University-Industry Relationships
and the Design of Biotechnology Research

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University-industry relationships (UIRs) have emerged as key forces in the development and commercialization of agricultural biotechnology. During the past two decades, changes in patent law and federal policy, new commercial opportunities, and the relative decline of public research funding have altered and strengthened the collaborative research relationships between university and industry. There are a number of indications that UIRs have strengthened over the past few decades. For example, by 1990, approximately 1,056 university-industry R&D centers had been established in the United States, almost 60% of them during the 1980s (Cohen et al. 1998). Industry-funded university research increased from $630 million in 1985 to 1.896 billion in 1998 (NSB 2000), and a recent survey of U.S. science faculty revealed that many of them want even closer partnerships with industry (Morgan 1998).

These relationships are crucial for research financing, for the transfer of new knowledge from laboratory to marketplace, and for graduate education. Yet the university's dependence on private-sector support may be affecting its research agenda. In particular, research with few immediate commercial applications, such as projects impinging on the environmental impacts of new plant varieties, might be increasingly neglected.

Literature Review

The recent growth in private support for academic research has resulted in a rich literature on the forces, formation, and trends of university-industry collaboration, on the prevalence of UIRs, on industry/university motivations in establishing this collaboration, and on the debate about the potential benefits and risks of such alliances.

Santoro and Alok (1999) review the importance of university-industry relationships and contend that a good fit exists between industry's needs and current university missions. Access to complementary research activity and research results, and to the human capital at universities, are the two broad motivations private firms have for engaging in a university-industry relationships. Cohen et al. (1998) provide a selective review of literature, which in general emphasizes that university research enhances firms' sales, R&D productivity, and patenting activity. As contrasted with providing a substitute for it, Hall (2000) claims that UIRs stimulate and enhance the power of R&D conducted in industry.

Huffman (2001) looks at public- and private-sector linkages and their importance in creating value from agricultural research and development. He points out that discoveries from basic research are primarily global public goods, while those embodied in products or processes are patentable and are either private or impure public goods.

Other analysts have sought to identify and measure the links between academic research and industrial innovation. Mansfield, for example, finds that 11% of the new products and 9% of the new processes introduced by surveyed industries could not have been developed in the absence of the academic research carried out during the 15 years preceding the commercialization.

Blumenthal and colleagues have administered survey and case studies on the prevalence, magnitude, commercial benefits, and potential risks of UIRs. Nearly one-half of surveyed biotechnology companies fund research in universities. And over 60 percent of companies providing support for life-science research in universities had received patents, products, or sales as a result of those relationships (Blumenthal et al. 1986a). Per dollar invested, university research has produced more than four times as many patent applications as has commercial research. Two separate surveys of universities (Blumenthal 1986b, Blumenthal et al. 1996) indicate that researchers with industrial support publish at higher rates, patent more frequently, participate in more administrative and professional activities, and earn more than do colleagues without such support. But no statistically significant differences were found in teaching time.

In a related study, Lee (2000) finds an overwhelming majority of faculty members, 94%, and industry technology managers, 91%, think they are likely to expand or at least maintain the present level of collaboration with one another.

Other work has concentrated on the rising citation linkage between U.S. patents and scientific research papers. By tracing the rapidly growing references of U.S. patents to scientific papers, Narin and his colleagues (1997) find that 73% of the papers cited in U.S. industry patents are to public science, authored at academic, governmental, and other public institutions. Only 27% are authored by industrial scientists.

Zucker and Darby (2002) focus on the use of basic science knowledge in commercial firms and on the impact of that knowledge on firm performance. They identify 327 "star" bio-scientists, based upon genetic-sequence discoveries reported in GenBank. Co-publishing between academic and firm scientists is used as a detector of joint research and university-industry technology transfer. Their results confirm academic science's strong effects on firm success.

However, most studies on UIRs have been descriptive. Little econometric modeling has been devoted to them, and the econometric studies available specialize on very specific aspects of the innovation and technology transfer system. No tests have been undertaken on the manner in which UIRs affect the scientist's research agenda, and in particular on how they affect the provision of public goods in agricultural biotechnology. New theory and data are needed for these purposes.

Objective

The central objective of the present paper is to examine how university bioscientists select their research agendas, with special attention to biotechnology firms' influence on those agendas. Among other issues, we will assess UIRs' potential effects on the private appropriability of the characteristics of bioengineered crop and animal varieties, and on the basicness and breadth of a scientist's research. Factors that potentially would affect scientists' research agenda include the university's size, reputation, resources, culture, and total government funding; the scientist's academic position and communication network; and the market power, cultures, and specialties of the biotech firms with which the university has research relationships. An electronic survey of academic life scientists, concentrating on their research objectives, funding sources, collaborators, contracts, and budgets, will form much of the data for testing these models.

