conclusions. First, collaboration with industry had only a slight impact on university research. Second, while few patents were generated, research results were absorbed by industrial participants and had some positive impact on their internal R&D projects. One way to interpret this finding is that industrial sponsors used university-industry centers principally to acquire new sources of knowledge for their own R&D activities rather than as sources of developed product and process innovations. Rees (1990, 1991) conducted a study of potential industrial participants in state-sponsored university-industry technology centers and found that only a small share of these firms (35 out of 216 respondents) were actually involved in state-funded centers. Companies were more likely to be linked to universities in other ways such as contract research or enrolling employees in courses.

Despite the recent proliferation of UIRCs and their prominence in recent discussions of science and technology policy, a comprehensive description and analysis of activities of university-industry research centers does not exist. As noted above, numerous case studies of UIRCs have been conducted, and in a small number of cases, some parts of the population of UIRCs have been examined, (e.g., Rees' (1991) examination of state-sponsored centers and the GAO's (1988) examination of NSF Engineering Research Centers). Thus, one is left with descriptions of isolated "trees" or even species of trees but there is no description of the broader "forest" of UIRCs as a whole. The objective of our survey was to make some headway in understanding what that forest looks like.

1. Study Design

The research was designed to provide a comprehensive picture of the level and nature of the activities of UIRCs, and to examine the effects of UIRCs on technical advance in industry and the conduct of university research. The research involved a combination of research methods and strategies, including historical research, field research, personal interviews, site visits, case studies and, most importantly, survey research. This section discusses the major thrust of our research effort—the survey research.

To develop the survey questionnaire, we built upon the existing social science and historical literatures concerning innovation and university-industry research efforts and conducted our own field research comprised of site visits to a number of UIRCs. We also solicited comments from leading academics and experts in the field, directors of UIRCs, government officials, industrial R&D managers and industrial participants in UIRCs. The questionnaire is available from the authors upon request.

Several methods were used to identify the population of UIRCs. An initial list of UIRCs was compiled from existing sources such as the *Gale Research Centers Directory*, the directory of *State Technology Programs in the United States* compiled by the Minnesota Department of Trade and Economic Development (1988), National Science Foundation reports and other sources. The accuracy and completeness of this list was tested through detailed phone interviews with research administrators from 10 of the universities from the broader list. The interviews revealed that the existing lists were incomplete and contained out-of-date listings. Thus, we compiled our own list.

To develop an accurate and comprehensive list of the population of UIRCs, we conducted a national survey of research administrators at the 437 American universities and colleges identified by the National Science Foundation (1990) as having had industry-sponsored research and development expenditures during the 1981-88 period. This survey achieved a response rate of 92.4 percent and identified a total of 1,466 UIRCs affiliated with 213 American universities and colleges.[2]

For this study, UIRCs were defined as: (1) university-affiliated research centers, institutes, laboratories, facilities, stations or other organizations; that (2) conducted research and development in science and engineering fields; (3) had a total 1990 budget of at least $100,000; with (4) part of the budget consisting of industry-sponsored funds. A UIRC was defined as "university-affiliated" if it received university budgetary contributions, employed university personnel and used university-owned facilities. Our criteria excluded academic colleges, departments and individual faculty investigators engaged in private consulting or industry-sponsored research outside the context of a formal UIRC.

The survey was administered to the directors of all 1,466 UIRCs that we identified. We took a number of steps to ensure the validity of the survey responses. In analyzing the responses, 184 of the research centers were found to be ineligible for participation in the survey. These centers failed to meet our definition of a UIRC because they were no longer in operation or were too recently established. These centers were excluded from our sample population, reducing the number of UIRCs to 1,282. In total, the survey yielded useable questionnaires from 511 UIRCs representing 160 universities and colleges for a response rate of 39.9 percent (Appendix A provides a list of universities represented in the sample of UIRCs).

We subsequently administered a survey of non-respondents to assess whether our survey respondents were representative of the overall population of UIRCs. A group of 140 UIRCs was randomly selected from the 771 UIRCs that did not respond. These 140 UIRCs were asked to participate in a short telephone follow-up survey. Of these 140 non-respondents, 116 were successfully contacted and 73 agreed to participate. We learned that of the 43 centers that were contacted but did not participate in the follow-up telephone survey, 34 did not meet the definition of a UIRC. This suggested that the actual number of UIRCs was less than initially thought. We estimated that 192 of the remaining 655 non-responding UIRCs were also ineligible by extrapolating from the 29.3 percent (34 of 116) of the non-responding UIRCs that did not meet the eligibility criteria. Thus, our final estimate of the number of UIRCs existing in 1990 is 1,056 implying an adjusted survey response rate of 48.4 percent.

We compared differences in the nature and level of activities between respondents and non-respondents (using two-tailed "t-tests," see Appendix B). There were no significant differences in terms of total annual budget, number of research and development projects, and number of companies providing funding support in 1990, indicating that UIRCs in the sample are representative in terms of the scale of their activities. Significant differences were, however, found with regard to the share of effort allocated to R&D, technology transfer, and education and training. UIRCs in the sample tended to dedicate significantly greater effort to research and development and less effort to education and training and technology transfer activities. Generalizations about national trends in UIRCs made below need to be understood with these sample characteristics taken into account.

2. Magnitude and Scope

Both the number of UIRCs and the magnitude of R&D effort associated with them are quite large. Based on our survey findings, we estimate that there were 1,056 UIRCs in 1990. Our estimate for total budgeted expenditures for UIRCs is approximately $4.12 billion in 1990. Of this total, we estimate that approximately $2.53 billion is devoted to research and development.

We estimated UIRC expenditures as follows. According to the survey results, the total of the budgeted expenditures represented by the 410 UIRCs that responded to this question was $1.60 billion. These respondents represent 38.8 percent of the estimated population of 1,056 UIRCs. If one assumes that the total expenditures for these UIRCs are representative of the broader UIRC population, this implies total budgeted expenditures in 1990 of $4.12 billion. This estimate may be conservative since our sample did not include all the universities that may house UIRCs; only 92.4 percent of universities responded to the first stage survey.

UIRCs make a substantial contribution to academic R&D. Indeed, two-thirds (66 percent) of the effort of UIRCs is devoted to R&D. Since non-responding UIRCs devote approximately 12 percent less effort toward R&D than respondents (see the non-respondent survey results presented in Appendix B), we estimate (using our $4.12 billion total expenditure figure for 1990) that UIRCs accounted for approximately $2.53 billion of R&D in 1990. To put this in context, consider that the total R&D expenditures of the National Science Foundation for 1990 were $1.73 billion (National Science Board 1993: 342), and that total federal spending on academic R&D at universities and colleges was $9.64 billion (National Science Board 1993: 331). Total national spending for academic science and engineering R&D at universities and colleges in 1990 was $16.3 billion (National Science Board 1993: 397). Thus, estimated UIRC R&D expenditures represent 15.2 percent of total spending for academic R&D in 1990.

The average total budget per UIRC in 1990 was approximately $4.05 million (including in-kind contributions). This figure partly reflects the effects of a handful of particularly large UIRCs. The median expenditure per UIRC in 1990 was $1.40 million. Table 1 shows the distribution of UIRCs by size of expenditures. Roughly two-thirds of UIRCs fell between $100,000 and $2.5 million in total budgeted expenditures. About 15 percent had expenditures between $2.5 and $5 million; almost 10 percent fell between $5 and $10 million; and 8.5 percent were in the range of $10 and $55 million.

TABLE 1

Size Distribution of UIRCs by Expenditure: 1990

Expenditure Range	Percent of UIRCs
$100,000 - $500,000	22.7
$500,001 - $1,000,000	19.3
$1,000,001 - $2,500,000	24.9
$2,500,001 - $5,000,000	14.9
$5,000,001 - $10,000,000	9.8
$10,000,001 - $55,000,000	8.5

N=410

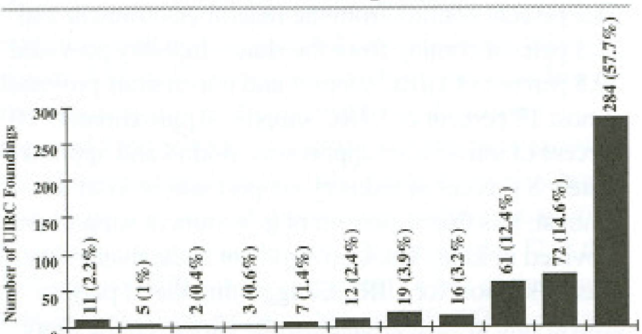
Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

A relatively small number of UIRCs account for a disproportionate share of total UIRC expenditures. The 42 UIRCs that comprise the top 10 percent of 1990 UIRC budgets in our sample accounted for 54 percent of total budgeted expenditures. The 21 UIRCs ranked in the top 5 percent of 1990 UIRC budgets accounted for 39 percent of total budgeted expenditures. UIRCs engaged in agriculture-related research represent almost half of the top 5 percent (9 of 21) in terms of spending. Although only 20 percent (103) of UIRCs listed agriculture as at least one of their areas of activity, expenditures for these 89 agriculture-related account for 35 percent of total budgeted UIRC expenditures. (Most of these UIRCs indicated that they conduct manufacturing-related R&D as well.) The next largest UIRCs in terms of spending were in the field of computing, specifically supercomputing.

The number of UIRCs has grown rapidly in the past decade. Our survey data provide the year of founding for responding UIRCs. As Figure 1 shows, 284 or about 58 percent of the sample UIRCs were founded in the period 1980-89, with the five year period, 1984-1989, being the most active.[3] Despite the recent increase in their number, UIRCs are not a new type of institution. Of the sample UIRCs, 16 were founded before 1900 and 59 before 1950.

FIGURE 1

UIRC Foundings by Decade, 1880-1989, for UIRCs Existing in 1990



N=492

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Company involvement in UIRCs is widespread (see Table 2). While the UIRC survey does not allow us to identify how many companies nationwide participate in UIRCs, the data indicate that the average number of companies participating in UIRCs in 1990 was 17.6 per center and that the median was six. The average in 1986 was 11.4 and the median was three. Two-thirds of UIRCs had relationships with 10 or fewer companies as of 1990. Twenty-eight percent had relationships with between 10 and 50 companies. Slightly more than 5 percent (5.5 percent) had relationships with more than 50 companies. The average number of R&D projects per UIRC in 1990 was 35.4, and the median was 15.

TABLE 2

Distribution of UIRCs by Number of Participating Companies: 1990

Number of Participating Companies	Percent of UIRCs
1 - 5	44.6
6 - 10	21.5
11 - 20	15.7
21 - 50	12.7
51 - 100	3.3
101 plus	2.2
MEAN - 17.6 companies per UIRC	

N=489

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Table 3 reports the numbers of faculty, research scientists, postdoctoral fellows, technical and support staff, graduate students and undergraduates employed by the UIRCs. Each UIRC involved an average of 66.6 and a median number of 23 employees including faculty, research scientists, students and staff. This included an average of 11.5 faculty, 6.5 research scientists, 3.1 postdoctoral fellows, 15.9 graduate students, 9.0 undergraduates and 20.6 staff. The median numbers for each category were substantially smaller, with a median of two faculty, three graduate students, four staff, one research scientist, one postdoctoral fellow and no undergraduates involved at UIRCs.[4]

TABLE 3

UIRC Personnel: 1990

Type of Personnel	Mean	Median
Faculty	11.5	2
Research Scientists	6.5	1
Postdoctoral Fellows	3.1	1
Staff	20.6	4
Graduate Students	15.9	3
Undergraduates	9.0	0
Total	66.6	23

N=442

Note: Full-time personnel only

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

A considerable number of university faculty, researchers and students are involved in, or at the very least exposed to, UIRC activities. We estimate that in 1990 approximately 12,000 university faculty members participated in the 1,056 UIRCs nationwide. We estimate that approximately 22,300 doctoral-level researchers including faculty, research scientists and postdoctoral fellows were involved in UIRCs nationwide, representing almost 16.5 percent of the 135,739 doctoral-level scientists and engineers involved in academic R&D in 1989 (National Science Board 1993: 406).[5] We further estimate that approximately 16,800 graduate students were exposed to UIRCs. This compares to roughly 5.8 percent of the 288,981 full-time graduate students enrolled in science and engineering programs in 1989 (National Science Board 1993: 415).

