Articles

University-Industry Research Relationships in Biotechnology: Implications for the University

DAVID BLUMENTHAL, MICHAEL GLUCK, KAREN SEASHORE LOUIS, MICHAEL A. STOTO, DAVID WISE

The growth of university-industry research relationships in biotechnology has raised questions concerning their effects, both positive and negative, on universities. A survey of over 1200 faculty members at 40 major universities in the United States reveals that biotechnology researchers with industrial support publish at higher rates, patent more frequently, participate in more administrative and professional activities and earn more than colleagues without such support. At the same time, faculty with industry funds are much more likely than other biotechnology faculty to report that their research has resulted in trade secrets and that commercial considerations have influenced their choice of research projects. Although the data do not establish a causal connection between industrial support and these faculty behaviors, our findings strongly suggest that university-industry research relationships have both benefits and risks for academic institutions. The challenge for universities is to find ways to manage these relationships that will preserve the benefits while minimizing the risks.

UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS (UIRR's) in biotechnology have grown increasingly important for both industries and universities in the United States. Recent research indicates that nearly half the firms conducting or supporting research in biotechnology are involved in UIRR's. Their funds may account for 16 to 24% of all external support for university research in biotechnology (*1*).

The growth of UIRR's in biotechnology and other fields, however, has raised critical questions concerning their effects on institutions of higher education. Do such relationships affect the scholarly or commercial productivity of university faculty? Do UIRR's influence the commitment of faculty members to teaching or their participation in the time-consuming, sometimes tedious administrative activities so essential to the health of universities or a field of science? Do industrial research relationships encourage secrecy among scientists, disrupt relationships among scientific colleagues, or lead faculty to shift the direction of their research toward applied or commercially oriented projects?

From a survey of over 1200 faculty members in 40 of the most research-intensive U.S. universities, we report on the effect of UIRR's on faculty whose work involves the "new biotechnologies" (*2*). These fields include recombinant DNA technology, monoclonal antibody techniques, gene synthesis, gene sequencing, cell and tissue culture techniques, large-scale fermentation, and enzymology. The expansion of UIRR's in these scientific fields has been especially dramatic in recent years. UIRR's in the new biotechnologies, therefore, provide an intriguing case study for exploring both the potential risks and the potential benefits of UIRR's generally for academic institutions.

Study Design

The analysis presented here is based on a survey of university faculty conducted in the winter of 1985. A sample of 1997 faculty was selected in a two-step process. First, we selected 40 universities from among the 50 schools that receive the largest amounts of federal research funds in the United States (*3*).

Second, for those 40 universities, we developed a list of 3180 life science faculty members (instructors, lecturers, assistant professors, associate professors, and full professors) included in published catalogs as members of the departments of biochemistry, molecular biology, genetics, microbiology, biology, cellular biology, or botany (*4*). We selected these departments because we judged them to be most likely to contain faculty conducting research involving the new biotechnologies. From this list, we randomly selected 1594 individuals. A comparison group of 403 nonlife scientists was drawn from a list of 1211 faculty in departments of chemistry and engineering from the same institutions. We sought such a comparison group in order to assess the relative prevalence of UIRR's in biotechnology and in other fields known to have a long history of involvement with industry.

Each of the 1997 faculty in our sample was mailed an eight-page questionnaire dealing primarily with his or her research activities and involvement with industry. If the questionnaire was not returned within 3 weeks, a second mailing was sent. One hundred fifty-six respondents were ineligible (deceased, retired, no longer associated with the university, or incorrectly reported as a faculty member in the catalog). Of eligible respondents, 69% (993) in the life sciences and 65% (245) in chemistry and engineering returned completed questionnaires. Table 1 summarizes pertinent characteristics of respondents.

