CHALLENGES TO RESEARCH UNIVERSITIES

Roger G. Noll
Editor

Challenges to Research Universities

ROGER G. NOLL
Editor

Brookings Institution Press
Washington, D.C.

Chapter 7

Industry and the Academy: Uneasy Partners in the Cause of Technological Advance

Wesley M. Cohen, Richard Florida, Lucien Randazzese, and John Walsh

The relationship between academic research and industrial R&D has come under intense scrutiny in the past fifteen years. Academic research is perceived to be both too distant from the needs of most industries and, for those few industries where its relevance is apparent, too close to industry. Reflecting the predominant sentiment that academic research is too distant from industry, policymakers, motivated by government spending constraints and stiffening international economic competition, have called on universities to advance commercial technology more effectively by making their science and engineering research more relevant to industry's needs. Even the National Science Foundation has embraced this mission with creation of the Science and Technology Centers and other programs that tie support to industrial participation. At the same time, controversy has been sparked by concerns that academic research has grown too close to industry in areas such as biotechnology. Critics fear that deepening commercial ties in such areas may be undermining academe's commitment to both basic research as

The authors thank Richard Nelson, a collaborator on a related project, for helpful discussions, and David Hounshell for comments.

well as the academic norm of free disclosure—a norm that contributes to research quality and to the cumulative advance of science and engineering more generally.[1]

Stimulated by these controversies, in this chapter we examine new survey evidence along with other recent findings to assess the impact of university research on industrial R&D. We also look at the effect of ties with industry on the conduct of academic research in science and engineering. We then consider possible implications of this evidence for the cause of technological advance itself.

This chapter draws heavily on two survey research projects in which the authors have been involved. The first examines university-industry R&D centers in the United States.[2] The second considers the impact of university R&D on industrial R&D for the U.S. manufacturing sector, as well as a broad range of other issues bearing on the nature and determinants of industrial R&D.[3]

The Effect of University R&D on Industry

This section briefly reviews recent findings on the effects of university research in science and engineering on industrial R&D and then reports selected findings from the 1994 Carnegie Mellon Survey on Industrial R&D in the U.S. manufacturing sector. Most of the findings from both the literature and the recent surveys concern relatively short-term effects of university research (that is, within twenty years). Although concerns about short-term effects fuel the current policy debate, the long-term effects of university research on technical advancement are clearly important but are not examined here. Because many suspect that these effects are considerable, omitting them is regrettable but unavoidable because of the dearth of systematic data on the subject.

The conventional view holds that the short-term impact of university research on industrial R&D is negligible except in a few industries.[4] Accumulating evidence suggests that we revise this perception. Studies published since 1989, as well as the results of the 1994 Carnegie Mellon Survey, suggest that university research provides critical short-term payoffs in some industries

(such as pharmaceuticals) and is broadly important in numerous industries.

Klevorick, Levin, Nelson, and Winter conducted a 1983 survey of 650 R&D managers in 128 industries (with industries defined between the three- and four-digit SIC code levels). The researchers asked respondents to indicate on a seven-point Likert scale the relevance to their industry's technological progress of university research for each of eleven scientific and engineering disciplines.[5] The results largely confirmed conventional wisdom. Of the seventy-five industries for which the researchers received three or more responses, only fourteen (less than 20 percent) gave an average Likert score of at least four for any discipline. These fourteen industries were predominantly in the health or agricultural fields; but the list also included materials-based industries, scientific instruments, and semiconductors, among others.

One of the main conclusions of this effort is that university research was highly relevant to industrial R&D in some industries. Where its relevance was high, the most relevant discipline usually was either an engineering or applied science discipline rather than a basic science. In a few technology areas, basic sciences (particularly biological sciences) made a clear contribution—as in the creation of drugs. The overall conclusion was that university research findings made an important contribution in few industries and only a modest contribution in still a minority of other industries.

The findings from the 1984 survey by Blumenthal and others of 110 biotechnology firms were consistent with the 1983 survey by Klevorick and others[6] since biotechnology falls largely into one of the few domains, drugs, where the latter found the role of university research to be critical to industrial R&D. The survey by Blumenthal and others indicated that 46 percent of their sample firms supported university research, suggesting that a significant percentage of firms in biotechnology recognize its importance. The authors of the survey also found that university research produced a comparable number of patents per R&D dollar to the firms' own in-house research.

Another, more recent survey by Blumenthal and others obtained qualitatively similar results for a sample of firms spanning more industries.[7] In a 1994 survey of large firms in the life sciences industries (defined as including agriculture, chemicals, and drugs), they found that 59 percent of the firms supported research in universities. Moreover, more than 60 percent of the firms supporting university research received patents on products as a consequence of their relationships with universities.

Mansfield's survey of seventy-six firms spanned even more industries, including information processing, electrical equipment, and instrument, drug, metal, and oil firms.[8] Respondents estimated that for the period 1975–85, 10 percent of new products and processes would have been "substantially delayed" in the absence of "recent" academic research, where "recent academic research" refers to research conducted within the prior fifteen years, and a "substantial delay" refers to one of a year or more. Of the surveyed industries, three (namely chemicals other than drugs, oil, and electrical) fell well below the average of 10 percent. Mansfield estimated that this 10 percent of new products and processes that would have been substantially delayed accounted for $24 billion in sales in 1985. On the basis of these data and estimates of the lags associated with the commercial effects of academic R&D, Mansfield estimated that the annual social rate of return to investment in academic research during 1975–78 was 28 percent.

Mansfield's survey findings and analysis highlight two important points. They suggest that the short-term effects of academic research may be more widespread than commonly thought. However tentative his analysis of the economic returns to academic R&D may be, it also shows that, though the effect of academic R&D may appear small relative to the level of economic activity more generally (for example, it affected "only" 10 percent of sales), its absolute effect and the associated returns to academic R&D may be quite large.[9]

Rather than employ survey research methods, in two studies Jaffe and Adams employ regression analyses in a production function framework to evaluate the impact of academic research on technical advance.[10] Employing state-level aggregations of industrial patenting activity and university R&D, Jaffe examines the effect of academic research on industrial patenting activity. Patents were classified in four broadly defined academic fields: drugs, chemicals, electronics, and the mechanical arts. Jaffe finds evidence of geographically mediated effects of university research on industrial patenting activity—most strongly in drugs, but also in chemicals and electronics. For a range of industrial activity even broader (although more aggregate) than that represented in Mansfield's study, Jaffe observes an apparent influence of university R&D that, while strongest for drug-related R&D, is reasonably pervasive.[11]