TABLE 4

Sources of Support for UIRCs: 1990

Source of Support	Mean Percent
Government	46.3
– Federal Government	34.2
– State Government	12.1
Industry	30.8
University	17.7
Private Foundations	2.5
Other	2.7

N=456

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

TABLE 5

Type of Government Funding for UIRCs: 1990

	Number of UIRCs	Percent of UIRCs
Centers with current Government Funding (N=499)	429	86.0
Centers with State Funding over last five years (N=502)	348	69.3
Major Federal Funding Sources: (N=497)		
NSF	274	55.1
Defense	225	45.3
Energy	168	33.8
NASA	136	27.4
NIH	133	26.8
EPA	124	24.9
USDA	103	20.7
DOT	59	11.9
FDA	26	5.2
Centers for Disease Control	14	2.8
HHS	6	1.2

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

3. Sources of Support

Government is the principal source of support for UIRCs. According to our survey, approximately 86 percent of UIRCs received some form of government support, including largely federal but also state support (see Tables 4 and 5). Government provided nearly half (46.3 percent) of UIRC financial support in 1990, with 34.2 percent coming from the federal government and 12.1 percent coming from the states. Industry provided 30.8 percent of UIRC support and universities provided almost 18 percent of UIRC support. Approximately 10 percent of university support was in-kind and approximately 8 percent of industry support was in-kind. In contrast, less than 1 percent of government support was provided in-kind. Thus, government is the major source of cash support for UIRCs, suggesting that it plays a critical role in such arrangements. However, the share of UIRC funding provided by government is significantly less than the government's share of overall support for academic research. In 1990, government accounted for 67.2 percent of total academic research funding—59.0 percent from the federal government and 8.2 percent from state and local government (National Science Board, 1993: 331). As Table 5 shows, the major federal agencies supporting UIRCs include: the National Science Foundation (NSF), Department of

Defense (DOD), Department of Energy (DOE), NASA, the National Institutes of Health (NIH), Environmental Protection Agency (EPA) and the Department of Agriculture.

Industry spent an estimated $779 million on UIRC R&D in 1990. This figure is derived using our estimates of total UIRC R&D spending in 1990 ($2.53 billion) and industry's share in supporting that R&D (30.8 percent). Industry's contribution of $779 million to UIRCs represents the preponderance of its support for academic R&D, constituting 69 percent of the $1.13 billion of total industry support for academic R&D in 1990 (National Science Board 1993: 331). However, this comparison should be qualified because the estimates of industry's contributions to UIRCs are reported by UIRC directors, not by the firms themselves who report directly to the Census and in turn to the National Science Foundation, which reports overall R&D statistics. Nonetheless, these data suggest that UIRCs were the predominant vehicle for industry support of academic R&D in 1990. Industry's $779 million expenditure on UIRC R&D represents approximately 1.11 percent of industry's own-financed total R&D spending of $75.7 billion in 1990 (National Science Board 1993: 333). It may be more appropriate to compare industry's UIRC contribution to industry's basic and applied research expenditures. This contribution was equivalent to 2.7 percent of the $28.5 billion industry spent on basic and applied research in 1990.

A substantial fraction of UIRCs receive only a small share of their support from industry. Of the 407 UIRCs reporting both budget data and funding source breakdowns, 152 or 37 percent received 10 percent or less of their support from industry, and 89 or 22 percent received 5 percent or less of their support from industry. However, since some UIRC budgets are very large, 5 or 10 percent of total support from industry may still be significant in absolute terms. For example, 72 of the 152 sample UIRCs with 10 percent or less of their support from industry received at least $50,000 in industry support in 1990.

Universities—and university faculty members in particular—provided the primary, direct impetus behind the formation of UIRCs. Almost three-quarters (72.5 percent) of UIRCs indicated that the primary impetus behind the university-industry relationship came from university faculty (60.9 percent) or university administrators (11.6 percent). Government provided the primary impetus for 10.9 percent of UIRCs (6.1 percent from the federal government and 4.8 percent from state government). Industry provided the primary and direct impetus for only 10.7 percent of UIRCs. This finding provides support for the view that university-industry relations are principally the result of the "entrepreneurial university" (Etzkowitz 1989) rather than the result of industry initiatives to develop universities as a resource for its own ends. Our survey findings also indicate that industry support was sought to offset what was perceived to be inadequate research funding from government. Indeed, 86 percent of UIRCs indicate that inadequate research support from government was at least "somewhat important" in motivating the center to obtain industry funding.

4. Role of Government

Despite their ties to industry, many UIRCs are chiefly interested in government, not industry support. A significant share of UIRCs actually seek industry support largely as a vehicle for obtaining government support. Forty-two percent of UIRCs indicate that they obtained support from industry because it was required (i.e., at least "somewhat important") for obtaining government support. Thus, many of the marriages between universities and industry have been encouraged — no less directly supported — by government policy.

An important question is whether government promotion and support of UIRCs are achieving something that would not be achieved in their absence. Specifically, are university and industry incentives such that they would do what they are currently doing without public support? Our data do not allow us to consider whether other formal and informal relationships or activities would substitute for UIRCs in their absence. The data do permit us, however, to consider the effects of government funding on UIRC formation and their activities. Our findings indicate that 71.4 percent of UIRCs were established either wholly or partially based upon funding provided by the federal or state government. Of those, 82.6 percent (or 59.0 percent of the entire sample) indicate that they would not have been established in the absence of government funding.

TABLE 6

Effects of Loss of Government Funding on UIRC Operations

		Number of UIRCs	Percent of UIRCs
Centers currently receiving government funding (N=499)		429	86.0
Would the center continue to operate if government funding were discontinued? (N=423)	(YES)	260	61.5
	(NO)	163	38.5
If yes, discontinuation in government support would result in a reduction in: (N=260)			
(A) Basic Research	(YES)	209	80.3
	(NO)	51	19.6
(B) Applied Research	(YES)	179	68.8
	(NO)	81	31.2
(C) Development	(YES)	136	52.3
	(NO)	124	47.9

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Would UIRCs that currently receive government support continue their activities in its absence? The findings suggest that 38.5 percent would not (Table 6). Of the more than 60 percent that would, the majority would continue to pursue their basic and applied research and educational activities to some degree. A withdrawal of such support would, however, result in two-thirds of these UIRCs increasing their efforts to obtain more industry support.

This last point might suggest that government support for these UIRCs is a substitute for private support, implying that private incentives to support UIRCs are not being sufficiently exploited. This is only weakly confirmed by the data, however. Approximately 80 percent of the UIRCs that would continue to operate in the absence of government support indicated that they would reduce their basic research without government support. Approximately two-thirds would reduce their applied research activities; and slightly more than half would reduce their development activities. These results reveal what one might expect — that basic research would be the hardest hit by the withdrawal of government support, perhaps because it is less likely to be supported by industry.

Government support has thus been both critical to the establishment of UIRCs and vital to their operations, particularly to the basic research component of those activities. While the survey data suggest that government funding is important to the activities of UIRCs, this raises the question of what is the effect of these activities on the technological progress realized by the industry participants as well as on the research that is conducted by universities. Before we explore these effects, we need to consider the broad range of goals which condition UIRC activities and their effects on technological progress.

5. Focus and Mission

Toward what activities and goals do UIRCs devote their effort? On average, UIRCs dedicate two-thirds (66.5 percent) of their effort to R&D, 18.8 percent to education and training, 6.6 percent to technical assistance, 6.3 percent to technology transfer and 1.8 percent to entrepreneurial support (see Table 7). With regard to R&D in particular, this effort is divided almost equally between basic and applied research, with, on average, 41.1 percent going to basic research and 43.2 percent going to applied research. Interestingly, 15.7 percent is dedicated to development, which is typically not associ-

TABLE 7

Mission and Focus of UIRCs: 1990

Type of Activity	Mean Percent
Percent of Effort Dedicated to: (N=493)	
R&D	66.5
Education and Training	18.8
Technical Assistance	6.6
Technology Transfer	6.3
Entrepreneurial Support	1.8
Percent of R&D Effort Dedicated to: (N=497)	
Basic Research	41.1
Applied Research	43.2
Development	15.7
Change in Relative Shares of Basic and Applied R&D[1]: (N=315)	
Stayed the same	55.6
Increase in Applied R&D	29.8
Increase in Basic Research	14.6

[1]Applies to centers established before 1985.

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

ated with university-based research. (The UIRC survey used the standard NSF definitions of basic research, applied research and development.)

UIRCs devote a greater share of their R&D effort to applied research and development than do universities as a whole. In 1990, universities devoted 65.4 percent of their R&D effort to basic research, 26.7 percent to applied research and 7.8 percent to development (National Science Board, 1993: 333-336). Thus, UIRCs devoted nearly twice the relative effort of universities as a whole to applied research and development. However, the proliferation of UIRCs during the 1980s is not reflected in any change in the composition of university research overall during that period. Indeed, the share of university research devoted to basic research remained stable over that period.

We considered whether the mix of UIRC activity between basic research versus applied research and development has changed for UIRCs founded before 1985. More than half (55.6 percent) of UIRCs report no change in the mix between basic and applied research and development since their founding. For 29.8 percent of UIRCs, the mix has moved toward more applied research and development, while 14.6 percent of the UIRCs increased the share of effort dedicated to basic research.

Not surprisingly, UIRCs see their primary goal as advancing scientific and technical knowledge. As shown in Table 8, 77.3 percent of UIRCs indicated that the goal, "to advance technological or scientific knowledge," was very important, based on a four-point Likert scale where responses vary from "not important" to

TABLE 8

Distribution of UIRCs by Importance of Selected Goals

	Number and Percentage [in brackets] of UIRCs Scoring Goals as:				
	Not Important	Somewhat Important	Important	Very Important	Mean Score[1]
To Advance Technological or Scientific Knowledge (N=497)	5 [1.0]	20 [4.0]	88 [17.7]	384 [77.3]	3.71
Education and Training (N=499)	14 [2.8]	56 [11.0]	149 [29.9]	281 [56.3]	3.40
To Demonstrate the Feasibility of New Technology (N=486)	44 [9.1]	118 [24.3]	160 [32.9]	164 [33.7]	2.91
To Transfer Technology to Industry (N=496)	55 [11.1]	127 [25.6]	185 [37.3]	129 [26.0]	2.78
To Improve Industry's Products or Processes (N=491)	68 [13.8]	133 [27.1]	164 [33.4]	126 [25.7]	2.71
To Create New Business (N=483)	203 [42.0]	163 [33.7]	76 [15.7]	41 [8.5]	1.91
To Create New Jobs (N=481)	199 [41.4]	157 [32.6]	76 [15.8]	49 [10.2]	1.95
To Attract New Industry to the Local Area or State (N=474)	201 [42.4]	144 [30.4]	85 [17.9]	44 [9.3]	1.94

[1]Mean computed where 1 = "Not Important"; 2 = "Somewhat Important"; 3 = "Important"; and 4 = "Very Important."
Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

"very important." The second most important goal was "education and training" with 56.3 percent responding very important. This latter goal is consistent with industry's interest in obtaining trained personnel from UIRCs. On a four-point Likert scale (where response categories ranged from one for "not important" to four for "very important"), the mean scores for the two key academic objectives "to advance technological or scientific knowledge" and "education and training" were 3.71 and 3.40 respectively.