Among life science respondents, 800 of 993 (81%) did research involving the new biotechnologies. In the body of the article, we refer to these respondents as "biotechnology" faculty and to the remaining 193 life science respondents as "other life science" faculty. Unless otherwise indicated, our analyses concern respondents in our biotechnology group. In comparing groups within our sample, we

D. Blumenthal is executive director of and M. Gluck is a research assistant at the Center for Health Policy and Management, John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138. K. S. Louis is senior researcher, Center for Survey Research, University of Massachusetts, Boston, MA 02116. M. A. Stoto is associate professor of public policy, Kennedy School of Government, and D. Wise is John F. Stambaugh Professor of Political Economy.

Table 1. Characteristics of the sample. Because of question nonresponse, numbers of faculty may not add to 1238 for certain characteristics.

Characteristic	Number	Proportion
Male	1117	0.90
Female	119	0.10
Professor	720	0.58
Associate professor	328	0.27
Assistant professor	166	0.13
Other	23	0.02
Years since completing highest degree		
0–5	45	0.04
6–10	173	0.14
11–20	485	0.39
21–30	320	0.26
31–40	161	0.13
>40	54	0.04
Total	1238	

used two-tailed z tests to assess differences of means or proportions. Multivariate analyses employed regressions with ordinary least-squares methodology.

We conducted a telephone survey of nonrespondents (from all disciplines) to collect minimal data regarding their research activities and involvements with industry. Of 104 nonrespondents reached, 63 provided limited information. The remainder refused, usually because they were "too busy," or "never answer questionnaires." Nonrespondents did not differ significantly from respondents in academic rank, the proportion receiving industrial research support, or the magnitude of industry support (as measured by the proportion of the faculty member's total direct research budget supplied by industry).

Despite our thoroughness, the data are subject to certain limitations. First, the faculty and universities surveyed are not representative of all faculty and academic institutions in the United States currently involved in UIRR's in biotechnology. Our faculty sample is drawn from departments that may be more involved in basic research than some other parts of universities (such as schools of agriculture) and from institutions that are more research intensive than the average American university. However, even though the population sampled is not typical of all scientists in all academic centers, it still constitutes an important and interesting group whose behavior is worthy of study.

Second, despite a high response rate for a mailed questionnaire, the fact that approximately 30% of faculty did not respond to our survey could introduce nonresponse biases into our data. Although limited information does not suggest any problems, we have no way of determining the full extent or directions of any biases created by the failure of some faculty to respond.

Third, faculty may have underreported certain behaviors or activities that they considered sensitive or embarrassing (for example, equity holding in companies) or overstated certain behaviors or activities that they considered desirable (such as publication rates and teaching time). Again, the extent of such possible biases cannot be ascertained.

Prevalence and Extent of Involvement in UIRR's

To ascertain the prevalence of UIRR's among faculty members, we asked respondents whether they were principal investigators (PI's) on any grants or contracts from industrial sources. Among biotechnology faculty, 23% responded affirmatively (*5*). These faculty were somewhat more likely to receive industry support than other life science faculty (17%, $P = 0.007$) but considerably less likely than faculty in chemistry and engineering (43%, $P < 0.001$).

Industry supplied 7.4% of all research funds (excluding overhead) received by biotechnology faculty in our sample, and 32% of funds received by chemistry and engineering faculty. Figure 1 shows the distribution of industrial support among faculty involved in UIRR's and compares biotechnology faculty with physical scientists in our sample. Although most faculty doing work in biotechnology received a relatively small proportion of their funds from industry, 6% received at least 50% of their research support from UIRR's, and 3% received at least 75% of their funds from this source.

For the 23% of biotechnology faculty who receive some industry funds, that support constitutes 34% of their total research budget. Among biotechnology faculty involved in UIRR's, 28% received at least 50% of their research support from UIRR's, and 15% received at least 75% of their funds from this source.

Our estimate of the proportion of biotechnology faculty's research support provided by industry differs considerably from our previous estimates of the proportion of university research in biotechnology supported by industry [7.4% compared to 16 to 24% (*1*)]. It should be noted, however, that this study was not designed to provide an accurate estimate of the proportion of university research in biotechnology that is funded by industry. Our sample underrepresents faculty in schools of medicine and did not include faculty from schools of agriculture, groups that might be expected to receive larger proportions of their research support from industry than do faculty in the departments surveyed (*6*).