In research covering almost the entire U.S. manufacturing sector (that is, eighteen of the twenty two-digit SIC manufacturing industries), Adams estimates the effects of academic R&D on manufacturing productivity and the lags associated with those effects. He found the effects to be important and pervasive.[12] Adams estimated that the time required for academic research in the basic sciences to affect industrial productivity is twenty years, but for applied sciences and engineering the lag is between zero and ten years.[13]

The 1994 Carnegie Mellon Survey (CMS) of 1,478 R&D lab managers in the U.S. manufacturing sector suggests that the short-run effects of university research on industrial R&D are widespread.[14] In contrast with the results Klevorick and others obtained from data gathered in 1983, the CMS indicates that in two-thirds of the U.S. manufacturing industries surveyed, R&D managers estimated on average that academic research in at least one field was at least "moderately important" to their R&D activities (that is, scoring at least a three on a four-point Likert scale).[15] As shown in table 7-1, the survey also found that for the manufacturing sector overall, 15 percent of R&D projects are reported as using university research. Although the question is phrased differently from Mansfield's, this figure is nonetheless consistent with the findings for his more restricted sample.

The percentage of R&D projects using university research varies substantially across industries. For eight of the thirty-four industries, respondents report that 20 percent or more of their R&D projects use university research. These industries include petroleum refining, food, drugs, miscellaneous chemicals (including specialty chemicals), steel, semiconductors, search and navigation equipment, and aerospace. This list of industries not only

Table 7-1. *Form of Academic Outputs Used in Industrial R&D*[a]
Mean

		Percentage of industrial R&D projects using academic output by form of output		
Industry	*N*	*Research*	*Prototypes*	*Instruments*
1500:Food	93	19.57	6.72	14.52
1700:Textiles	23	5.44	4.35	5.44
2100:Paper	30	17.33	5.83	15.00
2200:Printing/publishing	12	10.42	4.17	10.42
2320:Petroleum	15	24.67	1.67	11.33
2400:Chemicals	65	11.92	3.46	8.85
2411:Basic chemicals	37	12.84	1.35	8.78
2413:Plastic resins	28	7.14	0.89	8.93
2423:Drugs	52	32.40	9.14	17.31
2429:Miscellaneous chemicals	29	20.35	6.90	15.52
2500:Rubber/plastic	34	10.29	5.15	8.82
2600:Mineral products	19	14.21	2.63	9.21
2610:Glass	6	16.67	8.33	16.67
2695:Concrete, cement, lime	10	7.50	2.50	12.50
2700:Metal	8	18.75	3.13	12.50
2710:Steel	10	20.00	5.00	10.00
2800:Metal products	45	8.33	4.24	7.07
2910:General purpose machinery	76	10.20	6.84	7.24
2920:Special purpose machinery	68	14.34	6.18	8.75
2922:Machine tools	10	12.50	5.00	2.50
3010:Computers	22	12.50	1.14	11.36
3100:Electrical equipment	22	6.82	5.68	4.55
3110:Motor/generator	21	10.71	1.19	3.57
3130:Wiring	3	0.00	0.00	0.00
3210:Electronic components	26	14.42	7.69	11.35
3211:Semiconductors and related equipment	19	23.68	3.95	11.11
3220:Communications equipment	34	16.03	5.15	8.09
3230:TV/radio	8	12.50	12.50	21.88
3311:Medical equipment	69	19.49	6.09	11.88
3312:Precision instruments	36	9.03	8.89	15.97
3314:Search/navigational equipment	38	20.40	5.26	11.84
3410:Car/truck	9	16.67	8.33	19.45

Table 7–1. *continued*
Mean

		Percentage of industrial R&D projects using academic output by form of output		
Industry	*N*	*Research*	*Prototypes*	*Instruments*
3430:Autoparts	34	9.56	8.68	12.35
3530:Aerospace	49	22.45	8.16	13.78
3600:Other manufacturing	87	12.93	8.05	10.63
All	1,147	15.12	5.79	10.92

Source: W.M. Cohen, R.R. Nelson, and J. Walsh, "Links and Impacts: New Survey Results on the Influence of University Research on Industrial R&D," Carnegie Mellon University, 1996.

[a]Computed using 0 percent for response category 0–10 percent. Otherwise used midpoint means for the following response categories: (1) 11 to 40 percent; (2) 41 to 60 percent; (3) 61 to 90 percent; (4) 91 to 100 percent.

includes high-technology industries (semiconductors, drugs, and medical equipment) but also industries typically considered to be mature (petroleum refining and steel).

Another finding of the Carnegie Mellon Survey (CMS), consistent with the earlier arguments posed in studies by Rosenberg and others, is that industrial R&D labs use research techniques and instrumentation developed in universities.[16] Examples are magnetic resonance imaging (MRI) and recombinant DNA research. As reported in table 7-1 for manufacturing overall, respondents report that 11 percent of industrial projects make use of techniques or instrumentation developed in universities. Again, cross-industry differences are significant. Fifteen percent or more of industrial R&D projects are reported to use techniques and instrumentation developed in universities in seven of thirty-four industries, including paper, drugs, miscellaneous chemicals (including specialty chemicals), glass, television and radio, precision instruments, and cars and trucks.

The CMS sheds light on how information from university research contributes to industrial R&D. One view of the role of university research, consistent with a long-standing conception of the role of basic research generally, is that it produces new ideas for industrial R&D projects.[17] University research also serves a second function, phrased in the survey as "contributing to the execution of existing R&D projects"—what may be called problem solving. This function could be seen as solving problems on how to do research. The survey finds that university research suggests new R&D projects and contributes to project execution almost comparably across the manufacturing sector, with the latter being a little more important. Again, however, there are significant cross-industry differences in the patterns regarding the role of university research. The CMS finds that university research contributes principally to problem-solving in medical equipment, search and navigation equipment, cars and trucks, and aerospace, among others. University research principally provides new R&D project ideas in petroleum refining, steel, machine tools, semiconductors, and precision instruments.

Another measure of the importance of university research to industrial R&D is provided by comparing its contribution with that of three other well-recognized extramural information sources: buyers, suppliers, and competitors (although with somewhat different effect). The CMS results indicate that universities do not have as important an effect as buyers and suppliers; however, universities are as significant a source of information as competitors. This finding is important in light of the wealth of empirical studies (surveyed by Griliches) that indicate that "R&D spillovers" from competitors make substantial contributions to technical advance and productivity growth within industries.[18] If universities are comparable in importance to competitors, they have a substantial effect on industrial R&D.