Conceptual Analysis

As a conceptual basis for implementing such a study, suppose a university life scientist pursues a number of research projects, each with its own set of objectives. In a given time period, let's define the following variables:

$\mathbf{S}$ the vector of the scientist's research objectives;

Pub	the quantity and quality of the scientist's research publications;
G	the scientist's total grant funding;
$\mathbf{C_{univ}}$	characteristics of the scientist's university (e.g., university size, reputation, resources, culture, and government funding, and university policy regarding scientists' equity shares in patent revenues or start-up firms);
$\mathbf{C_{scientist}}$	the scientist's demographic variables and attitudes (e.g. academic position, years in profession, and communication network);
$\mathbf{C_{firm}}$	characteristics of the biotechnology firms with which the university has a research relationship (e.g., the market power, research cultures, and specialties of these firms);
$\mathbf{C_{policy}}$	relevant government policies (e.g. the legislature's current preference for basic *versus* applied research, and availability of state formula funding).

The scientist reasonably would make choices among alternative research objectives in such a way as to maximize her utility U, taking into consideration the influence the objectives have on the amount of funding to which she will have access. The optimization problem, then, is to choose **S** to

$$(1) \qquad \text{Max } U = U\,[Pub\,(G, \mathbf{S}),\ G,\ \mathbf{C_{univ}}, \mathbf{C_{scientist}}, \mathbf{C_{firm}}, \mathbf{C_{policy}}\,]$$

$$(2) \qquad \text{s.t.} \quad G = G\,(\mathbf{S}, \mathbf{C_{univ}}, \mathbf{C_{scientist}}, \mathbf{C_{firm}}, \mathbf{C_{policy}}).$$

We assume in equations (1) and (2) that the bioscientist's utility is a direct function of her publication quantity and quality, total grant funds, and exogenous variables $\mathbf{C_{univ}}$, $\mathbf{C_{scientist}}$, $\mathbf{C_{firm}}$, and $\mathbf{C_{policy}}$. Publication quality and quantity in turn are a function of the scientist's total grant funding and research objectives. In this way, the scientist's choices among alternative research objectives, and total grant funding, each affect her utility both directly and indirectly.

In particular observe that, by way of equation (2), *G* is a function of the bioscientist's research objectives **S** and of all exogenous variables. Grant funding is, in contrast to a scientist choice variable, determined by the agencies which fund research. These agencies are, in their own turn, influenced by the scientist's research objectives and human capital, the characteristics of the university at which the scientist works, and the characteristics of the firm(s) providing research resources.

Solving this optimization problem gives the reduced form

$$(3) \qquad \mathbf{S} = f\,(\mathbf{C}_{\mathbf{univ}}\,,\ \mathbf{C}_{\mathbf{scientist}}\,,\ \mathbf{C}_{\mathbf{firm}}\,,\ \mathbf{C}_{\mathbf{policy}}).$$

The relationship between a bioscientist's research behavior and the factors potentially influencing it can be characterized in this reduced form. Equation (3) says that the scientist's research objectives are a function of the characteristics of the university, scientist, and firm, including the scientist's demographic variables and attitudes, the scientist's geographic location, and university and government policies.

Empirical Analysis

In the present study, we will express bioscience research objectives in four dimensions. A scientist will select her research objectives (**S**) according to: (a) alternative crop, plant, and animal categories; (b) alternative research specialties such as genetics and biomolecular structure; (c) basic *versus* applied research; and (d) public *versus* private research, i.e. projects whose benefits are nonrival and nonexcludable *versus* those which are privately appropriable.

To reflect crop, plant, and animal categories, we ask the scientist to indicate the primary organism with which she is working, the alternatives being: major crop/animal, minor crop/animal, and model (e.g., arabidopsis, microorganisms). We are interested in the organism of ultimate interest rather than the organism with which the scientist happens to be working as a tool. Therefore, we let

$\mathbf{S^a}$: be the vector of the bioscientist's crop, plant, and animal category alternatives, where $\mathbf{S^a} = \| S_i^{\,a} \|$, $i = 1, 2, 3$. $S_i^{\,a} = 1$ if alternative i is chosen, $S_i^{\,a} = 0$ otherwise.

In terms of research specialty, we characterize the bioscientist's research specialties in the following six categories: agronomic/production properties (including herbicide tolerance), developmental mechanisms, environmental response mechanisms, pest/disease resistance, risk assessment, and product quality. Therefore, we let

$\mathbf{S^b}$: be the vector of the bioscientist's research specialty alternatives, where $\mathbf{S^b} = \| S_j^{\,b} \|$, $j = 1, \ldots, 6$. $S_j^{\,b} = 1$ if alternative j is chosen, $S_j^{\,b} = 0$ otherwise.