Industry's other more tangible and immediate interests ranked well behind these more conventional academic objectives. Only 25.7 percent of UIRCs or 126 indicated that the goal of improving industry's products or processes was very important (33.4 percent ranked this goal as important); and 26.0 percent indicated that the goal of transferring technology to industry was very important (37.3 percent ranked this goal as important). The mean scores for these two key industry-related objectives, namely "to improve industry's products and processes" and "to transfer technology to industry," were 2.78 and 2.71, respectively. One-third (33.7 percent) of UIRCs saw the goal of demonstrating the feasibility of new technology as very important (and 32.9 percent ranked this as important); the mean score for this objective was 2.91.

Public policy, particularly at the state level, has frequently promoted UIRC programs and expenditures on the grounds that such university-industry relationships can stimulate regional economic growth. The findings presented in Table 8 indicate, however, that economic development is less important to UIRCs than other goals with only about 9 to10 percent of respondents viewing either the creation of new businesses, job creation or the attraction of new industry as very important goals. Indeed, more than 40 percent of the respondents viewed such economic development goals as unimportant.

Differences in key goals is surely one of the most important ways that UIRCs differ from one another, and a key difference is the degree to which UIRCs attend to the relatively applied needs and concerns of their industrial participants. Table 9 breaks down the shares of UIRC activity devoted to basic research, applied research and development by the importance that UIRCs attach to the goal of improving industry's products or processes. Not surprisingly, Table 9 shows that UIRCs that are more commercially oriented devote a much higher share of their activity to applied research, particularly to development. UIRCs that viewed commercial concerns as unimportant devote the bulk of their activity to basic research, with only a small share of their total effort going to development.

Our findings suggest that more recently established UIRCs tend to have a more applied orientation (Figure 2), at least as revealed by the importance they attach to the goal of improving industry's products and processes. For example, only 16.4 percent of UIRCs founded before 1980 indicated that improving industry's products and processes was "very important," while 32.7 percent of those founded after 1980 ranked this as very important.[6] These figures are consistent with the recent emphasis that funding agencies have placed upon university-industry research relationships as a vehicle for promoting technical advance in the U.S. manufacturing sector.

TABLE 9

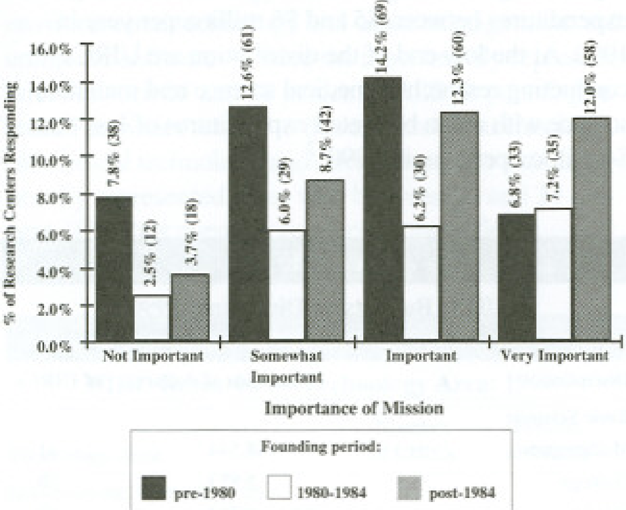
Types of Research by Importance of Mission of Improving Industry's Products or Processes: 1990

Share of Research Devoted to:	Basic Research	Applied Research	Development
Percent of Entire Sample (N=497)	41.1	43.2	15.7
Percent of UIRCs by Mission Importance:			
(1) Not Important (N=66)	62.5	32.9	4.6
(2) Somewhat Important (N=130)	43.2	44.7	12.1
(3) Important (N=162)	43.4	41.2	15.4
(4) Very Important (N=123)	24.4	49.3	26.3

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

FIGURE 2

Importance of Mission to Improve Industry's Products or Processes by Period of Founding



Note: N in parentheses with total N=485.

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

In short, UIRCs differ considerably in their goals and objectives. Perhaps the most salient difference is the degree to which they focus on affecting technological change in an immediate and tangible way that can directly impact industry. While some UIRCs, particularly those founded in recent years, hold that goal quite dear, others were concerned with more purely academic objectives. Furthermore, a relatively small share of UIRCs emphasize direct contributions to economic development.

6. Industries, Disciplines and Technologies

UIRCs are quite diverse, and the research of UIRCs is relevant to a wide array of sectors and industries. More than one-quarter (27.3 percent or 137) of UIRCs conduct R&D relevant to the manufacturing sector exclusively, while more than two-thirds (67.9 percent or 340 UIRCs) conduct R&D that is relevant to both the manufacturing and non-manufacturing sectors. Less than 5 percent (4.8 percent or 24 UIRCs) conduct R&D that is exclusively relevant to the non-manufacturing sector.

Tables 10 through 13 show the industries, academic disciplines and technological areas to which UIRC research is relevant. Here, it is important to note that the survey questionnaire asks each respondent to identify *all* the disciplines, industries and fields of technology to which their research is relevant.

Table 10 shows the number and percentage of UIRCs associated with a given industry. As these data indicate, UIRC research is concentrated in chemicals, including pharmaceuticals (41.7 percent), computers (35.0 percent), electronic equipment excluding computers (29.0 percent), petroleum and coal products (28.2 percent) and software (26.0 percent). No other industry accounts for more than 22 percent of UIRC research activity.

TABLE 10

UIRC Research by Industry: 1990

Industry	Number of UIRCs	Percent of UIRCs
Chemical/Pharmaceutical	213	41.7
Computer	179	35.0
Electronic Equipment	148	29.0
Petroleum and Coal	144	28.2
Software and Computer Services	133	26.0
Food Products	110	21.5
Fabricated Metals	107	20.9
Agriculture	102	20.0
Utilities	100	19.6
Rubber and Plastics	88	17.2
Transportation	86	16.8
Transportation Equipment	79	15.5
Mining	78	15.3
Communications	78	15.3
Industrial/Commercial Machinery	78	15.3
Lumber and Wood	77	15.0
Primary Metals	76	14.9
Paper and Allied Products	75	14.7

N=511

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

UIRCs span numerous scientific and engineering disciplines. Table 11 provides a disciplinary breakdown of UIRCs on the basis of the fields of science and engineering to which they contribute. Biology and chemistry are the most heavily represented of the basic sciences, each of these accounting for more than one-third of UIRCs. Roughly two-thirds (65.6 percent) of

UIRCs are contributing to at least one basic science. Materials science and computer science are the most heavily represented of the applied sciences. Materials, electrical, mechanical and chemical engineering are the most heavily represented of the engineering fields. Each of these is associated with more than one-quarter of UIRCs.

TABLE 11

UIRC Research by Discipline: 1990

Discipline	Number of UIRCs	Percent of UIRCs
Basic Science:		
Chemistry	192	38.6
Biology	169	34.0
Physics	120	24.1
Geology and Earth Sciences	98	19.7
Mathematics	54	10.7
Engineering:		
Materials	171	34.4
Electrical	159	32.0
Mechanical	155	31.2
Chemical	137	27.6
Civil	103	20.7
Industrial	87	17.5
Aeronautical and Astronautical	58	11.7
Applied Science:		
Materials	145	29.2
Computer Science	130	26.2
Agricultural	106	21.3
Medical Sciences	93	18.7
Applied Math and Operations Research	57	11.5
Atmospheric	45	9.1
Oceanography	27	5.4
Astronomy	6	1.2

N=497

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Spending by UIRCs also differs considerably by discipline. Table 12 shows that there are considerable differences in the mean budgets of UIRCs. At the top of the list are UIRCs conducting research in astronomy ($9.2 million) and atmospheric science ($8.8 million), with mean total budgeted expenditures in excess of twice the mean for all UIRCs. UIRCs conducting research in agricultural science, geology, mathematics, physics and aeronautical engineering also had mean budgeted expenditures in excess of $6 million. Centers conducting research in biology, chemistry, industrial engineering and computer science had mean budgeted expenditures between $5 and $6 million per year in 1990. At the low end of the distribution are UIRCs conducting research in medical science and materials science with mean budgeted expenditures of less than $4 million per year in 1990.[7]

TABLE 12

UIRC Budgets by Discipline: 1990

Discipline	Mean Budget (thousands of dollars)	Number of UIRCs
Basic Science:		
Mathematics	$8,544	41
Geology	6,853	80
Physics	6,702	99
Biology	5,933	142
Chemistry	5,135	167
Other Basic	5,214	34
Engineering:		
Aeronautical	6,212	45
Industrial	5,751	72
Electrical	4,991	128
Civil	4,797	85
Mechanical	4,746	128
Chemical	4,714	117
Materials	3,903	139
Other Engineering	5,084	67
Applied Science:		
Astronomy	9,220	5
Atmospheric Science	8,858	34
Agricultural Science	6,778	87
Computer Science	5,934	103
Applied Math and Operations Research	4,666	51
Oceanography	4,660	22
Medical Science	3,993	78
Material Science	3,685	119

N=498

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

In addition to identifying UIRCs by discipline and industry, we sought to identify UIRCs by the areas of technology that they seek to advance. As Table 13 shows, three technology areas — advanced materials, environmental technology and waste management, and computer software — were the most heavily represented, with between 25 and 30 percent of UIRCs pursuing research activities related to these fields. Biotechnology, biomedical technology and energy were the next most heavily represented areas with between 20 and 24 percent of UIRCs pursuing research in these fields.

TABLE 13

UIRC Research by Technology Area: 1990

Technology Area	Number of UIRCs	Percent of UIRCs
Environmental Technology and Waste Management	147	29.8
Advanced Materials	135	27.3
Computer Software	129	26.1
Biotechnology	109	22.0
Biomedical	108	21.9
Energy	100	20.2
Manufacturing (Industrial, Automotive and Robotics)	98	19.8
Agriculture and Food	89	18.0
Chemicals	77	15.6
Scientific Instruments	67	13.6
Semiconductor Electronics	64	13.0
Aerospace	61	12.3
Pharmaceuticals	61	12.3
Computer Hardware	50	10.1
Telecommunications	48	9.7
Transportation	37	7.5

N=494

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

7. Performance

Evaluating the effects of UIRCs on the pace of innovation and technical advance is a difficult and complicated undertaking due to difficulties in constructing reliable and consistent outcome measures, lags in the innovation process and the complexity of the process of technological change. Also, a complete evaluation of these effects should include firms' own views of their experiences with UIRCs that our survey of UIRC directors obviously does not provide. Nevertheless, there are a series of tangible measures of innovation that can be used to consider the output of UIRCs. Examples of such measures include: invention disclosures, patents issued, patent applications, prototypes, copyrights, licenses and research papers.

The 511 UIRCs that responded to our survey reported the following outputs in total: 679 inventions, 459 patent applications, 211 patents granted, 160 licenses, 464 copyrights, 44 trade secrets, 426 prototypes, 293 new products and 390 new processes. Note that these figures reflect the total number of outputs reported only by the respondents to the UIRC survey; the analogous figures for the overall population of 1,056 UIRCs would be considerably higher.