The Carnegie Mellon Survey provides valuable insights into how useful information moves from universities to industrial R&D facilities. To evaluate the importance of the different information channels with the CMS data, we computed the percentage of respondents indicating that a given channel is at least "moderately important." As shown in table 7-2, the four dominant channels of communication between university research and industrial R&D are publications (with 41 percent of respondents indicating that publications are at least "moderately important"), public meetings and conferences (34 percent), informal information channels (35 percent), and consulting (32 percent). A factor analysis indicates that these four

information channels tend to be used together. This indicates that person-to-person interactions, such as informal information exchange or consulting, tend to be used with and complement more public channels, such as publications or conferences.[19] Other, less important channels of communication include recent hires, joint or cooperative ventures between industry and universities, patents, and contract research.

In summary, the recent CMS results suggest that academic R&D is central to technical advance in a small number of industries and is also broadly useful. This overall result (though consistent with more recent analyses) signals a change, particularly from the study by Klevorick and others, which based its results on a survey administered in 1983, eleven years before.[20] Why the change? There are a number of possible explanations.

First, the change may be real. One factor that could account for the growing influence of academic research across the manufacturing sector is deepening ties that have developed between universities and industry since 1980 (discussed below). These ties have been stimulated by an aggressive response by faculty and university administrations to shifts in policy surrounding the support of academic research. A complementary factor may be downsizing of central and typically more upstream industrial R&D activities, which is believed to have occurred over the past decade.[21] Downsizing may have induced firms to rely more on academics for the kind of research that they supported internally in the past.

A second possible explanation for the new findings is that the change is simply perceptual. According to this explanation, nothing has changed. However—perhaps due to the greater visibility of selected academic R&D activities in biotechnology, computer science, robotics, and the like—firms simply believe that academics are contributing more to industrial R&D.

A third possible explanation is that the new results reflect only different samples and a new survey instrument that poses both different questions and similar questions differently. This last possibility raises the question of which survey to believe. The CMS offers advantages leading one to conclude that it is more reliable. Rather than restrict itself exclusively to one question

Table 7-2. *Importance to Industrial R&D of Information Sources on University Research*

Percentage respondents indicating "moderately" or "very" important

	N	*Patents*	*Pubs.*	*Meetings or conferences*	*Informal channels*	*Hires*	*Licenses*	*JV's*	*Contract research*	*Consulting*	*Personal exchange*
1500:Food	92	9.78	51.09	38.04	43.48	21.74	10.87	22.83	29.35	46.74	7.61
1700:Textiles	23	13.04	26.09	26.09	21.74	21.74	0.00	13.04	8.70	13.04	0.00
2100:Paper	31	9.68	45.16	35.48	32.26	9.68	0.00	19.35	35.48	22.58	3.23
2200:Printing/publishing	12	16.67	33.33	25.00	16.67	8.33	8.33	0.00	16.67	25.00	0.00
2320:Petroleum	15	0.00	46.67	53.33	33.33	13.33	13.33	13.33	26.67	46.67	0.00
2400:Chemicals	64	25.00	34.37	28.12	18.75	18.75	7.81	15.62	20.63	26.56	9.37
2411:Basic chemicals	36	16.67	30.56	25.00	33.33	19.44	2.78	16.67	19.44	33.33	2.78
2413:Plastic resins	26	11.54	34.62	26.92	23.08	23.08	0.00	3.85	11.54	15.38	0.00
2423:Drugs	51	56.86	72.55	60.78	60.78	31.37	35.29	41.18	54.90	54.90	7.84
2429:Miscellaneous chemicals	29	27.59	37.93	27.59	31.03	24.14	3.45	3.45	13.79	24.14	0.00
2500:Rubber/plastic	34	5.88	17.65	14.71	8.82	14.71	2.94	11.76	8.82	20.59	0.00
2600:Mineral products	19	5.26	26.32	21.05	21.05	31.58	5.26	10.53	10.53	26.32	10.53
2610:Glass	6	33.33	50.00	50.00	50.00	50.00	16.67	50.00	33.33	33.33	0.00
2695:Concrete, cement, lime	10	30.00	50.00	30.00	20.00	30.00	30.00	10.00	10.00	10.00	10.00
2700:Metal	7	28.57	71.43	71.43	85.71	28.57	0.00	28.57	42.86	57.14	14.29
2710:Steel	11	18.18	36.36	54.55	45.45	18.18	18.18	36.36	54.55	36.36	18.18
2800:Metal products	47	21.28	27.66	14.89	25.53	19.15	8.51	14.89	10.64	23.40	4.26
2910:General purpose machinery	73	16.44	31.94	26.03	30.14	13.70	8.22	10.96	13.70	32.88	1.37
2920:Special purpose machinery	67	19.40	31.34	32.84	26.87	17.91	11.94	17.91	16.42	32.84	2.99
2922:Machine Tools	10	10.00	40.00	40.00	40.00	20.00	0.00	10.00	20.00	40.00	0.00
3010:Computers	24	8.33	41.67	41.67	33.33	33.33	4.17	8.33	8.33	29.17	4.17
3100:Electrical Equipment	22	9.09	31.82	22.73	22.73	0.00	0.00	9.09	13.64	9.09	0.00
3110:Motor/Generator	22	4.55	40.91	36.36	45.45	13.64	0.00	22.73	13.64	31.82	4.55
3210:Electronic Components	25	20.00	36.00	28.00	36.00	32.00	12.00	12.00	8.00	33.33	4.00
3211:Semiconductors and Related Equipment	18	22.22	61.11	55.56	64.71	27.78	16.67	27.78	16.67	33.33	5.56
3220:Communications Equipment	34	5.88	50.00	32.35	32.35	29.41	8.82	8.82	17.65	29.41	20.59
3230:TV/Radio	8	25.00	75.00	37.50	37.50	25.00	12.50	37.50	25.00	25.00	12.50
3311:Medical Equipment	69	27.54	37.68	34.78	46.38	18.84	18.84	23.19	23.19	44.93	5.80
3312:Precision Instruments	36	25.00	50.00	44.44	44.44	11.11	13.89	19.44	8.33	36.11	5.56
3314:Search/Navigational Equipment	37	5.41	51.35	48.65	48.65	21.62	13.51	29.73	35.14	43.24	13.51
3410:Car/Truck	9	33.33	33.33	11.11	33.33	11.11	11.11	22.22	33.33	22.22	11.11
3430:Autoparts	32	9.37	43.75	31.25	25.00	18.75	9.37	21.87	18.75	21.87	9.37
3530:Aerospace	48	14.58	58.33	50.00	54.17	18.75	6.25	39.58	35.42	39.58	4.17
3600:Other Manufacturing	83	13.25	33.73	33.73	32.53	18.07	6.02	10.84	18.07	21.69	8.43
All	1,130	17.61	40.91	34.42	35.28	19.91	9.73	18.49	21.26	32.15	5.84

Source: Cohen, Nelson, and Walsh, "Links and Impacts."

using subjective response categories defined along a Likert scale, the CMS poses numerous questions on the subject, most of which provided objective response categories. Moreover, in the process, the CMS forced respondents to think about the contribution of university research in tangible ways.

