Universities as Research Partners

Bronwyn H. Hall
Department of Economics
University of California at Berkeley and NBER
Berkeley, CA 94720-3880
(510) 642-3878
bhhall@econ.berkeley.edu

Albert N. Link
Department of Economics
University of North Carolina at Greensboro
Greensboro, NC 27412
(336) 334-5146
al_link@uncg.edu

John T. Scott
Department of Economics
Dartmouth College
Hanover, NH 03755
(603) 646-2941
john.t.scott@dartmouth.edu

Revised February 16, 2000

Abstract

Universities are a key institution in the US innovation system and an important aspect of their involvement is the role they play in Private-Public Partnering activities. This study seeks to gain a better understanding of the performance of university-industry research partnerships using a sample survey of pre-commercial research projects funded the U.S. government's Advanced Technology Program. Although results must be interpreted cautiously due to the small size of the sample, the study finds that projects with university involvement tend to be in areas involving "new" science and therefore experience more difficulty and delay but also are more likely not to be aborted prematurely. We interpret this finding to imply that universities are contributing to basic research awareness and insight among the partners in ATP-funded projects.

We are grateful for comments from Lee Baldwin, Adam Jaffe, Don Siegel, and participants at the ASSA 2000 meetings in Boston and the Wake Forest University economics workshop on an earlier version of this paper. Also, we appreciate the suggestions and guidance of Rosalie Ruegg and Jeanne Powell, both of the Advanced Technology Program, during the data collection stage.

Universities as Research Partners

I. Introduction

> The U.S. research and development enterprise finds itself in a wrenching period of change with the end of the Cold War, the globalization of the world economy and the drive to eliminate the federal deficit. … The U.S R&D establishment has now entered a pivotal phase of transition—one that will determine our nation's long-term capacity to make and exploit discoveries and innovations in critical areas, while providing world-class institutions, facilities and education in science, mathematics and engineering.
>
> R&D partnerships hold the key to meeting the challenge of transition that our nation now faces. … Over the next several years, participants in the U.S. R&D enterprise will have to continue experimenting with different types of partnerships to respond to the economic constraints, competitive pressures and technological demands that are forcing adjustments across the board. … [and in response] industry is increasingly relying on partnerships with universities …

This view by the Council on Competitiveness (1996, pp. 3-4) is not surprising. There are a number of indications that industry/university research relationships have strengthened over the past few decades. For example, university participation in formal research joint ventures (RJVs) has increased steadily since the mid-1980s (Link 1996), the number of industry/university R&D centers has increased by more than 60 percent during the 1980s (Cohen et al. 1997), and a recent survey of U.S. science faculty revealed that many desire even more partnership relationships with industry (Morgan 1998). Mowery and Teece (1996, p. 111) contend that such growth in strategic alliances in R&D is indicative of a "broad restructuring of the U.S. national R&D system."

It is, however, surprising that very little is known about the types of roles that universities play in such research partnerships or about the economic consequences associated with those roles. Our investigation is a first effort to provide some empirical information about these issues. Thus, we view this paper as reporting our findings from an exploratory inquiry.

What research there is on the topic of universities as research partners falls broadly into either examinations of industry motivations or of university motivations for engaging in an industry/university research relationship. The extant research has not investigated the economic impacts associated with university participation as thoroughly, especially at the project level.

The literature has identified two broad industry motivations for engaging in an industry/university research relationship. The first is access to complementary research activity and research results.[1] Cohen et al. (1997) provide a selective review of this literature, emphasizing the studies that have documented that university research enhances firms' sales, R&D productivity, and patenting activity.[2] As Rosenberg and Nelson (1994, p. 340) note:

> What university research most often does today is to stimulate and enhance the power of R&D done in industry, as contrasted with providing a substitute for it.

Pavitt (1998), based on his review of this literature, is more specific. He concludes that academic research augments the capacity of businesses to solve complex problems. The second industry motivation is access to key university personnel.[3]

University motivations for partnering with industry seem to be financially based. Administration-based financial pressures for faculty to engage in applied commercial research with industry are growing.[4] Zeckhauser (1996, p. 12746), for example, is subtle when he refers to the supposed importance of industry-supported research to universities as he describes how such relationships might develop:

> Information gifts [to industry] may be a part of [a university's] commercial courtship ritual.