Effects of UIRR's in Biotechnology

Publication, teaching, and other traditional university activities. A major concern among critics of UIRR's in biotechnology and other fields is that faculty receiving industrial support may be less interested in and committed to traditional university activities, such as scholarship, teaching, and participation in other activities vital to the health of universities and scientific disciplines. Critics argue either that faculty will become more interested in commercializing research findings, thus pursuing subjects of less scholarly value, or else that their involvement with industry will require or encourage them to

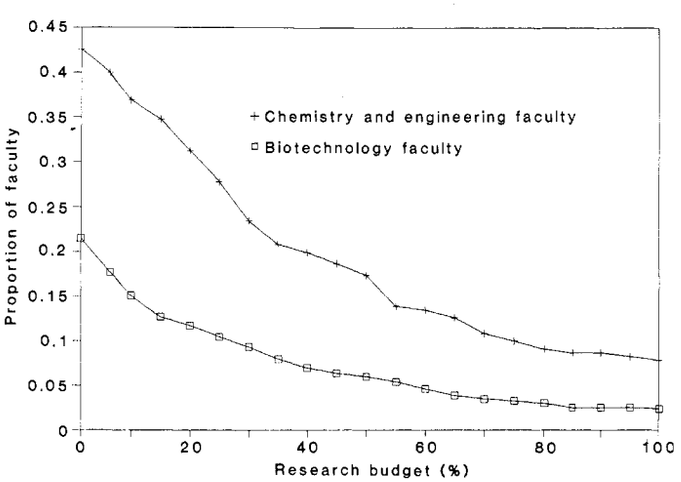

Fig. 1. Extent of industry support for faculty research. Proportion of biotechnology faculty and chemistry and engineering faculty receiving at least x% of their research budget from industry sources, as x varies from 0 to 100%. For $x = 0$, the proportion of faculty with any industry funding is shown.

participate in time-consuming chores, such as consulting, that will compete with university activities.

To assess whether such shifts in behavior are occurring among biotechnology faculty who are involved in UIRR's, we asked respondents to tell us how many articles they had published in refereed journals during the last 3 years, how many hours of contact they had weekly (including laboratory supervision) with students or postdoctoral fellows, and whether they had served in any of several professional roles within or outside the university in the last 3 years (*7*).

Compared with colleagues doing biotechnology research, faculty receiving industry support in biotechnology reported significantly more publications and involvements with other professional activities but no statistically significant differences in teaching time (Table 2). However, such simple comparisons of faculty with and without industry support could be misleading. In order to be classified as receiving industry support, faculty in our sample had to be principal investigators on at least one industrial grant or contract. In contrast, the group without industry support includes some faculty who are not PI's on projects of any sort and may be less senior than or differ in other ways from principal investigators on industry projects.

To correct for such confounding effects, we performed multivariate analyses that examined the association between key faculty behaviors and industry support while controlling for the faculty member's academic rank, the number of years since completing his or her highest degree, the faculty member's total research budget from all sources, his or her involvement in consulting or other relationships with industry, and a variety of other characteristics of faculty and the universities in which they work. In taking account of sample faculties' research budgets from all sources, we effectively controlled for whether they were PI's on at least one externally funded grant or contract. Because of the way our questionnaire was constructed, faculty could report receiving research funds only for projects on which they were PI's. These multivariate analyses confirmed the significance and direction of the associations reported in Table 2.

It is possible that faculty with industry funds are publishing less than they did before they began receiving industry support, even though they still compare favorably along this dimension with faculty not participating in UIRR's. To examine this possibility, we asked faculty how many papers they had published in refereed journals during their professional careers and then compared their publication rates for an average 3-year period with their reported rates during the last 3 years (*8*). As Table 2 shows, biotechnology faculty with and without industry support reported publishing more in the last 3 years than they did during an average 3-year period. Faculty with industry support reported a greater increment in their publications than did other faculty. However, the difference was not statistically significant ($P = 0.14$), a finding confirmed in multivariate analysis.