Effects of Industrial Ties on Academic Research

This section considers the impact of these deepening ties with industry on academic research, specifically on its composition and public dissemination. Although this is of interest for its own sake, the composition and dissemination of university R&D also may have important implications for technological progress in the long run.

The relationship between university research and industry has deepened substantially since the mid-1970s. There were an estimated 1,056 university-industry R&D centers in the United States as of 1990.[22] One survey indicates that although the first of these centers was established in the 1880s, almost 60 percent were established between 1980 and 1989. Moreover, the magnitude of R&D activity performed by these centers is substantial. These centers spent an estimated total of $4.1 billion in 1990, with $2.9 billion spent on R&D. This is more than double the National Science Foundation's $1.3 billion in support for all academic R&D in 1990, and almost one-fifth of all U.S. academic R&D expenditures in science and engineering.

Another indicator that university research is moving closer to the commercial sector is academic patenting activity. In 1974, 177 patents were awarded to the top 100 research universities. In 1984, that number increased to 408, and in 1994 it jumped dramatically to 1,486 patents.[23] Related to this increase in university patenting activity, gross royalties from licenses have also increased. According to a survey conducted by the Association of University Technology Managers, gross royalties from licenses from 101 surveyed universities grew from $163 million in 1991 to $318 million by 1994.[24] The formation of university offices administering technology transfer and licensing also reflects growing ties between industry and university research. In 1980, twenty-five American universities had such offices; by 1990, the number had grown to 200.[25]

The share of academic R&D supported by industry has also increased. Although government still supports the bulk of academic R&D, the share accounted for by industry more than doubled between 1970 and 1990. In 1970 the industry share of support for academic R&D was 2.6 percent. That share grew to 3.9 percent in 1980 and 6.9 percent in 1990. Moreover, we estimate that about half of industry support for academic R&D actually went to university-industry R&D centers in 1990.[26] Although we have no systematic data on either spin-offs or faculty participation in new firms, the anecdotal evidence indicates an increase over the past fifteen years, particularly in biotechnology and software. A related development over the past five years—again, one that is not well documented—is the growing number of instances in which universities hold equity stakes in firms that are spun off to commercialize innovations originating from the universities' research.[27]

Any consideration of the impact of these deepening ties with industry on academic research requires an understanding of the impetus behind those relationships, the reasons such relationships emerged, and the broader incentives of the parties involved. The impetus behind increased industry support for university research comes primarily from universities, not industry. Consistent with Etzkowitz's argument that a norm of entrepreneurialism has diffused across research universities, the results presented in table 7-3 indicate that 73 percent of university-industry research centers (UIRCs) were established because of an immediate impetus originating from universities.[28] A breakdown of that 73 percent figure shows that 61 percent were the result of an impetus from faculty and 12 percent of an impetus from university administrations. Government provided the impetus for approximately 11 percent of these centers, and industry provided it for approximately 11 percent. The funds for university-industry R&D centers, however, come principally from government, not from industry, with government providing 46 percent and industry 31 percent of the funds per center, on average, in 1990.[29]

Table 7-3. *Sources of Immediate Impetus behind Center Formation*

Source	*Percentage of centers*
University	
Faculty	60.9
Administration	11.6
Government	10.9
Industry	10.7
Other	5.9

Source: W.M. Cohen, R. Florida, and L. Randazzese, *For Knowledge and Profit: University-Industry R&D Centers in the United States* (Oxford University Press, forthcoming).

The important and obvious question is, why have the links between industry and universities strengthened since the late 1970s? In light of this discussion, the underlying issue is why faculty are seeking support from industry more aggressively than they had before. The reason is the money, of course, but why now? Academics apparently have felt the need to search for sources of support other than government since 1980 as a result of changes in the policy environment.

The first important change in policy is that competition for federal support has increased since the mid-1970s. Between 1979 and 1991, although the absolute level of federal spending on university research increased, federal support per academic researcher declined.[30] Specifically, federal funding per full time academic scientist active in R&D fell by 9.4 percent in real terms. Moreover, the federal share of academic R&D dropped from 69 percent in 1973 to 58 percent in 1991.[31]

The second policy change is a shift in government attitudes toward collaborations between industry and universities. Prompted largely by growing international competition, legislative changes have encouraged academics to solicit support from industry and have also given industry an incentive to be more forthcoming. Specifically, the Economic Recovery Tax Act of 1981 extended industrial R&D tax breaks to support research at universities. In addition, since the 1970s there has been substantial growth in government programs (such as the NSF's Science and Technology Centers and Engineering Research Centers) that tie government support for university research to industry participation.

Third, policy has changed regarding the ability of universities to profit from their research. The Patent and Trademark Act of 1980, otherwise known as Bayh-Dole, permits universities and other nonprofit institutions to obtain patent rights to the products of federally sponsored research. This legislation permits universities to profit from federal research projects both directly and by assigning patent rights to others, frequently industrial cosponsors.

In addition to understanding the institutional reasons for the deepening ties between industry and universities, it is also helpful to understand the broader incentives of the parties involved. First, consider the firms. They want to profit from the fruits of their support for university research, namely from new or improved processes or products made possible by university research. The immediate outputs of supported research do not necessarily take tangible form, such as inventions, patents, or prototypes. Rather, they often are "intermediate outcomes"—essentially pieces of intangible knowledge that help firms conduct their R&D more efficiently, suggest ideas for new projects, or open up whole new domains for research.[32] Intermediate knowledge outcomes may be transferred to the firm in numerous ways, including papers, informal interactions, hiring of students, and so on.