Along those same lines, Cohen et al. (1997, p. 177) contend that:[5]

---

[1] See Blumenthal et al. (1986), Jaffe (1989), Adams (1990), Berman (1990), Feller (1990), Mansfield (1991, 1992), Van de Ven (1993), Bonaccorsi and Piccaluga (1994), Klevorick et al. (1994), Zucker et al. (1994), Henderson et al. (1995), Mansfield and Lee (1996), Zeckhauser (1996), Campbell (1997), Cohen et al. (1997), and Baldwin and Link (1998).

[2] Cockburn and Henderson (1997) show that it was important for innovative pharmaceutical firms to maintain ties to universities. Perhaps research ties with universities increase the "absorptive capacity," in the Cohen and Leventhal (1990) sense, of the innovative firms.

[3] See Leyden and Link (1992) and Burnham (1997). Link (1995) documents that one reason for the growth of Research Triangle Park (North Carolina) was the desire of industrial research firms to locate near the triangle universities (University of North Carolina in Chapel Hill, North Carolina State University in Raleigh, and Duke University in Durham).

[4] See Berman (1990), Feller (1990), and Henderson et al. (1995), and Siegel et al. (1999).

[5] Siegel et al. (1999) document that university administrators consider licensing and royalty revenues from industry as an important output from university technology transfer offices.

> University administrators appear to be interested chiefly in the revenue generated by relationships with industry.

They are also of the opinion that faculty, who are fundamental to making such relationships work:[6]

> … desire support, *per se*, because it contributes to their personal incomes [and] eminence … primarily through foundation research that provides the building blocks for other research and therefore tends to be widely cited.

On the other hand, several drawbacks to university involvement with industry have been identified, such as the diversion of faculty time and effort from teaching, the conflict between industrial trade secrecy and traditional academic openness, and the distorting effect of industry funding on the university budget allocation process (in particular, the tension induced when the distribution of resources is vastly unequal across departments and schools).

The remainder of this paper is outlined as follows. We describe the sample of research partnerships studied in Section II. This sample comes from the population of research projects funded by the Advanced Technology Program (ATP) between 1991 and 1997. Our quantitative inquiry into the role of universities in research partnerships, based on survey data, is presented in Section III. Therein we ask three general questions about the roles and effects of universities in research partnerships, and we provide descriptive information to answer each based on an analysis of university involvement in ATP-funded projects. Finally, in Section IV we offer some concluding observations in an effort to set the stage for future research in this area.

II. An Analysis of the Data

A. Identifying an Appropriate Database

No systematic data exist regarding universities as research partners at either the firm level or the project level. While general information can be gleaned about formal research joint ventures and university participation in them from the *Federal Register* (such information is filed under the National Cooperative Research Act), it is insufficient for a detailed investigation of universities as research partners.[7] And, given our priors about the potentially heterogeneous research role that universities might

---

[6] As an aside, while this argument is prevalent, the fact is that federal support to universities has increased over the past decade in real terms, from 10.6 billion 1992 dollars in 1990 to 14.1 billion 1992 dollars in 1999 (National Science Foundation/SRS 1997).

[7] These data have been analyzed in Link (1996). See also Hagedoorn, Link and Vonortas (forthcoming).

take, we preferred project-level data. One source of project-level data is the Advanced Technology Program.

As background, the ATP was established within the National Institute of Standards and Technology (NIST) through the Omnibus Trade and Competitiveness Act of 1988,[8] and modified by the American Technology Preeminence Act of 1991. The goals of the ATP, as stated in its enabling legislation, are to assist U.S. businesses in creating and applying the generic technology and research results necessary to:

(1) commercialize significant new scientific discoveries and technologies rapidly; and
(2) refine manufacturing technologies.

These same goals were restated in the *Federal Register* on July 24, 1990:

> The ATP . . . will assist U.S. businesses to improve their competitive position and promote U.S. economic growth by accelerating the development of a variety of pre-competitive generic technologies by means of grants and cooperative agreements.

The ATP received its first appropriation from Congress in FY 1990.