Table 14 summarizes the average output per UIRC for UIRCs reporting innovative output. This table reports two averages for each type of output because it is difficult to know whether a blank response indicates zero or is a missing value. We compute the first mean (the lower number) on the assumption that a blank answer to a question signifies zero when a respondent answers at least one item in a question category but leaves the others blank. The second mean treats the blanks as missing values. These figures are computed for the entire sample. For UIRCs reporting such results, the average outputs per UIRC for 1990 were: 1.08-1.39 patent applications, 0.50-0.68 patents issued, 0.38-0.53 licenses, 1.00-1.49 prototypes, 0.69-1.06 new products invented, 0.92-1.39 new processes invented and 1.09-1.73 copyrights. The medians for almost all of these outputs are zero. The output of research papers was high with the average for 1990 being 42.47-43.60. Educational outputs were also considerable. The average number of Ph.D.s that were based on R&D conducted at a UIRC was 4.38-4.60, and the average number of master's degrees was 7.03-7.53.

TABLE 14

Output per UIRC: 1990

	Mean[1] (N=425)	Mean[2]	Median[1]	Median[2]
Research Papers	42.47	43.60 (414)	20	20
Invention Disclosures	1.60	2.11 (321)	0	1
Copyrights	1.09	1.73 (268)	0	0
Prototypes	1.00	1.49 (286)	0	1
New Products Invented	0.69	1.06 (277)	0	0
New Processes Invented	0.92	1.39 (281)	0	0
Patent Applications	1.08	1.39 (330)	0	0
Patents Issued	0.50	0.68 (311)	0	0
Licenses	0.38	0.53 (301)	0	0
Ph.D.s	4.38*	4.60 (410)	2	2
Master's Degrees	7.03*	7.53 (402)	3	3

Note: N in parentheses in second column.

[1]Computed assuming blank responses signify zero, as long as there is a response to at least one of the category items.

[2]Computed assuming blank responses are missing values.

*N=431

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

TABLE 15

1990 Output per UIRC for UIRCs founded prior to 1987 vs. UIRCs founded 1987-1989

	Pre-1987 Mean[1] (N=332)	1987-89 Mean[1] (N=93)	Pre-1987 Mean[2]	1987-89 Mean[2]
Research Papers	47.94	22.95	48.67 (327)	24.53 (87)
Invention Disclosures	1.63	1.49	2.16 (250)	1.96 (71)
Copyrights	1.29	0.38	1.94 (221)	0.74 (47)
Prototypes	0.96	1.34	1.41 (227)	1.78 (59)
New Products Invented	0.70	0.65	1.05 (222)	1.09 (55)
New Processes Invented	0.97	0.74	1.43 (225)	1.23 (56)
Patent Applications	1.14	0.88	1.46 (258)	1.14 (72)
Patents Issued	0.55	0.32	0.74 (245)	0.45 (66)
Licenses	0.44	0.16	0.60 (242)	0.25 (59)
Ph.D.s	4.75*	3.02**	5.00 (322)	3.16 (88)
Master's Degrees	7.57*	5.03**	8.07 (318)	5.51 (84)

Note: N in parentheses in third and fourth columns.

[1]Computed assuming blank responses signify zero, as long as there is a response to at least one of the category items.

[2]Computed assuming blank responses are missing values.

*N=339

**N=92

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

The innovation process is characterized by a lag or gestation period, as noted above. Therefore, in Table 15, we estimate UIRC outputs taking this lag into account, comparing the average outputs of UIRCs established prior to 1987 to those established in the 1987-1989 period. The lagged outputs are all higher with the exception of prototypes.

Intermediate Outcomes

Although measuring outputs such as patents, inventions and prototypes is useful and important, such measures do not fully capture the effects of UIRCs on technological advance. In particular, such measures do not capture the full contribution of UIRCs or similar organizations to the knowledge base and associated R&D activities of participating firms (Feller 1988).

Thus, we developed a series of "intermediate outcome" measures to assess better the effects of UIRCs on technical advance. The concept of an intermediate outcome refers to the effect of the knowledge generated by UIRC research on the R&D activities of firms. In particular, we were concerned with the ways firms used UIRC research to revise their own views of the feasibility of particular technologies, make their own R&D process more efficient, and make improvements in existing products and processes. Accordingly, the survey asked the center directors to indicate, to the extent possible, how frequently knowledge produced by UIRCs was used by participating firms in 1990 to: (1) improve existing products, (2) improve existing processes, (3) introduce new products, (4) introduce new processes, (5) make existing R&D projects more efficient, and (6) introduce new R&D projects.

Participating firms are obviously more qualified to answer this question than the UIRC directors who responded to our survey. Nevertheless, UIRCs provide an important source of information on this issue. Moreover, the questionnaire allowed UIRC directors to indicate that they did not know the answer, and from 36 to 44 percent of the respondents (depending upon the specific question) indicated that was the case. Table 16 reports the findings for intermediate outcomes. The results indicate that of those respondents claiming they could answer, between 13 and 21 percent of responding UIRCs, depending upon the particular measure in question, reported that they never observed a given effect.

Of the 190 UIRCs that indicated they could respond to all the intermediate outcome questions, 6.3 percent indicated that none of these outcomes had ever been realized by participating companies.

These findings indicate that UIRCs principally contribute to the improvement of existing processes or products and increase the efficiency of existing R&D projects. The findings indicate that UIRCs typically realized each of the six types of intermediate outcomes between one and five times.[8] As Table 16 indicates, the mode and median values for all six types of intermediate outcomes fall in the range of one to five times or three times if the mid-point is used (as in Table 16). On the basis of the mean and mid-point values, we see that UIRCs contributed to the improvement of new products and processes and to the increased efficiency of existing R&D somewhat more than they contributed to the introduction of new products or processes or the introduction of new R&D projects by industry.

TABLE 16

Frequency of Intermediate Outcomes: 1990
[Percent in brackets]

Use of UIRC Research:[1]	0 times	1-5 times	6-10 times	11-15 times	15+ times	Don't Know	Summary Scores[2] Mean[3]	Median	Mode
To improve existing products (N=487)	77 [15.8]	158 [32.4]	35 [7.2]	10 [2.1]	22 [4.5]	185 [38.0]	4.23	3	3
To improve existing manufacturing processes (N=480)	67 [14.0]	159 [33.1]	41 [8.5]	13 [2.7]	27 [5.6]	173 [36.0]	4.58	3	3
To introduce new products (N=487)	104 [21.4]	145 [29.8]	24 [4.9]	8 [1.6]	9 [1.8]	197 [40.5]	3.05	3	3
To introduce new processes (N=478)	97 [20.3]	128 [26.8]	24 [5.0]	6 [1.3]	11 [2.3]	212 [44.4]	3.20	3	3
To make existing R&D projects more efficient (N=487)	62 [12.7]	133 [27.3]	40 [8.2]	17 [3.5]	22 [4.5]	213 [43.7]	4.66	3	3
To introduce new R&D projects (N=485)	61 [12.6]	159 [32.8]	35 [7.2]	10 [2.1]	13 [2.7]	207 [42.7]	3.72	3	3

[1]UIRC directors' estimates of frequency with which UIRC research was used by participating firms in each of the following ways.

[2]Excluding "don't know" responses from the distribution. To compute Summary Score indices, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

[3]Means computed for centers established prior to 1987 were similar.

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Productivity

Since UIRCs differ significantly by size, we normalized all output measures to examine the output of UIRCs per million dollars of spending. In the following discussion, we use the term productivity not in the conventional causal sense, but rather to characterize output normalized by contemporaneous size, where size is measured as budgeted UIRC expenditures.[9] We treat blank responses as in our discussion of Table 14 above. As Table 17 shows, for UIRCs reporting both outputs and budgeted expenditures, the average outputs per million dollars per center in 1990 were as follows: 1.12-1.64 prototypes; 0.80-1.22 new product inventions; 0.72-1.07 new process inventions; 0.75-0.96 patent applications; 0.42-0.57 patents issued; 0.53-0.83 copyrights; and 0.23-0.32 licenses. The productivity of UIRCs in terms of academic outputs was considerable. UIRCs generated an average of 23.58-24.45 research papers per million dollars per center. There was no consistent pattern across types of output when we compared 1990 productivity figures for UIRCs founded in the 1987-1989 period compared with those founded before 1987, suggesting little consistent effect of any lag.

To compute our intermediate outcome productivity figures, we used the midpoints for all the categorical responses except the highest category (i.e. "15+" times), which was assumed to equal 15 (see summary scores on Table 16). With regard to intermediate outcomes, UIRC productivity appeared to be substantial, although it is difficult to know exactly how important these contributions are since we have little basis for comparison. UIRCs reported that knowledge generated in the center yielded an average of 5.82 improvements in existing products, 5.27 improvements in existing processes, 3.46 new product introductions and 2.98 new process introductions per million dollars of expenditure per center. UIRCs reported that knowledge generated by the center resulted in the introduction of an average of 4.28 new R&D projects to industrial sponsors and helped to make their sponsors' R&D more effective an average of 5.69 times per million dollars of expenditure. Note that ranges (due to different treatments of blank responses) are not indicated for the intermediate outcome results because these questions were closed-ended and clearly distinguished a "zero" response from a "don't know" response.

TABLE 17

UIRC Productivity: 1990
(Output per million dollars)

	Mean[1]	Mean[2]	Mean[2] (Founded pre-1987)
Innovation Outcomes:			
Research Papers	23.58 (353)	24.45 (343)	24.33 (268)
Invention Disclosures	1.04 (353)	1.37 (268)	1.10 (208)
Copyrights	0.53 (353)	0.83 (225)	0.84 (186)
Prototypes	1.12 (353)	1.64 (241)	1.52 (189)
New Products Invented	0.80 (353)	1.22 (233)	1.00 (186)
New Processes Invented	0.72 (353)	1.07 (237)	0.99 (189)
Patent Applications	0.75 (353)	0.96 (278)	0.87 (217)
Patents Issued	0.42 (353)	0.57 (260)	0.62 (205)
Licenses	0.23 (353)	0.32 (254)	0.28 (204)
Education Outcomes:			
Ph.D.s	3.09 (352)	3.22 (338)	3.27 (265)
Master's Degrees	5.65 (352)	6.02 (330)	5.57 (257)
Intermediate Outcomes:[3]			
Improve Existing Products		5.82 (260)	5.80 (209)
Improve Existing Processes		5.27 (267)	5.01 (213)
Introduce New Products		3.46 (255)	3.05 (202)
Introduce New Processes		2.98 (237)	2.84 (187)
Make R&D More Efficient		5.69 (243)	5.16 (182)
Introduce New R&D Projects		4.28 (241)	3.62 (185)

Note: N in parentheses

[1]Computed assuming blank responses signify zero, as long as there is a response to at least one of the category items. This assumption was not applied to the intermediate outcomes because this question category was close-ended and provided the option of responding "don't know" or zero.

[2]Computed assuming blank responses are missing values.

[3]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Performance Benchmarks

Performance benchmarks are useful for providing a more complete picture of the performance of UIRCs compared to other relevant types of organizations. While appropriate benchmarking data is unavailable for most of the performance indicators in our survey, there are a few relevant measures, such as patents and research papers, for which such benchmarking data are available.

Patents are perhaps the most important dimension for which accurate benchmarking data can be obtained. While the following calculations are crude, the results are revealing. In 1990, about 60 percent of the UIRCs in our survey reported patents. These 311 UIRCs reported a total of 211 patents. That same year, the total number of patents granted to universities was 1,174 (National Science Board 1993: 430). Thus, the reported patent output of the sample UIRCs was equivalent to 18 percent of the total number of patents granted to universities nationwide.[10] The patent performance of UIRCs is at least comparable to that for universities as a whole. In 1990, for UIRCs reporting both innovative outputs and R&D budget data, the total number of patents equaled 158. The total budgeted R&D expenditures for all 347 of these centers was $855.6 million, implying an aggregate productivity of 0.185 patents per million dollars. Universities generated .072 patents per million dollars, dividing the total 1,174 university patents by $16 billion in university spending on scientific and engineering R&D. This figure rises to 0.21 patents per million when dividing the total 1,174 patents by the $5.66 billion universities spent only on applied scientific and engineering R&D.