Directly measuring or distinguishing between "basic" and "applied," or "public" and "private," either in the scientist's research specialties or in the crop/animal types she studies, is not easy. Smaller crops tend to be more public in the sense that the researcher can't gain much profit from working on them. The more basic research tends to be more public because it has numerous applications, many of which are nonrival and nonexludable. However, some basic research projects target particular major crop types, for example when the research is directed toward plasmid vectors or promoters considered most useful in the bioengineering of those crops.

In order to accurately and extensively examine such issues, we might wish the scientists themselves to indicate the degree of basicness and publicness of the research they are conducting. In our survey, we ask the scientist to estimate the basicness or publicness of their research by revealing "basic *versus* applied" and "public *versus* private" on a five-point Likert scale. The scale runs from unity for 'purely basic' or 'purely public' research to five for 'purely applied' or 'purely private' research. By combining the scientist's own view of the basicness and publicness of her research on the one hand with her research specialties and targeted crop, plant, and animal type on the other, we can obtain a better view of her research orientation. Let

$\mathbf{S^c}$: be the vector indicating the basicness of the bioscientist's research program, where $\mathbf{S^c} = \| S_m{}^c \|$, $m = 1, \ldots, 5$. $S_m{}^c = 1$ if alternative m is chosen, $S_m{}^c = 0$ otherwise.

$\mathbf{S^d}$: be the vector indicating the publicness of the bioscientist's research program, where $\mathbf{S^d} = \| S_n{}^d \|$, $n = 1, \ldots, 5$. $S_n{}^d = 1$ if alternative n is chosen, $S_n{}^d = 0$ otherwise.

Exogenous vectors $\mathbf{C_{scientist}}$, $\mathbf{C_{univ}}$, $\mathbf{C_{firm}}$, and $\mathbf{C_{policy}}$ in the reduced-form conceptual framework of equation (3) can be defined more specifically as follows. Let

Year be the scientist's experience in years;

ap be the scientist's academic position (e.g. assistant, associate, or full professor);

lg be the variable indicating the "culture" of the scientist's university: $lg = 1$ if it is Land Grant, $lg = 0$ otherwise;

tg be total government funding of the scientist's university;

α	be any royalty rate the scientist obtains from her patent licenses, indicating the university's licensing policy;
sf	be the scientist's state or formula funding;
loc	be the geographic location of any biotechnology firm with which the scientist may be working, where *loc* = 1 if the biotechnology firm is located near the scientist's university and *loc* = 0 otherwise;
size	be the size of any biotechnology firms with which the scientist may have a research relationship.

An econometrically estimable version of equation (3) can now be specified as

$$\mathbf{S^a} = f\ (year,\ ap,\ lg,\ tg,\ \alpha,\ sf,\ loc,\ size) \tag{1'}$$

$$\mathbf{S^b} = g\ (year,\ ap,\ lg,\ tg,\ \alpha,\ sf,\ loc,\ size) \tag{2'}$$

$$\mathbf{S^c} = h\ (year,\ ap,\ lg,\ tg,\ \alpha,\ sf,\ loc,\ size) \tag{3'}$$

$$\mathbf{S^d} = i\ (year,\ ap,\ lg,\ tg,\ \alpha,\ sf,\ loc,\ size) \tag{4'}$$

As is evident, all the dependent variables in this model are discrete. A probit model is therefore appropriate. The probit model estimates the probability of choosing research project alternative *i*, *j*, *m*, and *n* given the characteristics of the scientist, university, and biotechnology firm, which do not vary across alternatives.

To illustrate, consider the scientist's decision regarding the basicness of her research projects. Let the expected utility of choosing basicness alternative *m* be

$$U_m^{\,c} = U^{\,c}\,(\,year,\ ap,\ lg,\ tg,\ \alpha,\ sf,\ loc,\ size) + \varepsilon_m \qquad m = 1, \ldots, 5. \tag{5'}$$

Residual ε_m represents unobserved factors which influence expected utility. The scientist's decision is to choose the basicness alternative giving the highest expected utility. That is, the individual chooses alternative *m* if

$$(6') \qquad U_m^c > U_l^c \qquad \forall \quad m \neq l$$

The probability the scientist will choose alternative *m* is

$$(7') \qquad P_m^c \;=\; \text{Prob}\,(\,S_m^c \;=\; 1\,) \;=\; \text{Prob}\,(\,U_m^c > U_l^c\,) \qquad \forall \quad m \neq l\,,$$

as conditioned by the exogenous variables.

We expect to estimate jointly two ordered probit models of basicness and publicness, and two multinomial models of the choice of research specialty and of major *versus* minor crop/animal type. It is reasonable to allow correlations among the errors of the four probit models because the scientist selects among her four-dimensional research objectives simultaneously.

Hypotheses

Model (1') – (4') can be used to test hypotheses about the principal factors affecting the scientist's research behavior.