Faculty who receive a large proportion of their research support from industry, or combine such heavy support with other types of industrial relationships, may be more affected by industrial support of university research than faculty with lesser levels of involvement with industry. To see whether this might be the case, we examined the reported behavior of several subgroups of biotechnology respondents: faculty who received more than 50% of their biotechnology research support from industry; faculty who received more than 50% of their research support from industry and also added at least 20% to their base salary from consulting to a for-profit company; faculty with more than 50% of their support from UIRR's who also consulted exclusively for one biotechnology company; faculty who received more than 80% of their research support from industry; and a series of other combinations of characteristics that might signal heavy involvement with industry. Controlling for other factors, these heavily involved groups reported publication rates, hours of student or postdoctoral contact, and involvements in other professional activities that did not differ significantly from (and in some cases exceeded) those of other faculty.

Table 2. Selected measures of behavior among biotechnology faculty. Publications refers to publications in refereed journals during the previous 3 years. Teaching time refers to the average number of hours of contact per week with graduate students or postdoctoral fellows. Activities refers to the number of activities in universities or professional roles (university administration, professional journals, and officer in professional association). Publication trends refers to the difference between the number of refereed publications during last 3 years and number of publications for an average 3-year period during a faculty member's career.

Status	Publications	Teaching time	Activities	Publication trends
No industry support	11.3*	20.3	1.1*	2.2
Industry support	14.6*	22.2	1.4*	3.3

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

The measures used here to assess the relation between faculty behavior and industrial support of their research have obvious limitations. Simple figures on publication rates and teaching time could have missed differences in the quality or nature of publications or teaching among biotechnology faculty with and without industrial support. By lumping classroom teaching together with laboratory supervision, we could have missed differences in the way faculty with and without industry funds distribute their time among these very different types of educational activities. Nevertheless, the findings should on balance prove reassuring to the university community. Certainly, our data on selected indicators provide no evidence that industrial support of faculty research in biotechnology is associated with decreased faculty productivity. If anything, the opposite seems the case.

Commercial productivity among faculty. One of the possible benefits of UIRR's in biotechnology and other fields is that they may encourage faculty to commercialize their research findings more readily than faculty without industrial research support. Such a tendency could result in greater income for the university and benefits to society through increasing the rate at which research results are transferred into practical application.

To examine this hypothesis, we asked biotechnology faculty in our sample whether their university research had resulted in any patent applications, patents, or trade secrets. Faculty with industry support were more than twice as likely (37 versus 17%, $P < 0.001$) as faculty without such support to answer affirmatively.

These data do not establish that industrial support actually increased the commercial productivity of faculty. It may be that industry successfully seeks out faculty whose work seems likely to have commercial application. However, faculty seem to feel that industrial support is helpful in producing commercially useful results from their research. Among biotechnology faculty participating in UIRR's who reported patent applications, patents, or trade secrets, 48% said that industry support had contributed significantly to the work that led to these commercialization efforts. When asked about the benefits of industrial support of university research, a majority of faculty with and without industry research funds agreed that UIRR's increase the rate of applications from basic research to some extent or a great extent (Table 3).

Involvement in UIRR's may also offer faculty opportunities to increase their personal income through royalties from licensed patents, consulting to industry, and other means. Such additional earnings may reduce pressures on universities to increase faculty

Table 3. Benefits reported by biotechnology faculty.