UIRC patent productivity was approximately one-third that of industrial R&D, which is understandable since industry's incentives to patent are typically greater than universities'. In 1990, U.S. owned companies accounted for 33,359 patents and spent $64.4 billion on R&D. (National Science Board 1993: 333, 455). Thus, industrial firms generated 0.52 patents per million dollars of total U.S. corporate R&D expenditure.

A second area of comparison is research papers. In 1990, the UIRCs in our sample generated 18,050 research papers. Based on that, we estimate that all 1,056 UIRCs nationwide may generate as many as 46,000 research papers. To compare, the most recent available data indicate that scientists and engineers engaged in R&D at universities generated roughly 141,000 articles in 1989 (National Science Board 1993: 428). Of course, this comparison must be qualified by the fact that the UIRCs in our sample are reporting research papers, while the data for universities reflects published papers only. Nevertheless, if we divide the 14,004 papers reported by the 347 UIRCs that produce any innovative output by the $855.6 million sum of all those centers' budgets, we find that UIRCs generated 16.4 research papers per million dollars of expenditure. This compares to 9.4 published articles per million dollars of R&D spending for universities nationwide in 1989.

These findings suggest that the rate of UIRC patent generation per million dollars is at least comparable to that of university science and engineering R&D generally, and less than that of industry. At the same time, UIRCs are generating academic papers at a rate that is at least comparable to universities more generally.

Diversity

UIRCs are extremely heterogeneous and, as such, are likely to have distinct outputs. The performance of UIRCs is likely to differ across dimensions such as size, source of funding, mission, academic discipline, the industries with which they collaborate and the focus of their activity. It is also important to recognize that different types of output are appropriate to different kinds of UIRCs. For example, prototypes may be a useful measure for a UIRC devoted to process commercialization, but it will not be particularly informative for one whose main mission is to advance basic science. While space limitations prevent us from disaggregating UIRCs along every possible dimension of interest, it is useful to distinguish the output and productivity of UIRCs by the goals they pursue, by technology areas, by size and by their different sources of funding. For Tables 18 through 22, all "innovation outcome" and "education outcome" category data are computed assuming that blank responses signify zero as long as there is a response to at least one of the category items. "Intermediate outcome" category data are computed assuming blanks signify missing data because the question category was close-ended and provided the option of responding "don't know" or zero.

Goals: The goals that distinguish UIRCs are likely to affect the types and magnitudes of their outputs. Table 18 reports the average absolute levels of UIRC output and Table 19 reports average UIRC productivity (i.e. output per million dollars of UIRC expenditures per UIRC) by the degree to which the UIRCs subscribe to the goal of improving industry's products or processes. As Table 19 shows, there are clear differences in both innovative outputs and intermediate outcomes when this goal is taken into account. The UIRCs that view the mission of improving industry's products and processes

TABLE 18

UIRC Output by Importance of Mission to Improve Industry's Products or Processes: 1990

	Not Important	Somewhat Important	Important	Very Important	N[1]
Innovation Outcomes:					
Inventions Disclosed	0.81	1.51	1.50	2.23	418
Patent Applications	1.15	0.82	1.08	1.37	418
Patents Issued	0.70	0.36	0.49	0.54	418
Licenses	0.19	0.30	0.43	0.49	418
Prototypes	0.23	0.75	1.03	1.66	418
New Products Invented	0.30	0.50	0.58	1.27	418
New Processes Invented	0.38	0.52	1.32	1.10	418
Trade Secrets	0.02	0.03	0.15	0.16	418
Copyrights	1.09	0.40	1.94	0.80	418
Research Papers	56.64	48.55	40.91	29.69	418
Education Outcomes:					
Ph.D.s Granted	4.13	4.45	4.51	3.61	422
Master's Degrees Granted	6.20	7.93	8.13	5.17	422
Intermediate Outcomes:[2]					
Improve Existing Products	1.22	3.46	3.80	6.04	288
Improve Existing Processes	1.16	3.43	4.58	6.55	294
Introduce New Products	1.86	2.97	2.71	4.10	278
Introduce New Processes	1.79	2.02	2.83	4.84	255
Make R&D More Efficient	2.49	4.61	4.76	5.61	263
Introduce New R&D Projects	2.53	3.45	3.88	5.06	270

[1]N refers to number of UIRCs reporting both outcome and importance of the mission to improve industry's products or processes.
[2]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."
Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

as "very important" report productivity that ranges from twice to 12 times that of the UIRCs that view this goal as "unimportant" for all innovation outcome items except patents and research papers. For example, UIRCs that view improving industry's products and processes as "very important" reported 1.07 invention disclosures per million dollars, compared to 0.27 inventions for those that saw this as "not important." Similarly, UIRCs that view the improvement of industry's products and processes as very important reported 0.90 new processes per million dollars versus 0.42 new processes per million for the UIRCs viewing this mission as unimportant. There is a similar pattern for almost all of the intermediate outcomes, with the levels typically on the order of twice to nearly seven times greater. For example, the most industrially-oriented UIRCs reported 8.52 product improvements and 8.65 process improvements per million dollars, compared to 2.04 product improvements and 1.29 process improvements by the least industrially-oriented UIRCs.

One might expect that the most purely academic outputs—namely research papers—might decline as the mission of improving products and processes increases in importance. As Table 18 shows, the absolute number of research papers declines by almost 50 percent as this commercial mission increases in importance. However, when we examine the academic productivity of UIRCs (i.e. the number of academic papers produced per million dollars of expenditure), this decline diminishes to 23 percent (Table 19).

Technology Area: The fields of technology in which UIRCs focus their activity are also likely to affect the magnitude and types of their outputs. For example, an output which is relevant to one field of technology may be irrelevant to another. Studies of industrial R&D, for example, suggest that the propensity to patent varies considerably across technology areas (Levin et al. 1987). Furthermore, some technology areas may lend themselves more readily to prototyping, product improvements or process improvements. Table 20 sum-

TABLE 19

UIRC Productivity by Importance of Mission to Improve Industry's Products or Processes: 1990
(Output per million dollars)

	Not Important	Somewhat Important	Important	Very Important	N[1]
Innovation Outcomes:					
Inventions Disclosed	0.27	1.02	1.33	1.07	349
Patent Applications	0.28	0.72	1.06	0.65	349
Patents Issued	0.37	0.48	0.53	0.22	349
Licenses	0.11	0.14	0.30	0.28	349
Prototypes	0.33	0.90	1.29	1.53	349
New Products Invented	0.19	0.38	0.84	1.52	349
New Processes Invented	0.42	0.31	1.01	0.90	349
Trade Secrets	0.02	0.06	0.13	0.25	349
Copyrights	0.15	0.22	1.00	0.44	349
Research Papers	22.48	32.08	22.84	17.42	349
Education Outcomes:					
Ph.D.s Granted	1.92	3.82	3.55	2.60	346
Master's Degrees Granted	2.76	7.33	6.00	5.29	346
Intermediate Outcomes:[2]					
Improve Existing Products	2.04	4.16	6.31	8.52	250
Improve Existing Processes	1.29	3.70	5.07	8.65	258
Introduce New Products	1.72	3.04	3.71	4.75	245
Introduce New Processes	1.72	1.55	2.79	4.97	228
Make R&D More Efficient	2.95	4.62	7.61	5.71	237
Introduce New R&D Projects	3.93	3.59	4.90	4.30	237

[1]N refers to number of UIRCs reporting outcome, total center budget and importance of the mission to improve industry's products or processes.

[2]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

marizes output productivity (i.e. outputs per million of dollars of UIRC budgets) for the six most heavily represented technology areas in our sample: advanced materials, biomedical, biotechnology, computer software, manufacturing and environmental technology. As this table shows, there are clear differences in productivity along selected dimensions of output. For patent productivity, advanced materials and biotechnology are the leading areas. For licenses, the top performers are biomedical and computer software. Biotechnology is the leader in new products, while computer software leads in the development of new processes. Computer software and manufacturing lead in prototypes. For academic output, the area of advanced materials leads in research paper productivity with nearly double the output of the lowest ranked field on this dimension, computer software. Taken together, these findings indicate that types of output vary considerably by field of technology.

Size: Another important dimension where UIRC performance differs is size. Table 21 compares the productivity of small UIRCs (those with budgets of $500,000 or less) with that of large UIRCs (those with budgets of greater than $500,000). The results are striking. Along every measure of output—whether tangible innovative outputs like patents, educational outcomes such as Ph.D.s, or intermediate outcomes—the productivity of small UIRCs is greater than that of large UIRCs. The productivity of small centers, depending upon the output dimension selected, is from two to six times greater than large centers. An important question is whether these differences are actually related to size, or whether they simply reflect underlying differences associated with industries, fields of technology or academic disciplines. To probe this possibility, we conducted a series of regression analyses that explored the

TABLE 20

UIRC Productivity for Leading Technology Areas: 1990
(Output per million dollars)

	Advanced Materials	Bio-Medical	Bio-Technology	Computer Software	Manufacturing	Environmental
Innovation Outcomes:						
Inventions Disclosed	1.44 (95)	0.86 (75)	1.29 (81)	0.62 (89)	0.90 (67)	1.02 (109)
Patent Applications	1.21 (95)	0.71 (75)	1.06 (81)	0.46 (89)	0.49 (67)	0.88 (109)
Patents Issued	0.79 (95)	0.26 (75)	0.50 (81)	0.18 (89)	0.44 (67)	0.75 (109)
Licenses	0.21 (95)	0.33 (75)	0.23 (81)	0.30 (89)	0.22 (67)	0.25 (109)
Prototypes	1.38 (95)	1.29 (75)	0.96 (81)	2.04 (89)	2.06 (67)	1.23 (109)
New Products Invented	0.72 (95)	0.65 (75)	1.00 (81)	0.62 (89)	0.37 (67)	0.69 (109)
New Processes Invented	0.79 (95)	0.58 (75)	0.63 (81)	1.05 (89)	0.54 (67)	0.84 (109)
Copyrights	0.42 (95)	0.32 (75)	0.36 (81)	1.09 (89)	1.59 (67)	0.21 (109)
Research Papers	30.79 (95)	24.44 (75)	26.61 (81)	16.42 (89)	19.36 (67)	22.20 (109)
Education Outcomes:						
Ph.D.s Granted	4.26 (91)	2.42 (75)	3.25 (75)	2.64 (88)	3.89 (69)	2.93 (104)
Master's Degrees Granted	6.66 (91)	3.42 (75)	4.95 (75)	5.40 (88)	11.85 (69)	6.96 (104)
Intermediate Outcomes:[1]						
Improve Existing Products	6.06 (67)	6.69 (61)	5.41 (60)	5.12 (75)	5.93 (52)	4.61 (78)
Improve Existing Processes	4.51 (71)	4.20 (55)	5.71 (57)	5.51 (73)	6.14 (52)	3.89 (89)
Introduce New Products	3.06 (66)	3.22 (61)	4.25 (57)	3.33 (66)	3.23 (45)	3.03 (77)
Introduce New Processes	2.72 (64)	2.00 (51)	2.88 (52)	3.45 (56)	3.62 (45)	2.28 (73)
Make R&D More Efficient	6.22 (65)	5.97 (54)	5.52 (49)	5.81 (70)	6.47 (52)	3.80 (72)
Introduce New R&D Projects	2.77 (66)	3.58 (50)	3.53 (50)	4.95 (68)	4.20 (50)	3.39 (72)

Note: N in parentheses

[1]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

effect of UIRC size on each of our productivity dimensions while controlling respectively for industry, discipline and technology area differences. Although the results indicate that the basic finding that smaller UIRCs are more productive than larger UIRCs is robust, they also suggest that size may affect productivity for a given type of output only when the UIRC is producing that type of output to begin with. Size, however, may not affect the types of output produced. The regression results further indicate that the effect of size is non-linear, with the smallest UIRCs being the most productive.