On the university side of the relationship are two parties, administration and faculty. University administrators appear to be interested chiefly in the revenue generated by relationships with industry. The faculty, who tend to be the prime movers behind these relationships, have two motives.[33] They undoubtedly desire support, per se, because it contributes to their personal incomes (such as by providing summer support or by making them more desirable on the academic market) and allows them to do the research they want to do. In addition, and with important implications for faculty-industry interactions, industry support assists faculty members in conducting research that allows them to achieve academic eminence. Eminence is achieved primarily through foundational research that provides the building blocks for other research and therefore tends to be widely cited. The free and open disclosure of research that provides for its broad dissemination is essential to the achievement of eminence.

The academic quest for eminence, involving the open disclosure of foundational research, conflicts with the profit incentive of firms.[34] Firms tend to be less interested in foundational research because it typically does not address their needs and concerns in a direct, usable way. Firms also prefer less disclosure of research findings to increase the appropriability of the profits of any process or product innovations that may grow out of the research. As highlighted by Dasgupta and David, this conflict between the incentives for academics and those for firms suggests that to secure industry support or otherwise to conduct research for commercial gain, faculty may be induced to shift to more applied research and restrict the disclosure of their research findings.[35]

Consider the evidence that industry support shifts academic research away from more basic research to more applied research and development. In studying the life sciences industry, Blumenthal and others find that industry-supported research tends to be short term.[36] Survey research studies by Rahm and Morgan find an empirical association between greater faculty interaction with industry and more applied research.[37] As shown in table 7-4, the survey of university-industry R&D centers (UIRCs) found that the mission of improving industry's products and processes is indeed associated with a declining share of UIRC effort going toward basic research.[38] Specifically, centers that attach little or no importance to that mission devote 61 percent of their effort to basic research, in contrast with 29 percent of the R&D effort of centers that consider the mission of improving industry's products and processes to be "very important."

Though this evidence may appear compelling, it is inconclusive. It is unclear whether pressure from industry (or, similarly, the lure of personal commercial gain) induces academics to change their research agendas, or whether faculty who are already doing more applied research simply attract more support from industry. This latter possibility is suggested by National Science Board data showing that the composition of academic R&D over the past fifteen years has been relatively stable.[39] NSB data show that the fraction of university R&D dedicated to basic research was 67 percent during 1980–83 and 66 percent during 1990–93. For 1994–95, the NSB estimates that universities devoted

Table 7-4. *Effects of Industrial Orientation on Research Effort*

	Research			
Share of research	*Basic*	*Applied*	*Development*	*N*
Entire sample	41.0	42.1	16.8	496
Centers distinguished by priority attached to mission of improving industry's products or processes				
Not important	61.2	35.5	3.2	66
Somewhat important	39.0	46.6	14.4	130
Important	38.3	42.2	19.5	162
Very important	28.9	42.6	28.4	122

Source: Cohen, Florida, and Randazzese, *For Knowledge and Profit*.

approximately 67 percent of their R&D effort to basic research. In 1970–73, the NSB reports that 77 percent of university R&D effort was dedicated to basic research, indicating that the reorientation of university R&D away from basic research largely predated the significant strengthening of university-industry ties that began in the mid-1970s and picked up steam in the 1980s. In any event, since 1980, universities have apparently not changed the composition of their research much, despite growing links with industry and the commercial sector. Thus, perhaps industry money for university research was attracted by the applied component of university research that had already emerged prior to any increase in industry support or interest.

Though still limited, the evidence that growing ties with industry are inducing academics to accept restrictions on the disclosure of their research is more persuasive. Recent anecdotal evidence is strong. For example, based on a *New England Journal of Medicine* article by Stephen Rosenberg, chief surgeon and leading investigator of the National Cancer Institute, the *New York Times* reported: "In recent years, going against a long tradition of openness in science, many researchers have accepted secrecy as a common working practice. This change is impeding progress in cancer research and other fields. The trend toward secrecy . . . has grown . . . as competition for federal science grants has increased and more scientists have come to rely on grants or contracts from private companies that are investing in biomedical research."[40] Likewise, the *Wall Street Journal* reported that one drug company suppressed findings from research that it supported at the University of California at San Francisco. The research found that cheaper drugs made by other manufacturers were therapeutically effective substitutes for its drug, Synthroid, which dominates the $600 million market for drugs to control hypothyroidism.[41]

More broad-based quantitative evidence also signals a relationship between disclosure restrictions and industry support. Blumenthal and others report that 82 percent of the companies they surveyed that support life science research within universities require academic researchers to keep information confidential to allow for the filing of a patent application, but they further report that 47 percent of firms indicate that their agreements with universities occasionally require academic institutions to keep confidential the results of the sponsored research longer than is necessary to file a patent application. In a yet more recent survey research study Blumenthal and others find that, while withholding research results is not particularly widespread among life science researchers generally, "Participation in the commercialization of research, which can occur with or without support from industry, is associated with both delays in publication and refusal to share research results upon request."[42]

In similar survey research, Rahm asked 1,134 university technology managers and faculty at the 100 top R&D performing universities in the United States about the extent of communication and publication restrictions that the firms they deal with seek to impose.[43] Thirty-nine percent of the technology managers indicated that, in order to protect the secrecy of a potential commercial product, the firms they have dealt with have placed restrictions on faculty sharing information regarding R&D breakthroughs with department or center faculty. Seventy-nine percent of the technology managers and 53 percent of the faculty with experience interacting with firms reported that firms had asked for R&D results to be delayed or kept from publication.

The survey conducted by Cohen, Florida, and Goe examined UIRC policies regarding restrictions placed on publication and informal communication.[44] As shown in table 7-5, 53 percent of university-industry R&D centers permit firms to request publication delays, and 35 percent allow "information to be deleted from research papers prior to submission for publication."[45] Of the 117 centers in the sample that strongly embraced the mission of improving industry's products or processes (that is, that indicated this mission to be "very important"), 63 percent permit publication delays, and 54 percent permit the deletion of information from prospective publications.[46]

This same survey asked respondents whether center faculty and staff are ever restricted in sharing information about their projects with others, including other faculty and staff within their home universities, faculty and staff at other institutions, and the general public. The results, presented in table 7-6, are broadly consistent with those bearing on publication restrictions. Across all centers in the sample, 21 percent report communication restrictions with other faculty and staff within the home university, 29 percent report restrictions with faculty and staff at other universities, and 42 percent report restrictions with the general public. For centers that consider the mission of improving industry's products or processes to be "very important," 37 percent report communication restrictions with other faculty or staff at the home university, 46 percent with faculty or staff at other universities, and 55 percent with the general public.[47]

Our consideration of the impacts of deepening ties with industry on the conduct and disclosure of academic research has been limited to the case where established firms provide research support to the university. We have not considered faculty participation in firms or the formation of new firms by academies (that

Table 7-5. *Research Disclosure Policies of Centers*
Percent (unless otherwise specified)

	Information can be deleted from publication	*Publication can be delayed*	*Both restrictions*	*N*
Entire sample	34.8	52.5	31.1	496
Centers distinguished by priority attached to mission of improving industry's products or processes				
Not important	20.9	48.8	19.4	66
Somewhat important	22.9	46.6	19.8	130
Important	37.7	55.3	33.3	162
Very important	53.9	63.2	48.7	122

Source: Cohen, Florida, and Randazzese, *For Knowledge and Profit*.