Question	"To some extent or to great extent" (%)	
	In-dustry sup-port	No in-dustry sup-port
To what extent does industry research support		
Involve less red tape than federal funding	76	51*
Increase the rate of applications from basic research	67	52*
Provide resources not obtainable elsewhere	63	36*
Enhance career opportunities for students	60	43*
Enhance scholarly productivity	41	20*
Produce patents that increase university revenues	41	33

*Significantly different from faculty with industry support ($P < 0.01$).

salaries during periods of financial hardship and may, therefore, be counted among the benefits of UIRR's in biotechnology and other fields. In fact, involved biotechnology faculty in our sample did report that, measured as a percentage of their base salary, they earned more in additional compensation (14 versus 12% of their base salaries) each year than did faculty without industrial support for their research. Multivariate analysis controlling for faculty and university characteristics confirmed the significance ($P < 0.05$) of this association between increased faculty earnings and receipt of industry research support.

Perceived benefits of UIRR's. To capture other positive effects of UIRR's we asked biotechnology faculty about the extent to which industrial support of university research offered several possible benefits. As Table 3 shows, a majority of biotechnology respondents with industry funds reported that four of the six potential benefits occurred to some extent or a great extent. Biotechnology faculty without industrial support were consistently less enthusiastic about the consequences of UIRR's, but a majority agreed that to some extent or a great extent, UIRR's involved less red tape than federal funding and increased the rate of practical applications from basic research.

Secrecy in the university. Critics of UIRR's have argued that these arrangements may create incentives for faculty to keep their research secret and that industry is more likely to restrict publication of research findings than are other sources of support. Either effect could impede the free, rapid, and unbiased dissemination of research results. Certain of our findings lend support to these concerns.

Biotechnology faculty with industry support were four times as likely as other biotechnology faculty (12 versus 3%, $P < 0.001$) to report that trade secrets had resulted from their university research. Trade secrets were defined as "information kept secret to protect its proprietary value (*9*)."

To assess whether industry sponsors placed more restrictions on publications than other sources of research support, we asked biotechnology faculty the following question: "Have you personally conducted any research at your university the results of which are the property of the sponsor and cannot be published without their consent?" Respondents were then asked to identify the sponsors of this research (federal government, industry, or other).

Among biotechnology faculty involved in UIRR's, 24% (including researchers at 22 of the 40 universities in our sample) responded affirmatively to the question above and identified industry as the sponsor for which the research was conducted. Among faculty with support from sources other than industry, only 5% indicated that they had performed research under the stated conditions for such nonindustrial sponsors.

These findings should be a matter of concern for universities. Even small numbers of faculty who withhold information that they would normally share with colleagues (or make available through publication) may have a corrosive effect on the university environment. When biotechnology faculty who do not receive industry support were asked whether UIRR's pose the risk of undermining intellectual exchange and cooperation within departments, 68% said they did so to some or to a great extent. Among their colleagues with industry support, 44% agreed (Table 4) (*10*).

Redirection of research. We asked biotechnology faculty the extent to which their choice of research topics had been affected by the likelihood that the results would have commercial application. Faculty members with industry support were more than four times as likely as faculty without industry funds (30 versus 7%, $P < 0.001$) to report that such considerations had influenced their choices to some extent or to a great extent.

Although some may see such attention to commercial applications as a positive development among university faculty, others may worry that it will lead to excessive emphasis on applied investigation at the expense of more fundamental research. To a surprising degree, biotechnology faculty share this concern. Among biotechnology faculty without industrial support, 78% said that, to some extent or a great extent, UIRR's pose the risk of shifting too much emphasis to applied research. Among their colleagues participating in UIRR's, 70% agreed (Table 4).

Equity holding in biotechnology companies. Biotechnology faculty face a serious potential conflict of interest when they receive funds for their university research from companies in which they hold equity and whose products or services are based upon the faculty member's university work. In particular, such investigators may encounter especially strong economic incentives to use their university time and university facilities to do company work.

Eight percent of all biotechnology faculty in our sample (62 of 800) reported holding equity in a company whose products or services are based on their research. However, only 0.5% (4 of 800) reported that they simultaneously held equity in such a company and received funds from it for their university research. Faculty may have underreported such situations because of their sensitivity. Nevertheless, on balance our data seem to indicate that this particular form of potential conflict of interest is uncommon among biotechnology faculty in our sample.