There are at least three possible explanations for the observed productivity differences between large and small UIRCs. First, there may be diminishing returns to R&D in any given area. Second, larger centers may be less efficient than smaller UIRCs. Third, smaller UIRCs may to some extent leverage the resources of the university's broader capabilities and infrastructure in science and technology, while larger UIRCs may be more self-sufficient or even contribute resources to the university's scientific and technical infrastructure. It is important to note, however, that this apparent size effect does not provide any guidance for policy. We cannot infer that smaller UIRCs are more effective in promoting technical advance than larger UIRCs without a more complete understanding of the sources of these productivity differences.

Funding Source: UIRCs also differ considerably by funding source. Centers supported principally by industry, for example, are likely to differ in their orientation,

TABLE 21

UIRC Productivity by Size: 1990
(Output per million dollars)

	Small Centers (Budget ≤ $500k) Mean	Large Centers (Budget > $500k) Mean
Innovation Outcomes:		
Inventions Disclosed	2.03 (81)	0.74 (272)
Patent Applications	1.57 (81)	0.51 (272)
Patents Issued	0.97 (81)	0.26 (272)
Licenses	0.48 (81)	0.15 (272)
Prototypes	2.70 (81)	0.65 (272)
New Products Invented	2.17 (81)	0.40 (272)
New Processes Invented	1.71 (81)	0.42 (272)
Copyrights	0.88 (81)	0.43 (272)
Research Papers	45.08 (81)	17.41 (272)
Education Outcomes:		
Ph.D.s Granted	7.20 (84)	1.81 (268)
Master's Degrees Granted	13.41 (84)	3.22 (268)
Intermediate Outcomes:[1]		
Improve Existing Products	15.56 (70)	2.24 (190)
Improve Existing Processes	12.95 (71)	2.50 (196)
Introduce New Products	7.92 (71)	1.74 (184)
Introduce New Processes	5.99 (66)	1.82 (171)
Make R&D More Efficient	13.83 (65)	2.72 (178)
Introduce New R&D Projects	10.74 (59)	2.18 (182)

Note: N in parentheses

[1]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

TABLE 22

UIRC Productivity by Primary Funding Source[1]: 1990
(Output per million dollars)

Source Providing Most Funding	Federal	State	Industry	N[2]
Innovation Outcomes:				
Inventions Disclosed	0.64	0.78	1.69	329
Patent Applications	0.47	0.40	1.24	329
Patents Issued	0.22	0.06	0.69	329
Licenses	0.20	0.09	0.22	329
Prototypes	0.56	0.66	1.74	329
New Products Invented	0.32	0.83	0.92	329
New Processes Invented	0.34	0.72	1.20	329
Trade Secrets	0.03	0.45	0.16	329
Copyrights	0.38	0.11	0.69	329
Research Papers	21.45	16.98	28.90	329
Education Outcomes:				
Ph.D.s Granted	2.12	1.89	4.60	325
Master's Degrees Granted	3.62	3.47	7.26	325
Intermediate Outcomes:[3]				
Improve Existing Products	2.65	2.21	10.13	233
Improve Existing Processes	3.02	3.06	9.16	240
Introduce New Products	1.69	3.32	4.91	220
Introduce New Processes	1.77	2.26	5.32	206
Make R&D More Efficient	3.08	1.85	10.76	213
Introduce New R&D Projects	2.36	2.86	7.31	213

[1]Primary funding source is the source (federal, state or industry) which accounts for the highest percent of the center's budget.

[2]N refers to number of UIRCs reporting outcome, funding sources and a total center budget.

[3]Excluding "don't know" responses from the distribution. To compute indices for intermediate outcomes, we assigned values of 0 to "zero times," 3 to "1-5 times," 8 to "6-10 times," 13 to "11-15 times" and 15 to "15+ times."

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

objectives and expectations from those funded principally by the federal government. Table 22 summarizes UIRC productivity per million dollars by the major funding sources: federal government, state government and industry. The 124 industry-led centers appear to outperform the 205 government-led centers in terms of almost all performance dimensions. As Table 22 suggests, industry-led centers outperform both the 35 state and the 170 federally led centers in terms of inventions, patents, prototypes and other innovative outputs. The productivity of industry-led centers is greater in terms of intermediate outcomes, particularly those associated with improvements in industry's products and processes and those that make industrial R&D more efficient. For example, industry-led UIRCs reported that UIRC generated knowledge yielded nearly three times more product improvements than federally led UIRCs, and almost five times that of state-led UIRCs. Industry-led centers generated 10.13 product improvements per million dollars compared to 2.21 for state-led centers and 2.65 for federally led centers. Industry-led UIRCs also generated considerably more process improvements and new product and process introductions than either federal- or state-led centers. Surprisingly, industry-led centers are the most productive in terms of Ph.D.s and research papers as well. Industry-led centers generated 28.90 research papers per million dollars compared to 16.98 for state-led centers and 21.45 for federally led centers. Industry-led centers are no longer more productive with regard to academic outputs such as papers, however, once we control for industries, technologies or disciplines in a regression analysis.

Spinoff Companies

UIRCs also contribute to technical advance by yielding new process or product ideas that can be commercially exploited through the formation of new enterprises, commonly referred to as "spinoff" companies. The survey collected data on the number of such spinoff companies from UIRCs. As Table 23 shows, 22.5 percent of the respondents or 103 UIRCs indicated that new companies have been created as a result of UIRC activity. The mean for UIRCs reporting spinoffs was 2.38 spin-offs per UIRC, with 49 centers reporting one spinoff, 30 UIRCs reporting two spinoffs, 15 centers reporting three to four spinoffs and three UIRCs reporting 10 to 20 spinoffs.

TABLE 23

Total Number of Spinoff Companies from UIRCs

		Number of UIRCs	Percent of UIRCs
Centers with spin-off companies (N=493)		103	22.5
Centers with:	1 spinoff company	49	9.9
	2 spinoff companies	30	6.1
	3 spinoff companies	11	2.2
	4 spinoff companies	4	0.8
	5-9 spinoff companies	6	1.2
	10-20 spinoff companies	3	0.6
Mean number of spinoff companies per center reporting any spinoffs		2.38	

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Education and Training

An annual average of approximately four Ph.D.s and seven master's degrees were awarded based upon research conducted in UIRCs. Each UIRC employed an average of 15.9 graduate students, 9.0 undergraduates and 3.1 postdoctoral fellows in 1990 (see Table 3 above). Also, as noted earlier, a significant number of university faculty, researchers and students nationwide are exposed to UIRC activities. Thus, UIRCs make an important contribution to the economy and society through their education and training effort.

Our data suggest that research conducted at the UIRCs in our sample was the basis for the award of 1,886 Ph.D.s in 1990. That same year, universities nationwide produced 22,857 Ph.D.s in science and engineering (National Science Board 1993: 286). Thus, the research conducted by UIRCs in our sample provided the basis for the award of at least 8 percent of science and engineering Ph.D.s nationwide.

UIRCs also play an important role in providing trained employees to industry. The field research and interviews suggest that a key motive for industry participation in UIRCs is to gain access to a pool of trained, technically competent prospective employees who have gained practical experience as well as academic training. The survey findings indicate that UIRCs play an important role in providing trained employees to industry. On average, 5.70 students from each UIRC received permanent employment from participating companies in the two year period, 1989-1990, with 58.3 percent of the respondents indicating that at least one student had been employed by a participating firm in 1989 or 1990. (The mean employment for the two year period 1989-1990 for UIRCs founded before 1987 was 6.36 and the median was two.) Slightly more than half (50.4 percent) of UIRCs indicated that they provided industrial participants with privileged access to their students as prospective employees. In addition, 37.8 percent of responding UIRCs indicated that "practical experience for students in an industrial setting" was a benefit from their relationship with industry.

8. Technology Transfer

The effect of UIRCs on technical advance depends upon the transfer of knowledge and ideas from the UIRC to industry participants. In our survey, technology transfer was defined as the communication of scientific and technological knowledge resulting from UIRC R&D projects to private companies where it could be used for industrial applications. As indicated in Table 8 above, almost two-thirds (63.3 percent) of UIRCs scored the objective of transferring technology to industry as at least "important." However, only 6.3 percent of UIRC effort is allocated to technology transfer (see Table 7, above).

An important question concerns the effectiveness of various mechanisms for university-industry technology transfer. Table 24 reports on the use and the relative effectiveness of technology transfer mechanisms. Not surprisingly, research papers and reports, telephone

TABLE 24

Use and Effectiveness of Technology Transfer Mechanisms

	Number and Percentage [in brackets] of UIRCs Scoring Transfer Mechanisms as:				Summary Scores[1]		
	Not Effective	Somewhat Effective	Effective	Very Effective	Mean	Median	Mode
Collaborative R&D projects (N=323)	3 [0.9]	39 [12.1]	88 [27.2]	193 [59.8]	3.46	4	4
Seminars, workshops, symposiums (N=356)	5 [1.4]	94 [26.4]	165 [46.3]	92 [25.8]	2.97	3	3
Research papers and technical reports (N=428)	7 [1.6]	112 [26.2]	204 [47.7]	105 [24.5]	2.95	3	3
Telephone conversations (N=419)	6 [1.4]	108 [25.8]	205 [48.9]	100 [23.9]	2.95	3	3
UIRC personnel in industry labs (N=102)	0 [0]	22 [21.6]	43 [32.4]	77 [46.1]	3.25	3	4
Industry personnel in UIRC (N=144)	1 [0.7]	26 [18.1]	29 [20.1]	88 [61.1]	3.42	4	4
Informal meetings with industry personnel (N=419)	3 [0.7]	59 [14.1]	188 [44.9]	169 [40.3]	3.25	3	3
Delivery of prototypes or designs (N=111)	0 [0]	13 [11.7]	41 [36.9]	57 [57.4]	3.40	4	4

[1]Scores computed with 1 = "Not effective"; 2 = "Somewhat effective"; 3 = "Effective"; and 4 = "Very effective." Data are reported only for those centers that reported using the mechanisms.

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

conversations and informal meetings were cited as the most commonly used mechanism of technology transfer. Seminars, workshops and joint R&D projects were also widely used.

The survey asked the respondents to evaluate the effectiveness of different technology transfer mechanisms. In considering these findings, however, note that the technology transfer mechanisms we consider do not operate independently of one another. For example, a prototype may be delivered along with a technical report. Telephone conversations typically precede and follow face-to-face meetings. To the extent that these mechanisms operate in conjunction with one another, looking simply at the effectiveness scores for any single mechanism may be misleading. Moreover, the differences across the various technology transfer mechanisms are small.

Nevertheless, the most highly ranked technology transfer mechanisms include collaborative R&D, having industry personnel work within the UIRC, delivery of prototypes or designs, having UIRC personnel work in industry labs, and informal meetings between industry and university personnel. The respondents indicated that the traditional ways of transferring academic findings, namely research papers and technical reports and seminars, were not as effective as these other mechanisms, and roughly as effective as telephone conversations. Note that our effectiveness scores are computed only for those centers that have used a given technology transfer mechanism. In summary, the results suggest that face-to-face interactions are the most important component of effective technology transfer from UIRCs to industry.