Table 7-6. *Communication Restrictions*
Percent (unless otherwise specified)

If center personnel are ever restricted in sharing project-related information with:	*Other faculty and staff within the university*	*Faculty and staff at other universities*	*General public*	*N*
Entire sample	21.3	28.6	41.5	479
Centers distinguished by priority attached to mission of improving industry's products or processes				
Not important	8.1	11.3	17.7	62
Somewhat important	16.9	21	37.1	124
Important	19.1	27.4	43.9	157
Very important	37.2	46.3	55.4	121

Source: Cohen, Florida, and Randazzese, *For Knowlege and Profit*.

is, spin-offs). As we have noted, spin-offs from universities appear to have increased over the past fifteen years, especially in the domains of biotechnology and computer science, but we are not aware of any systematic data on the subject. The relevant issue is the implications of spin-offs for the empirical conclusions of this section. A priori, the prospect or existence of a spin-off company that capitalizes on academic research should impose pressures on the composition and disclosure of research qualitatively similar to those associated with industry support for academic research. The main difference in this case is that those pressures are internally generated by the faculty or university administrator, rather than externally induced. The National Science Board data indicating that the composition of U.S. academic research has been relatively stable since 1980 suggest that if there has been a proliferation of spin-off activity since that time, it has not affected the percentage of basic research performed in universities.48 Without data, however, it is hard to know if spin-off activity has had the same apparent effect in increasing disclosure restrictions as industry support.

University-Industry Relationships and Technological Change

The evidence strongly suggests that universities contribute substantially to industrial R&D, that ties between universities and

industry have grown, and that industry support in academic research is bringing greater restrictions on the disclosure of the results of university R&D. It is worth reflecting on possible implications of these trends for technological change.

On balance, the impacts of these deepening ties on technical advances are not obvious. The survey cited previously underscores the countervailing effects of these ties.[49] Specifically, for the sort of UIRC R&D outputs of more immediate value to industry (such as new processes, and new products), UIRC R&D productivity appears to be greater for centers that embrace the mission of improving industry's products and processes more strongly.[50] Controlling for technology, productivity per researcher, measured by inventions disclosed, patent applications, new products or new processes, is 25 percent higher in centers that report the mission to improve industry's products and processes to be very important than it is for centers that consider this mission to be unimportant. With some notable exceptions, as in biotechnology, there is a parallel decline in academic paper productivity (also by roughly 25 percent) as the importance of that industry mission increases. These results suggest that the most commercially oriented UIRCs have a greater short-term effect on technical advance but a countervailing effect in the long run, particularly in light of findings by Adams that academic papers contribute to technical advances.[51]

Although the UIRC productivity data are ambiguous with respect to whether technical advance will suffer (or prosper) in the long run as a result of closer integration of industry and academic research, they reflect only the narrow experience of UIRCs themselves. They tell us little about the diminution in technical advance that might accompany blocking the information channels that benefit the R&D of firms not participating in the UIRCs. From this broader perspective, the findings that restrictive policies often accompany the strengthening of university-industry research ties are unsettling.[52]

Increased disclosure restrictions have several effects. First, they compromise the norm of open science valued by researchers as an end in itself. More importantly, disclosure restrictions undermine the quality of academic research by diminishing the extent to which research methods and results are subjected to professional review and criticism. Moreover, by preventing results from entering the public domain, restrictions both increase wasteful duplication of research efforts and reduce the likelihood that research will contribute to further work, and may thus impede the cumulative advance of science and engineering. Disclosure restrictions also have broader effects than undermining the advance of academic research. Open disclosure underpins the university's contribution to industrial R&D and technical advance more generally. Recall the findings regarding the channels through which university research influences industrial R&D. Disclosure through publications and public meetings and conferences was found to complement more interactive channels, such as informal communication and consulting. Together, these channels appear to play the key role in transferring knowledge and technology from university to industry.

Disclosure restrictions thus apparently block the most important media through which universities contribute to technical advance. Though firms that directly team up with academic researchers will still presumably benefit from university research subject to disclosure restrictions, the more diffuse, decentralized benefits realized by other firms and industry generally will not be forthcoming. To the extent that these restrictions proliferate, even the firms granted these restricted information channels may suffer in the long run by diminishing the publicly available information that benefits them as well as others.

One countervailing influence to the disclosure restrictions is the spillovers from the downstream R&D conducted by firms that benefit from these restrictions. These spillovers are not likely to fully substitute for the information flows initially blocked for several reasons. First, firms will try to restrict spillovers to retain proprietary advantage. The subsequent revelation of the underlying knowledge also will be limited because it will tend to be conveyed indirectly—as, for example, through its embodiment in some product. Finally, there will typically be considerable lags between when the firm receives the privileged information and when information will spill over to other firms.

Industry's restriction of public disclosure of university research may thus undermine the long-term interest of industry itself, no less the consumers who benefit from industry's new and improved products and process. The challenge is that posed by the decentralized provision of many public goods. The argument through which one might see a "tragedy of the commons" unfolding begins with the recognition that, given the option, it will rarely be in the interest of any one firm providing support to academic R&D to eschew some form of disclosure restriction. The firm will see a tangible benefit in restricting public disclosure of the research—a benefit that comes from denying its rivals access to that research. At the same time, with little reason to believe that its behavior will have much effect on that of others, the firm will expect that the effect on its own profits from diminishing the pool of publicly accessible information is imperceptible. As a consequence, the expected private benefit of a restriction will far outweigh the expected cost.

This argument and the empirical findings that underpin it suggest that the conventional public good argument for government intervention may apply to the question of disclosure restrictions. Government cannot and should not compel firms to support university research if firms do not find it in their interests to do so, and a key dimension of those interests may include restricting the disclosure of research findings. Moreover, it is not even industry that is driving the formation of most of these relationships, but the academy itself—providing all the more reason why firms cannot be compelled to support academic research from which they cannot profit.