Discussion

Data from this survey provide important insights into the consequences of UIRR's in biotechnology for university life. Some of our most significant findings speak to potential benefits of such arrangements for higher education.

Industry support of biotechnology research in universities, constituting roughly one-fifth of all available funds, is undoubtedly a welcome addition to federal funding for this dynamic area of investigation. As Table 3 shows, faculty perceive UIRR's in biotechnology to have a number of other benefits as well. Perhaps most intriguing, however, is the suggestion that UIRR's may be associated with heightened faculty productivity along a number of dimensions. Controlling for other factors, faculty in our sample who were receiving industry support tended to publish more, patent more, earn more, serve in more administrative roles, and teach just as much as faculty without industry funds.

The most obvious explanation for this observed relation between faculty accomplishments and industry support is that companies selectively support talented and energetic faculty who were already highly productive before they received industry funds. If accurate,

this explanation would suggest at a minimum that industries are supporting faculty who are very important to their parent institutions.

In this respect, it is interesting to note that faculty involved in UIRR's seem capable of commercial as well as academic productivity. This lends support to the anecdotal observation that individuals who are highly successful in one dimension, such as scholarship, seem also to be capable of success in rather different dimensions, such as the production of intellectual property with potential commercial value. It should prove reassuring to universities that the commercial accomplishments of faculty involved in UIRR's do not seem to diminish their commitments to publication, teaching, or other forms of service to the university or scientific community, at least by the measures employed in our survey. This finding is consistent with other research showing that faculty who consult to outside agencies do not show diminished productivity in their university roles (*11*).

Another possible explanation for the observed productivity of faculty involved in UIRR's is that industrial support enhances their performance along some or all of the dimensions we examined. It would seem perfectly plausible that contact with industrial sponsors, even through agreements that support basic research, would increase the commercial productivity and the earnings of university faculty. Less obvious, but equally plausible, is the possibility that UIRR's could increase the scholarly productivity of faculty, either through adding to their research support, or through exposing them to new perspectives on their work. A considerable body of scholarly work suggests that interaction between scientists doing applied and basic research may enhance the work of both groups (*12, 13*).

A critical question, of course, is whether these apparent benefits of UIRR's in biotechnology for universities and their faculties are associated with any risks to traditional university values or practices. Our data strongly suggest that such risks exist.

One of the most important is an apparent tendency toward increased secrecy among faculty supported by industries. Other risks include an apparent tendency, worrisome to the great majority of respondents, for UIRR's to shift university research in more applied directions and the frequency with which industries seem to place restrictions on publication beyond requiring simply that they be allowed to review papers prior to submission. In previous work, we also reported that students and fellows supported by industry funds often face obligations to work on projects identified by industry, or to work for industries when their training is completed—conditions not imposed by governmental sponsors (*1*).

In some respects, however, even our findings concerning the risks of UIRR's in biotechnology are reassuring. Only a tiny minority of biotechnology faculty in our sample report that they hold equity in companies supporting their university research. Some observers may even find reassuring the frequency with which faculty report that they are concerned about the risks posed by industrial support of biotechnology research. These figures offer some evidence that, at least at current levels of involvement with industry, faculty remain sensitive and committed to traditional university values and practices. Although not a guarantee against erosion of these values, such faculty attitudes may indicate that they retain a capacity to police their own relationships with industrial sponsors. Those whose major interest is the field of biotechnology may also find it reassuring that biotechnology faculty are still much less likely than chemists and engineers to have connections with industry, though this, of course, may change over time.

In assessing the risks of UIRR's, however, the limits of our study should be kept in mind. Because faculty may have been unwilling to report certain behavior, we may have underestimated the prevalence of certain worrisome situations. Our quantitative measures of faculty productivity could have missed important qualitative effects of industrial support on their work. A survey of faculty inevitably fails to explore adequately the full effects of UIRR's on students. Such effects remain to be explored more thoroughly.

Table 4. Risks reported by biotechnology faculty.