The survey also asked UIRC directors to assess the relative effectiveness of interactions between university and different types of industry personnel for technology transfer. This question was framed in terms of a similar four-point Likert scale. Interactions with bench scientists and engineers in central R&D laboratories (39.1 percent responding very effective) and the directors of such laboratories (32.9 percent responding very effective) were seen to be most effective. Another 22.0 percent of respondents indicated that interactions with bench scientists and engineers at development laboratories associated with manufacturing units were very effective. Not surprisingly, interaction with top executives was seen to be relatively less important (just 18.4 percent responding very effective). Interactions with engineers and technicians in actual manufacturing operations were reported as least effective with just 13.9 percent responding very effective.

Our survey findings suggest that the means of communication may make some difference with regard to the effect of university-based knowledge on firms and, hence, technical advance. Moreover, UIRCs provide vehicles for technology transfer that emphasize face-to-face interaction that may be more effective than other mechanisms for technology transfer. UIRCs also provide a vehicle for interacting with those technical personnel within industry that may be best able to exploit university research.

The role of geographic proximity in innovation, technical advance and technology transfer is an issue that is attracting a great deal of attention from geographers and regional scientists, economists and organizational theorists (Arthur 1986, 1987; Feldman and Florida 1994; Jaffe 1989; Krugman 1991). Our survey examined to what extent UIRCs are related to local industrial and technological capabilities (e.g. locally-based manufacturing establishments and/or R&D laboratories), and to what extent they produce local spin-off companies. The average number of participant companies with local R&D laboratories was 5.70, and the median was one, while the average number of companies with local manufacturing facilities was 5.33, and the median again was one. These figures compare to an average number of participant companies per UIRC of 17.6 and a median of six. Furthermore, of the 103 UIRCs that have created spinoff companies, 84 have done so in the local metropolitan area.

9. Implications for University Research

We now consider the effects of industry ties on UIRC research and the university's research mission more broadly. Building on the classic work of Merton (1973), Dasgupta and David (1987, 1992) caution that as university research becomes more closely tied to industry's drive to commercialize technology, industry's profit motive may displace the incentive of priority that has traditionally motivated university researchers. In the process, the norms of public disclosure that govern university research and the pursuit of basic scientific research may be undermined. In their view, such a process may generate significant social costs by consuming the "seed corn" that spawns technological advance in the long run. Thus, deepening ties between university and industry may not only compromise some of the fundamental tenets of academic research in the short run, but they may impose longer run social welfare costs in the form of a diminished rate of technical advance.

Although Dasgupta and David (1987, 1992) appropriately focus attention on the social costs of industry ties with university research, others suggest that the complex and interactive character of the innovation process (Rosenberg 1982; Rosenberg and Nelson 1994) may mitigate such costs in the long run. Research on the history of the interaction between science and technology (Rosenberg 1982) and universities and industry (Rosenberg and Nelson 1994) suggests that efforts to advance commercial technology often stimulate basic research as bottlenecks and opportunities for basic science are inevitably encountered. Thus, it follows that an immediate shift in resources away from basic research need not undermine basic science in the long run.

While the UIRC data cannot directly address either Dasgupta and David's or Rosenberg and Nelson's conjectures about the long run effects of deepening ties between university research and industry, the survey data do allow us to consider the short run implications of UIRC relationships for the public disclosure of research, the free flow of ideas in the academy, industry's ability to influence and shape the agenda of university research, and the immediate influence on technical advance of growing commercialization of UIRC research.

An important issue is the ability of participant firms to influence the research agenda of UIRCs. Table 25 reports findings about industry influence over the research agenda. On a four-point Likert scale where response categories ranged from "no influence" to "strong influence," the responses indicate there is significant company influence on the research agenda of UIRCs. Nearly two-thirds (64.5 percent) of respondents indicated that participating companies had moderate or strong influence over the research agenda of the UIRC. However, industry had little or no influence over the fiscal management or operating procedures of UIRCs.

TABLE 25

Industry Influence on UIRCs (Percent of UIRCs by Degree of Influence)

	No Influence	Little Influence	Moderate Influence	Strong Influence
Industry Influence on:				
Research Agenda (N=496)	13.3% (66)	22.2% (110)	36.3% (180)	28.2% (140)
Fiscal Management (N=495)	70.9% (351)	20.6% (102)	6.3% (31)	2.2% (11)
Operating Procedures (N=495)	65.9% (326)	22.4% (111)	9.9% (49)	1.8% (9)

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Traditionally, university research has been regarded as a public good, and universities have strongly subscribed to the norm of the free flow of ideas. UIRC activity appears to have compromised these traditional features of university research. Table 26 shows that participating firms were allowed to restrict communication and information flow both inside and outside of UIRCs. Not surprisingly, participating companies restricted the flow of information to other companies. Perhaps more significantly, the UIRC directors responding to our survey indicated that the faculty and staff associated with the UIRC are sometimes restricted in sharing information about the UIRC projects on which they work. Here, 13.4 percent of UIRC respondents indicated that sharing of information related to particular projects is at times restricted among faculty within the UIRC itself. In addition, 21.3 percent reported that information sharing is at times restricted between UIRC faculty and other faculty within the same university. Twenty-nine percent of respondents reported that communication is restricted between UIRC faculty and faculty at other universities. Furthermore, 41.5 percent of UIRCs reported that information sharing between UIRC faculty and the general public is at times restricted.

TABLE 26

Industry Effect on Communication and Information Flows: 1990

	Number of UIRCs	Percent of UIRCs
No restrictions	208	43.4
UIRCs Where Industry Participants Can Place Restrictions on Communication with or among:		
UIRC faculty	64	13.4
Other faculty members	102	21.3
Faculty at other universities	137	28.6
Participating companies (not involved in a project)	191	39.9
Non-participant companies	254	53.0
General public	199	41.5

N=479

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

A related issue is the ability of participant firms to affect publication either by imposing a delay or requiring information to be deleted from research papers before submission for publication (see Table 27). Almost 35 percent reported that participating companies can require information to be deleted from research papers before submission for publication. More than half (52.5%) reported that participating companies can delay the publication of research findings. Almost one-third of UIRCs (31.1 percent) reported that participating companies are able to both delay publication and have information deleted from research papers and reports. Note that our survey asked UIRC directors to report whether participating companies *can* delay publication or require that information be deleted. Our data do not indicate the actual frequency with which publication is delayed or information deleted. Furthermore, our survey data do not indicate what kind of information (e.g., proprietary) companies can ask to have deleted.

TABLE 27

Research Disclosure Restrictions by Importance of of Mission to Improve Industry's Products or Processes: 1990

	Information Can Be Deleted from Publication	Publication Can Be Delayed	Both Restrictions
Percent of Entire Sample (N=488)	34.8	52.5	31.1
Percent of UIRCs by Mission Importance:			
(1) Not Important (N=67)	20.9	38.8	19.4
(2) Somewhat Important (N=131)	22.9	46.6	19.8
(3) Important (N=159)	37.7	55.3	33.3
(4) Very Important (N=117)	53.9	63.2	48.7

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

TABLE 28

Type of Intellectual Property Granted by UIRCs to Participating Companies by Importance of Mission to Improve Industry's Products or Processes: 1990

Type of Intellectual Property Granted by UIRCs	Licenses	Patents	Exclusive Licenses	Copyrights
Percent of Entire Sample (N=511)	45.8	26.0	26.0	14.5
Percent of UIRCs by Mission Importance:				
(1) Not Important (N=68)	36.8	16.2	11.8	10.3
(2) Somewhat Important (N=133)	42.1	17.3	18.8	10.5
(3) Important (N=164)	46.3	26.8	30.5	15.9
(4) Very Important (N=126)	54.8	40.5	35.7	21.4

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

Not surprisingly, the extent of industry's influence over publication varies with the degree of importance the UIRC attaches to the goal of improving industry's products or processes. Compared to UIRCs that indicate this goal is unimportant, UIRCs that hold this goal as very important are more than twice as likely to permit participating firms to have information deleted, and more than 50 percent more likely to allow firms to delay publication.

Table 28 reports the types of intellectual property UIRCs provide to industrial participants. A little more than half of the respondents (52.8 percent) indicated that patents, licenses or copyrights were granted. Slightly more than one-quarter (26.0 percent) of all UIRCs assigned patents to industry, 45.8 percent granted licenses, 26.0 percent granted exclusive licenses and 14.5 percent granted copyrights. Thus, many UIRCs appear willing to grant proprietary rights over intellectual property to participating companies. Here again, one might suspect that UIRCs that see their primary mission as improving industry's products and processes to be more likely to confer intellectual property rights than UIRCs that have a more academic orientation. As Table 28 shows, the survey data confirm this conjecture. The willingness of UIRCs to grant such property rights clearly increases with the degree of importance they attach to this commercial mission. The granting of exclusive licenses shows the sharpest trend, increasing threefold along this dimension.

Offsetting the costs represented by restrictions on the public disclosure of research, UIRCs—and universities more broadly—derive benefits from their relationships with industry. The most obvious benefit is financial support. As Table 29 shows, more than 90 percent (91.3 percent) of UIRCs report this as a benefit. More than two-thirds (68.1 percent) of UIRCs reported that they received equipment from industry. A large share of UIRCs reported that the ability to interact with industry was important in itself, with 69.7 percent of UIRCs viewing the "opportunity to confer with industry" as important. More than half (55.8 percent) indicated that "information on industry needs" was obtained and another 44.8 percent indicated that access to industrial facilities and data was obtained from interacting with industry. Thirty-six percent indicated that industry provided research direction for the center.

TABLE 29

UIRC Benefits to Universities: 1990

	Number of UIRCs	Percent of UIRCs
R&D Funds	461	91.3
Opportunity to Confer with Industry	352	69.7
Equipment	344	68.1
Information on Industry Needs	282	55.8
Operational Funds	245	48.5
Access to Industrial Facilities	226	44.8
Practical Experience for Students	191	37.8
Research Direction	180	35.6
Industry Personnel Loaned to Academic Programs	112	22.2
Other	31	6.1
None of the above	4	0.8

N=505

Source: Cohen, Florida and Goe, *UIRC Survey*, Carnegie Mellon University, 1991.

The results of the UIRC survey suggest there is a tradeoff between UIRCs' commitment to the traditional academic norm of the free flow of ideas and the advance of commercial technology. In order to elicit industry participation in UIRCs, universities have weakened their norms regarding full public disclosure of research findings. Industry is able to place restrictions on information sharing, including communication with other university faculty members and with the general public. Participating companies can also restrict the publication of research findings. There appears to be, however, a social benefit acquired at the cost of these restrictions. Table 19 shows that as UIRCs embrace industry's goals, the tangible and intangible UIRC outputs that stimulate technical advance increase, at least in the short run. Moreover, the social cost of these restrictions may not be so significant if the alternative to conducting this research within UIRCs is conducting the same research within industry subject to even greater restrictions.

10. Conclusion

Our study has examined the magnitude, scope and activities of UIRCs and their role in technical advance, technology transfer, and science and technology policy. Generally speaking, the data suggest that the link between universities and industries is growing more extensive as UIRCs have expanded considerably over the past decade. Thus, what were once thought of as unusual arrangements are now commonplace. The results of this study inform five major conclusions.

First, the magnitude of UIRC activity is significant. UIRCs spent an estimated $4.12 billion on research and related activities in 1990. There are an estimated 1,056 UIRCs at more than 200 American campuses, with more than half of these established in the 1980s. Government is the major contributor to UIRCs, providing nearly half of their total funding. Although industry was not the major source of financial support for UIRCs, its contribution to UIRCs in 1990 did constitute the preponderance of industrial support for academic R&D. Furthermore, a significant number of university faculty, researchers and students nationwide are exposed to UIRC activities. We estimate that as many as 12,000 university faculty members and 22,300 doctoral-level researchers participate in UIRCs.