- Scientists with lower academic rank, e.g. assistant professor, tend to conduct more basic research than do those with higher rank. Our reasoning is that newer professors have stronger theoretical skills and a greater incentive to distinguish themselves as competent basic scientists.

- Bioscientists at Land Grant universities tend to choose more applied research programs than do those at non-Land-Grant universities, given the nature of the Land Grant university mission.
- As patent license royalty rates (α) increase, scientists choose more privately funded research projects and hence are more likely to provide private rather than public goods.
- Bioscientists with higher proportions of private-sector funding are more likely to conduct research on problems with an applied focus, given the profit-making incentives of private firms.
- Bioscientists at universities attracting greater government funding tend to work on more public (less rival and excludable) characteristics of crop and animal varieties.

Other than test the above hypotheses, we can use our model to determine whether scientists from larger (smaller) universities collaborate more with larger (start-up) firms; whether there are differences between Land Grant, non-Land-Grant, and private universities in UIRs participation; and which subfields of agricultural biotechnology are more likely to be involved in UIRs.

Our model focuses on the scientist's intentions and behavior, not on her research results such as publication or patenting successes. Nor does it permit us to explain university or government policies themselves. Nevertheless, we may use our findings to assess alternative policy options for influencing the supply of public goods in agricultural biotechnology research. Alternative policy options include: (i) increasing total government funding, (ii) shifting government funding toward basic research, (iii) concentrating government funding on more or less productive universities, and (iv) steering government support toward or away from universities with extensive industry contacts.

Survey Design and Sample Selection

Survey

As mentioned earlier, an electronic survey of academic bioscientists, concentrating on their research objectives, resources, contracts, and budgets, will enable construction of the first laboratory-level economic data base on plant and animal biotechnology. The survey will form much of the data for testing the above models and therefore will provide the means for examining the impact on university bioscience agendas of a wide variety of university, industry, and public policies.

Our initial thinking was that project-by-project data would be necessary for an analysis of a scientist’s research objectives. The rationale was that project-level information would be essential for obtaining adequate sample variation on the proportions of a scientist's time allocated to alternative objectives (crop, specialty, publicness, and basicness). However, project-level information is possible only to the extent that a scientist’s research technology is nonjoint, i.e. that she operates a lab in which projects essentially are kept separate from one another. More likely, the technology is joint: the scientist's several "projects" feed into a joint research program. Furthermore, if her projects really are joint, trying to obtain data on each of them separately would confuse and frustrate the respondent and hence reduce our response rate. We therefore have decided to ask each scientist to provide responses only for her overall research program. By research program, we mean the portfolio of all of the scientist’s current research projects.

Sample Issues

Our targeted population includes all academic scientists who potentially are working in plant and animal biotechnology fields in the United States.

1. Sample universities

We first restrict our university population to "Doctoral/Research Universities – Extensive" in the Carnegie Classification. These institutions typically offer a wide range of baccalaureate programs, are committed to graduate education through the doctorate, and awarded 50 or more doctoral degrees per year across at least 15 disciplines. The total number of universities in this category is 151, among which 48 are Land Grant (including Cornell University), 55 are public non-Land-Grant, and 48 are private non-Land-Grant universities (excluding Cornell University). We then drew twenty universities in each of the three following categories: Land Grant, private non-Land-Grant, and public non-Land-Grant.

2. Sample departments

We next go to each university's website and record the names of all biologically-related departments at that university. Because faculty conducting research related to agricultural biotechnology are spread widely across departments, we are asking a panel of bioscientists to revise downward the departments we will employ for assembling our sample. Our approach for doing so is to ask the panel of experts to sort the departments into one of five categories, reflecting the probability they will contain bioscientists we wish to survey. The five categories are: (i) 0 percent, (ii) 1 - 25 percent, (iii) 26 - 50 percent, (iv) 51 - 75 percent, and (v) 76 - 100 percent engaged in research with direct or primary implications for plant and animal biotechnologies. After responses are obtained from our panel, we will assign an average probability to each department and rank each as a candidate for enumeration.

3. Sample bioscientists

Once the relevant departments are selected, we will obtain our list of faculty members by drawing their names and email addresses from university websites. Our survey instrument itself will contain further screening questions asking whether the scientist is pursuing research that is agricultural or would have agricultural implications.

The purpose of the above procedures is to obtain an unbiased national random sample of academic scientists who potentially are working in plant or animal biotechnology. This national database will, we believe, capture the diversity of university-industry relationships in agricultural biotechnology, permitting estimation of equations (1') – (4').

Our goal is to estimate how UIRs affect the breadth of scientific research, the public-good aspects of university research, and the types of new plant or animal characteristics likely to be forthcoming from it. The results should provide important insights to university, industry, and government policymakers in the management of university-industry relationships. They should also provoke broader discussions about UIRs themselves and about the rise of agricultural biotechnology.

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