Question	"To some extent or to great extent" (%)	
	In-dustry sup-port	No in-dustry sup-port
To what extent does industry research support pose the risk of		
Shifting too much emphasis to applied research	70	78*
Creating pressures for faculty to spend too much time on commercial activities	68	82†
Undermining intellectual exchange and cooperative activities within departments	44	68†
Creating conflict between faculty who support and oppose such activities	43	61†
Creating unreasonable delays in the publication of new findings	40	53†
Reducing the supply of talented university teachers	40	51*
Altering standards for promotion or tenure	27	41†

*Significantly different from faculty with industry support ($P < 0.05$); †Significantly different from faculty with industry support ($P < 0.01$).

In addition, even the small probability of certain devastating occurrences is sufficient to engender caution. Of greatest concern may be Krimsky's (*14*) suggestion that UIRR's, precisely because they involve very talented and productive faculty, could threaten the collective judgment or ethics of scientists in a field of research. The worry here is that researchers with industrial support or other types of involvement in commercial enterprises may be influenced by their personal financial interests in judging the merits of proposals submitted for peer review to funding agencies or in commenting on public policy problems. Another related concern is that junior faculty without commercial involvements may be reluctant to speak out on certain policy issues because they fear displeasing senior faculty whose financial interests might be adversely affected.

Another difficulty in comparing the benefits and risks of UIRR's in biotechnology or other fields is that the long-run implications of current findings are hard to estimate. Furthermore, the trade-off depends on how society values the various consequences of UIRR's. Any losses to science or to university values that result from marginal increases in the level of secrecy in universities may be more than offset by net additions to knowledge that result from the infusion of industry funds into the labs of talented faculty. Marginal shifts in the direction of university work toward more applied and commercially relevant projects may have benefits for human health and economic growth that far outweigh the risks to scientific progress. In the long run, the continued well-being of universities and university science depends importantly on the health of our economy and on public perception that supporting university research contributes directly to practical results.

Though much remains to be learned, our data at least suggest some ways in which universities and government can reduce any risks that industrial support poses for involved academic institutions. First, universities should carefully monitor their relationships with biotechnology companies. Universities may want to make clear to faculty and companies that they are opposed to the protection of trade secrets resulting from industrially supported research and that the right to publish research results (with modest delays for companies to file patents) must be protected. Past research has also

revealed that UIRR's with small companies (non–Fortune 500) are more likely to involve certain potentially risky arrangements than relationships with large companies (*1*).

Second, universities should be able to negotiate UIRR's that avoid objectionable restrictions on faculty behavior. Most universities are in a strong bargaining situation with respect to potential industrial sponsors (*15*). Companies are realizing substantial returns from UIRR's in biotechnology (*1*) and tend to fund strong faculty who can probably find support elsewhere if companies withdraw.

Third, government can assist universities in controlling the risks associated with UIRR's in biotechnology by continuing its support of university research. The availability of public funding will strengthen the resolve of universities and faculty in bargaining with potential industrial sponsors.

Fourth, government can further reduce the risks of UIRR's to universities by making certain that the patent system continues to provide adequate protection for the commercial value of intellectual property in the field of biotechnology. The best deterrent to secrecy in universities may be the perfection of methods that allow parties involved in UIRR's to disclose their research results while also protecting their proprietary interest in that information. Some industry observers (*16*) fear that patents may not provide adequate safeguards in the field of biotechnology and that secrecy may increase in the university and in industry as a result. In this context, much depends on how the judicial system interprets current law as biotechnology companies and universities bring suit to protect patents against what they regard as infringement (*17*).

The benefits of UIRR's in biotechnology to universities and industries make it clear that these relationships are likely to be an enduring phenomenon in American science. The associated risks for universities, and the difficulty in measuring them precisely, make it equally clear that UIRR's will continue to be controversial for some time to come. A major goal at this time should be finding ways to manage these relationships so as to preserve their benefits while minimizing any problems they create. To accomplish this, we must first increase our understanding of the impact of UIRR's on industrial productivity, university values, and the advance of science.