Second, the primary impetus for UIRCs has come from the entrepreneurial efforts of universities, encouraged by government programs that tie university research support to industry participation. This leads us to conclude that government funding—both its level and its character—constitutes an important policy tool affecting the relationship between university and industry.

Third, the output of UIRCs is significant. The UIRCs in our sample generated 211 patents, equivalent to almost 20 percent of the total of 1,174 patents granted to universities in 1990. UIRC patent productivity (patents per million of dollars) is at least comparable to that of the applied science and engineering research conducted at universities. UIRC patent productivity is roughly one-third that of industrial R&D laboratories. UIRC knowledge output appears to affect the innovation process importantly by contributing to product and process improvements and by helping to make private sector R&D more efficient. UIRCs have helped to reinforce and create channels through which both the knowledge emanating from university research can flow into industry and through which information on the needs of industry can inform and guide university science and technology. Furthermore, one of the most important effects of UIRCs is their educational function, with a significant number of students affiliated with UIRCs hired by participating firms.

Fourth, there is great diversity among UIRCs. An important way that UIRCs differ is in terms of the goals and objectives they pursue, and these differences are reflected in their output and performance. The greatest apparent impact on commercial technology comes from UIRCs whose main mission is the improvement of industry's products and manufacturing processes. These commercially-oriented UIRCs generate substantially more innovations, prototypes and licenses than those that are concerned with traditional academic pursuits. This does not imply, however, that the latter type of centers may not have an equally, if not a more profound effect on technical advance in the long run. The productivity and performance of UIRCs also varies by field of technology and by size, with small UIRCs apparently outperforming large UIRCs across virtually every dimension of output and productivity. However, we caution against drawing any policy implication from this finding until its underlying causes are more thoroughly understood. It is also important to note that our findings on output and performance reflect responses from UIRC directors, not from the industrial participants in UIRCs.

Fifth, the closer integration of industry and university research reflected in UIRC formation appears to pose a tradeoff for society. In simple terms, this tradeoff is between an industrial orientation that appears to promote technical advance in the short run and UIRC commitment to the traditional academic norm of free dissemination of research findings. Industrial participants are able to restrict communication flow and information sharing, and cause publication delays or deletions of certain findings. More than 40 percent reported that information sharing between UIRC faculty and the general public is at times restricted. Almost 35 percent of UIRCs reported that participating companies can require information be deleted from research papers before submission for publication. And, nearly one-half of UIRCs reported that participating companies can delay the publication of UIRC findings. Here, we reiterate that our survey asked UIRC directors to report whether participating companies *can* delay publication or require that information be deleted, not whether these restrictions were actually imposed.

Thus, largely to obtain industry funding, universities have weakened their long-held commitment to the free flow of information and the full public disclosure of research findings. Yet, the costs associated with the weakening of these traditional academic norms appears to be offset, at least to some extent, by the benefits of more effective mechanisms for advancing commercial technology. Our findings suggest that as UIRCs embrace industry's goals, they tend to have a greater impact on the advance of commercial technology, at least in the short run.

On a somewhat broader level, our findings have implications for the ongoing debate over the appropriate level and nature of federal government involvement in university research, and the relationships among government, the universities and industry. Mounting international economic pressure on American industry has led to calls for greater research relevance and to skepticism about the value of university research conducted in isolation from industrial concerns and priorities. There is also a growing movement toward evaluating university research more in terms of its economic value—an economic value that is both more tangible and immediate than heretofore. From what we have found, a significant number of UIRCs are already addressing these concerns.

About the Project

This report summarizes the key findings of a three-year study of university-industry research centers in the United States. The project's work was carried out by an interdisciplinary team of faculty members and graduate students at Carnegie Mellon University's H. John Heinz III School of Public Policy and Management, Department of Social and Decision Sciences, and Department of Engineering and Public Policy. The project was supported principally by a grant from the Ford Foundation with supplementary funding from the Duquesne Light Company.

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Endnotes

[1]Mansfield estimated the social rate of return to academic research during the 1975-1985 period to be 28 percent. A figure that in his words "is based upon crude (but somewhat conservative) calculations and that is presented only for exploratory and discussion purposes" (1991: 11). However, Mansfield's results indicate that the social rate of return to university research differs significantly by field.

[2]Research administrators for each of these universities were initially contacted by telephone and asked to provide a list of UIRCs that met the operational criteria. As a result of this phone survey, 386 (88.3 percent) of the universities responded. Out of the responding universities, 203 reported having affiliated UIRCs that met the operational criteria while 183 reported having none. During this phase of the research, a total of 1,074 UIRCs were identified at 203 American universities and colleges. Comparisons of the phone survey responses with the lists of UIRCs obtained from secondary sources revealed some discrepancies. Evaluations of the phone survey responses revealed that a number of listings did not conform to the operational definition of a UIRC. Consequently, a mail survey of the university research administrators was conducted. University research administrators were sent the list of UIRCs obtained from the phone survey of their respective universities and the list of UIRCs obtained from secondary sources. They were asked to verify the accuracy of the phone survey responses and evaluate the list from secondary sources to see if any of these listings also met the operational criteria. Universities not responding to the initial phone survey were also sent lists of UIRCs from secondary sources and asked to evaluate them as well as to provide listings of additional UIRCs not included on the secondary lists. This procedure both refined the accuracy of the list representing the universe of UIRCs and yielded responses from 18 additional universities that did not respond to the phone survey, increasing the response rate to 92.4 percent.

[3] Note, however, the sample of UIRCs is necessarily confined to UIRCs that were in existence in 1990.

[4]While these estimates are supposed to reflect full-time staff only, several responses are extraordinarily high and the overall distribution of responses is extremely skewed (the skewness for total employment is 7.1). Thus, it may be that a number of UIRCs responded to this question incorrectly.

[5]The National Science Foundation does not provide these data for 1990.

[6] More than half of UIRCs founded after 1980 ranked this goal as important. In addition, one-third of UIRCs (33.0 percent) founded between 1980 and 1984 ranked this goal as very important, and an additional 28.3 percent ranked it as important. Of the UIRCs established after 1984, two-thirds ranked it as important, with one-third (33.3 percent) responding very important and another third (33.3 percent) responding important.

[7] Recall that the survey question regarding discipline was not exclusive. The survey did not constrain UIRC directors to choose one discipline or to rank disciplines by the level of contribution, but simply to designate all disciplines to which the UIRC contributed.

[8]The intermediate outcomes were elicited from survey respondents as categorical variables. For the purpose of summarizing the mean and mode values for these measures, we assigned the following values to them. For zero, we simply use zero. For the category "1 to 5 times," we use 3. For the category "6 to 10 times," we use 8. For "11 to 15 times," we use 13. And for the category "greater than 15 times," we use 15.

[9]Absent time series data, we cannot estimate the lags that would permit us to link UIRC efforts to the outputs they actually generate.

[10]Since 26 percent of UIRCs grant patents to participating firms (see Table 28), we do not know what fraction of the UIRCs' 211 patents were assigned to universities and thus cannot express UIRC patent output as a fraction of university patent output.

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Appendix A

Universities and Colleges Represented in the Sample of University-Industry Research Centers

Arizona State University
Auburn University
Bowling Green State University
Brigham Young University
Brown University
California Institute of Technology
Carnegie Mellon University
City University of New York Mt. Sinai School of Medicine
Clarkson Univeristy
Clemson University
Cleveland State University
Colorado School of Mines
Colorado State University
Columbia University
Cornell University
Creighton University
Dartmouth College
Delta State University
Desert Research Institute
Drexel University
Duke University
Emory University
Florida Atlantic University
Fresno State University
George Mason University
George Washington University
Georgia Institute of Technology
Harvard University
Harvey Mudd College
Indiana State University
Institute of Textile Technology
Iowa State University
Johns Hopkins University
Kansas State University
Lamar University
Linfield College
Long Beach State University
Louisiana State University
Marquette University
Marshall University
Massachusetts Institute of Technology
Memphis State University
Miami University
Michigan State University
Michigan Technological University
Milwaukee School of Engineering
Mississippi State University
Montana College of Mineral Science and Technology
Montana State University
New Jersey Institute of Technology
New Mexico Institute of Mining and Technology
New Mexico State University
New York Institute of Technology
North Carolina State University
North Dakota State University
Northeastern University
Northwestern University
Oakland University
Ohio State University
Oklahoma State University
Old Dominion University
Oregon State University
Pennsylvania State University
Princeton University
Purdue University
Rensselaer Polytechnic Institute
Rochester Institute of Technology
Rutgers University
Santa Clara University
Southeastern Massachusetts Univeristy
Southern Illinois University-Carbondale
Southern Illinois University-Edwardsville
Southwest Texas State University
Stanford University
State University of New York College at Albany
State University of New York College at Binghamton
State University of New York College at Brockport
State University of New York College at Buffalo
State University of New York College of Environmental Science & Forestry
Stevens Institute of Technology
Tennessee Technological University
Texas A&M University
Tufts University
Tulane University
University of Akron
University of Alabama

University of Alabama-Huntsville
University of Alaska-Fairbanks
University of Arizona
University of Arkansas
University of California-Berkeley
University of California-Davis
University of California-Irvine
University of California-Los Angeles
University of California-Santa Barbara
University of California-Santa Cruz
University of Central Florida
University of Colorado
University of Connecticut
University of Dayton
University of Delaware
University of Denver
University of Detroit
University of Florida
University of Georgia
University of Houston
University of Idaho
University of Illinois-Chicago
University of Illinois-Urbana-Champaign
University of Iowa
University of Kansas
University of Kentucky
University of Lowell
University of Maine
University of Maryland
University of Massachusetts
University of Michigan
University of Minnesota
University of Mississippi
University of Missouri-Columbia
University of Missouri-Kansas City
University of Missouri-Rolla
University of Montana
University of Nebraska Medical Center at Omaha
University of New Hampshire
University of New Mexico
University of North Carolina at Chapel Hill
University of North Dakota
University of North Texas University of Oklahoma
University of Pennsylvania
University of Pittsburgh
University of Puerto Rico
University of South Alabama
University of Sourth Florida
University of Southern California
University of Southern Mississippi
University of Southwestern Louisiana
University of Tennessee
University of Texas-Austin
University of Toledo
University of Tulas
University of Utah
University of Vermont
University of Virginia
University of Washington
University of Wisconsin-Madison
University of Wisconsin-Milwaukee
University of Wyoming
Utah State University
Vanderbilt University
Washington State University
Wayne State University
Webb Institute of Naval Architecture
West Virginia University
Western Illinois University
Western Washington University
Wichita State University
Worcester Polytechnic Institute
Yale University

APPENDIX B

Difference in Means Between Responding and Non-Responding UIRCs

	Mean of Respondents	Mean of Non-respondents	*t statistic on difference of Means
Scale Variables			
Total Annual Cash Budget	$3,886,591	$3,207,412	0.70
	(412)	(68)	
Number of R&D Projects	35.40	42.50	0.47
	(487)	(70)	
Number of Companies providing support	17.60	18.57	0.18
	(491)	(69)	
Scope Variables			
% Effort Dedicated to R&D	66.24%	58.06%	2.73**
	(499)	(72)	
% Effort Dedicated to Education	18.86	24.04	2.32*
	(499)	(70)	
% Effort Dedicated to Technology Transfer	6.62	10.51	3.46**
	(499)	(70)	
% Effort Dedicated to Technical Assistance	6.45	4.94	0.96
	(499)	(70)	
% Effort Dedicated to Entrepreneurship	1.85	2.33	0.67
	(499)	(70)	

N in parentheses

*Differences were statistically significant ($P < 0.05$)

**Differences were statistically significant ($P < 0.01$)