One policy that would pull all concerned parties out of what may be collectively self-defeating behavior is public financial support of university research sufficient to obviate the need for industry support. In the current fiscal environment, such support is not likely to be forthcoming. Moreover, strong public support may also undermine some of the potentially important benefits—including the tangible contributions of universities to technical advance—that appear to accompany those ties. We should also not underestimate the effect that such ties have in altering university research agendas in socially useful ways by making university scientists and engineers more aware of the technical problems and opportunities confronting industry. The challenge, then, is to preserve the benefits of industrial ties while minimizing the most significant cost, namely, the imposition of disclosure restrictions. One policy option is to tie the tax benefit that firms receive for supporting university R&D to the disclosure of the supported research findings.

Another policy alternative would not involve government intervention of any sort. Academics may accede to more restrictive policies than are necessary as a consequence of having little bargaining power when the firms know that the faculty need research support and have few or no alternatives. The leverage academics hold may be strengthened if, during their negotiations with firms, they could invoke strong guidelines for research disclosure. Individual universities or research universities collectively could create such guidelines and could even back them up by monitoring the disclosure restrictions that come with industry support.

The issue of disclosure is clearly a sensitive one—surely one of degree and involving trade-offs. We should not allow the deepening of ties between academia and industry to undermine the norms and practices that benefit both the private sector and society in general. But there are no villains in this story. Industry and faculty alike are responding to their evolving constraints and incentives in legitimate ways. In the process, if we are not at least endangering one of the geese of golden egg fame, we may yet be undermining its habitat. Due care should be exercised to preserve it.

Endnotes

1. Although these controversies have intensified in the past fifteen years, they are not new. Weiner, for example, documents that there has been controversy in the field of biomedicine since the early twentieth century between those who wished to patent inventions originating from university labs versus those who thought such patenting was in conflict with making medical discoveries available for public use and further development. Charles Weiner, "Patenting and Academic Research: Historical Case Studies," in Vivian Weil and John W. Snapper, eds., *Owning Scientific and Technical Information: Value and Ethical Issues* (Rutgers University Press, 1989).

2. The full results of this study are forthcoming: Wesley Cohen, Richard Florida, and Lucien Randazzese, *For Knowledge and Profit: University-Industry R&D Centers in the United States* (Oxford University Press, forthcoming).

3. The complete results reporting this survey's findings on the effects of academic research on industrial R&D are presented in Wesley M. Cohen, Richard Nelson, and John Walsh, "Links and Impacts: New Survey Results on the Influence of University Research on Industrial R&D," Carnegie Mellon University, Department of Social and Decision Sciences, 1996.

4. A. K. Klevorick and others, "On the Sources and Significance of Interindustry Differences in Technological Opportunities," *Research Policy*, vol. 24, no. 2 (1994), pp. 195–206.

5. For purposes of comparison, it is important to recall that, although these results from the survey by Klevorick and others were not published until 1994, the survey was conducted in 1983.

6. David Blumenthal and others, "Industrial Support of University Research in Biotechnology," *Science*, vol. 231 (January 17, 1986), pp. 242–46; and Klevorick and others, "On the Sources and Significance of Interindustry Differences."

7. David Blumenthal and others, "Relationships between Academic Institutions and Industry in the Life Sciences—An Industry Survey," *New England Journal of Medicine*, vol. 334, no. 6 (February 8, 1996), pp. 368–73.

8. Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy*, vol. 20, no. 1 (February 1991), pp. 1–12.

9. Edwin Mansfield, "Academic Research and Industrial Innovation: A Further Note," *Research Policy*, vol. 21, no. 3 (June 1992), pp. 295–96.

10. Adam B. Jaffe, "Real Effects of Academic Research," *American Economic Review*, vol. 79, no. 5 (December 1989), pp. 957–78; and James D. Adams, "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, vol. 98, no. 4 (August 1990), pp. 673–702.

11. Jaffe, "Real Effects of Academic Research."

12. Adams, "Fundamental Stocks of Knowledge."

13. Because the effect of the basic sciences on industrial productivity often moves indirectly through applied sciences and engineering, the lags associated with some research in the basic sciences may be considerably less than twenty years. Cf. Nathan Rosenberg and Richard Nelson, "American Universities and Technical Advance in Industry," *Research Policy*, vol. 23, no. 3 (May 1994), pp. 323–48.

14. Cohen, Nelson, and Walsh, "Links and Impacts."

15. Klevorick and others, "On the Sources and Significance of Interindustry Differences."

16. Nathan Rosenberg, "Scientific Instrumentation and University Research," *Research Policy*, vol. 21 (1992), pp. 381–90.

17. Vannevar Bush, *Science, the Endless Frontier: A Report to the President* (Government Printing Office, 1945).

18. Zvi Griliches, "The Search for R&D Spillovers," Working Paper 3768 (Cambridge, Mass.: National Bureau of Economic Research, 1991). What economists call within-industry "R&D spillovers" essentially reflect useful knowledge flows that firms receive about the R&D activities of their rivals without paying their rivals for them.

19. In an earlier study of information usage in technological innovation, Gibbons and Johnston similarly found that the two sources of "personal contact" and the technical literature contributed significantly to industrial innovation. See Michael Gibbons and Ron Johnston, "The Roles of Science in Technological Innovation," *Research Policy*, vol. 3 (1975), pp. 220–42. Also resembling the Carnegie Mellon Survey results, Gibbons and Johnston found these two types of sources to be most beneficial when used together. They state, "the use of the two general sources in tandem led to new and relevant information which would have been very difficult to obtain in any other way" (p. 34). Faulkner and Senker confirm this finding in a recent study of public sector research and industrial innovation in biotechnology, engineering ceramics, and parallel computing. Wendy Faulkner and Jacqueline Senker, *Knowledge Frontiers: Public Sector Research and Industrial Innovation in Biotechnology, Engineering Ceramics, and Parallel Computing* (Oxford University Press, 1995).

20. Jaffe, "Real Effects of Academic Research"; Mansfield, "Academic Research and Industrial Innovation"; Adams, "Fundamental Stocks of Knowledge"; and Klevorick and others, "On the Sources and Significance of Interindustry Differences."