REFERENCES AND NOTES

1. D. Blumenthal, M. Gluck, K. S. Louis, D. Wise, *Science* **231**, 242 (1986).
2. Office of Technology Asssessment, *Commercial Biotechnology: An International Analysis* (Government Printing Office, Washington, DC, 1984).
3. Among the 50 most research-intensive universities, we decided to sample faculty from only the 40 that had responded to a separate survey we conducted of university research administrators in 100 universities and medical schools. This approach allowed us to control for university characteristics in analyzing the effect of UIRR's on faculty behavior. We chose to focus on research-intensive universities because they seemed likely to have large numbers of faculty who use the new biotechnologies and because these universities play a particularly vital role in the conduct of basic research.
4. Lists of faculty members were obtained from *Peterson's Guides to Graduate Programs in the Biological, Agricultural and Health Sciences 1984* (Peterson's Guides, Princeton, NJ, 1984) and *Peterson's Guides to Graduate Programs in Engineering and Applied Sciences, 1985* (Peterson's Guides, Princeton, NJ, 1985).
5. Measuring the prevalence of industrial support in this way has the advantage that respondents can state accurately the source of their research funds. It also avoids double counting in calculating for faculty with industry support, the amounts and proportions of their research funds provided by industry. However, it may lead us to underestimate the proportion of all faculty who receive some support from industry, since non-PI's working on multi-investigator grants would not be counted. In estimating amounts of nonindustrial research support, we similarly asked faculty to tell us how much money they received as PI's from sources other than industry. This enabled us to avoid double counting funds from nonindustrial sources and is relevant to our multivariate analyses.
6. Corroboration for our original estimate of the proportion of all university research in biotechnology supported by industry can be found in a separate but as yet unpublished survey that we conducted of university administrators in nearly 100 universities and medical schools. On average, these officials estimated that industry provided 20% of external support for biotechnology research received by their institutions. However, it is still possible that our original estimate and that provided by these officials are too high. The first estimate could be excessive if the National Science Foundation's estimate of total federal support of biotechnology research in 1983, upon which our original calculations were based (*1*), was too low. Estimates by university administrators could be too high if they were including in their calculations industrial funds for research that did not meet our narrow definition of biotechnology (such as clinical research involving drug testing and new diagnostic equipment).
7. Respondents were asked whether in the last 3 years they had been chair or associate chair of the university department, head or associate head of a research institute, a university-wide administrator, a member of a review panel or study section for a federal agency, an elected officer of a professional association, or editor of a professional journal.
8. Specifically, we divided total lifetime publications by the number of 3-year intervals since the faculty member completed his or her highest earned degree. This provided an estimate of the number of refereed publications produced during an average 3-year period in that faculty member's career. We then subtracted this figure from the number of publications in the most recent three-year period, and compared differences for faculty with and without industrial support.
9. Here again, it is possible that this relationship between trade secrecy and industry support may be explained in part by a tendency of companies to support researchers whose work has already resulted in trade secrets.
10. It should be noted that these figures report faculty perceptions of risk, rather than statements as to events or situations that have actually occurred.
11. D. C. Bok, *Harvard Magazine* (May–June 1981).
12. D. C. Pelz and F. M. Andrews, *Scientists in Organizations: Productive Climates for Research and Development* (Wiley, New York, 1966).
13. C. J. Ping, "Industry and the universities: Developing cooperative research relationships in the national interest" (National Commission on Research, Washington, DC, August 1980).
14. S. Krimsky, *geneWATCH* **1**, 5 (September–December 1984), p. 3.
15. H. Etzkowitz, *Minerva* **21**, 232 (1983).
16. A. Lemin, personal communication; H. J. P. Shoemaker, personal communication.
17. B. Cunningham, personal communication.

18. Supported by DHHS grant 100A-83, the Andrew Mellon Foundation, and the Alfred P. Sloan Foundation. The authors wish to acknowledge the contributions of S. Epstein, M. Kiely, and J. Durch.