21. David A. Hounshell, "The Evolution of Industrial Research in the United States," in Richard S. Rosenbloom and William J. Spencer, eds., *Engines of Innovation* (Boston: Harvard Business School Press, 1996), pp. 13–86; and Richard S. Rosenbloom and William J. Spencer, "Technology's Vanishing Wellspring,"in Rosenbloom and Spencer, eds., *Engines of Innovation*, pp. 1–9.

22. Wesley M. Cohen, Richard Florida, and W. Richard Goe, *University–Industry Research Centers in the United States*, report prepared for the Ford Foundation (Pittsburgh: Carnegie Mellon University, June 1994).

23. National Science Board, *Science and Engineering Indicators*, NSB Pub. 96–21 (1996), table 5–42, p. 249.

24. Association of University Technology Managers, Inc., "AUTM Licensing Survey Fiscal Year 1991–Fiscal Year 1994," (Norwalk, Conn., 1995), p. 5.

25. AUTM, "Licensing Survey."

26. Cohen, Florida, and Randazzese, *For Knowledge and Profit*.

27. Hsu recommends that universities use this strategy to profit from their patents. Richard C. Hsu, "No Money for Research? Try Investing," *New York Times*, September 29, 1996, pp. F12.

28. Henry Etzkowitz, "Entrepreneurial Science in the Academy: A Case of the Transformation of Norms," *Social Problems*, vol. 36, no. 1 (1989), pp. 14–29; and Cohen, Florida, and Randazzese, *For Knowledge and Profit*.

29. The balance of the funding comes from the universities themselves (18 percent), private foundations (3 percent), and other sources. Cohen, Florida, and Randazzese, *For Knowledge and Profit*.

30. Harvey Brooks and Lucien Randazzese, "Universities-Industry Relations: The Next Four Years and Beyond," in Lewis Branscomb and James Keller, eds., *Investing in Innovation: Creating a Research and Innovation Policy That Works* (MIT Press, forthcoming). Brooks and Randazzese indicate that this figure is calculated from National Science Board, *Science and Engineering Indicators*, Appendix tables 5–2 and 5–26, and also highlight that the price deflator used to calculate it is the consumer price index, which tends to understate R&D cost increases over time, suggesting that the 9.4 percent figure is probably an underestimate of the actual decline.

31. National Science Board, *Science and Engineering Indicators*.

32. W. M. Cohen, R. Florida, and R. Goe, "University-Industry Research Centers in the United States," report to the Ford Foundation, Carnegie Mellon University, 1994.

33. Wesley M. Cohen and Lucien Randazzese, "Eminence and Enterprise: The Impact of Industry Support on the Conduct of Academic Research in Science and Engineering," Carnegie Mellon University, August 1996.

34. Robert K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations* (University of Chicago Press, 1973); Partha Dasgupta and Paul David, "Information Disclosure and the Economics of Science and Technology," in George R. Feiwel, ed., *Arrow and the Ascent of Modern Economic Theory* (New York University Press, 1987); and Partha Dasgupta and Paul David, "Toward a New Economics of Science," Stanford University, Center for Economic Policy Research, 1992.

35. Dasgupta and David, "Information Disclosure and the Economics of Science and Technology"; and Dasgupta and David, "Toward a New Economics of Science."

36. Blumenthal and others, "Relationships between Academic Institutions and Industry."

37. Dianne Rahm, "University-Firm Linkages for Industrial Innovation," paper prepared for the Center for Economic Policy Re-

search/AAAS Conference on University Goals, Institutional Mechanisms and the "Industrial Transferability of Research," 1994; Robert P. Morgan and others, "Engineering Research in U.S. Universities: How Engineering Faculty View It," paper prepared for the 1993 Institute of Electrical and Electronics Engineers–American Society of Electrical Engineers (IEEE-ASEE) Frontiers in Education Conference; and Robert P. Morgan and others, "Engineering Research in U.S. Universities: How University-Based Research Directors See It," paper prepared for the 1994 annual meeting of the American Society of Electrical Engineers.

38. Cohen, Florida, and Goe, "University-Industry Research Centers in the United States."

39. National Science Board, *Science and Engineering Indicators.*

40. Lawrence K. Altman, "Medical Research Is Hurt by Secrecy, Official Says," *New York Times*, February 10, 1996, sec. 1, p. 9.

41. Ralph T. King Jr., "Bitter Pill: How a Drug Firm Paid for University Study, Then Undermined It," *Wall Street Journal*, April 25, 1996, pp. pp. A1, A13.

42. David Blumenthal and others, "Withholding Research Results in Academic Life Science: Evidence from a National Survey of Faculty," *Journal of the American Medical Association*, vol. 277, April 16, 1997, pp. 1224–28.

43. The 1,013 faculty and the 121 technology managers were from the disciplines of biology, chemistry, computer science, and electrical engineering and physics. Rahm, "University Linkages for Industrial Innovation."

44. Cohen, Florida, and Goe, "University-Industry Research Centers in the United States."

45. Note that respondents may have interpreted the phrase, "information to be deleted from research papers," broadly to include proprietary information originating from the firms themselves, as distinct from academic research findings. If this were the case, the propriety of restricting the disclosure of such information is apparent.

46. As background to these findings concerning disclosure restrictions, the results of the 1994 Carnegie Mellon Survey of Industrial R&D suggest that between 1983 and 1994 firms came to rely much more heavily on secrecy to protect their profits from innovation. Wesley M. Cohen, Richard R. Nelson, and John Walsh, "Appropriability Conditions and Why Firms Patent and Why They Do Not in the American Manufacturing Sector," Carnegie Mellon University, 1997.

47. Wesley M. Cohen, Richard Florida, and Lucien Randazzese, *For Knowledge and Profit: University-Industry R&D Centers in the United States* (forthcoming). It is important to reinforce exactly what the results from tables 7–5 and 7–6 do and do not reveal. Table 7–5 refers only to whether UIRCs permit publication restrictions, not whether such restrictions were implemented. Table 7–6 refers to whether UIRCs ever imposed specific communication restrictions, not whether such restrictions were routinely or commonly imposed.

48. National Science Board, *Science and Engineering Indicators.*

49. Cohen, Florida, and Goe, "University-Industry Research Centers in the United States."

50. Cohen, Florida and Goe, "University-Industry Research Centers in the United States"; and Cohen, Florida, and Randazzese, "University-Industry Research Centers in Biotechnology."

51. Adams, "Fundamental Stocks of Knowledge and Productivity Growth."

52. Blumenthal and others, "Relationships between Academic Institutions and Industry"; and Cohen, Florida, and Goe, "University-Industry Research Centers in the United States."