Because of the ATP program has a very particular set of goals, it is important to emphasize that studying ATP projects will not give a complete picture of the university-industry R&D interaction. Compared to a random sample of university-industry projects, the projects analyzed in this paper are more likely to be perceived as having high social value, will generally be riskier, involve generic technology, and be at such an early stage in development that the technology is not easily appropriable. In spite of this qualification, we feel it is worth obtaining a picture of this section of the public R&D infrastructure, while keeping the nature of the selection process firmly in mind.

B. The Population of ATP-Funded Projects

We offer here a number of stylized facts about the population of ATP-funded projects to provide general insights into funding characteristics of the program. This level of detail is especially important

[8] This section of the Omnibus Trade and Competitiveness Act of 1988 is also known as the Technology Competitiveness Act.

since there are very few innovation-related studies that use project-level data. Hence, our overview of ATP's population of funded projects may be of interest in itself.[9]

1. Since making its first awards in April 1991, ATP has funded 352 projects (though October 1997, the date this research study began). As of that date, 256 projects were active, 75 had been completed, 16 had been terminated due to an inability to meet project goals, and 5 had been terminated during the negotiation stages.
2. For the population of 352 projects, 234 are single applicants and 118 are joint ventures. Of the 234 single applicants, 54.7 percent involve a university as a subcontractor; and of the 118 joint ventures, 60.2 percent involve a university either as a research partner or as a subcontractor.[10]
3. The mean total (ATP plus industry funding) proposed cost of funded projects is \$6.59 million, with a range from \$490 thousand to \$62.97 million. By statute, ATP's maximum contribution to single applicant projects is \$2 million in direct costs;[11] ATP maximum contribution to joint ventures cannot exceed 50 percent of direct costs. The mean project cost for a joint venture is just over four times that of a single participant—\$13.24 million compared to \$3.24 million. For the population of 352 projects, the percentage of total cost funded by ATP is 56.1 percent, with a range from 11.8 percent to 94.6 percent. For joint ventures, the average ATP percentage is less than for single participant projects; 47.9 percent compared to 60.3 percent. Not only is the average level of ATP support, in percentage terms, less for joint ventures, the range of that support is more narrow. The range for single participant projects is 11.8 percent to 94.6 percent, compared to 32.4 percent to the statutory 50.0 percent for joint venture projects.
4. The ATP places each funded project into a unique technology area for reporting purposes. By far the largest number of funded projects relates to the broad technology area of information/computer systems (29 percent), followed by biotechnology (19 percent), and then materials (16 percent). A smaller number of projects funded related to electronics (12 percent), discrete manufacturing (11 percent), chemicals and chemical processing (7 percent), and energy and the environment (6 percent).
5. University involvement as a research partner in a joint venture is technology area specific. In biotechnology, 42 percent of funded joint ventures had a university as a research partner; in

[9] More detailed descriptive statistics on the population of ATP-funded projects are available upon request from the authors.

[10] We are using the generic term "partner" to refer to a university-industry relationship where the university is either a subcontractor to a single company or to a joint venture; or where the university is a research partner in a joint venture, which means that the university is a formal member of the joint venture. To refer to this latter case, we describe the university as a "research partner."

[11] Large single applicants must provide at least 60 percent of direct and indirect costs.

manufacturing, 39 percent had a university as a research partner; and in information/computer systems, 33 percent had a university as a research partner. In contrast, none of the joint ventures projects in energy and the environment or in chemicals and chemical processing had a university involved as a research partner, and only 7 percent of those in electronics did.

6. By statute, single applicant projects cannot exceed three years, and joint ventures cannot exceed five years. About 70 percent of funded projects are expected to last three years or more.[12]
7. The ATP classifies each funded project by the size of the lead participant. Each lead participant is placed into one of four ATP-defined size categories. Not-for-profit organizations are designated as a size category for ATP reporting purposes. Among the for-profit organizations, small is defined as an organization with fewer than 500 employees. Large is defined as a *Fortune* 500 or equivalent organization (a moving definition). At the same time our analysis was conducted, a *Fortune* 500 equivalent organization was one with more than $2.578 billion in revenue. Medium organizations are all others. More than one-half of the lead participants are small.

C. Selecting a Sample of ATP-Funded Projects

The sample of projects analyzed in this paper was selected from the population of 352 projects using a series of filters, some under our control and others not. The process of selection is summarized in Table 1; Table 2 gives a bit more detail on the sampling methodology. The first filter was the fact that 21 projects terminated early and were therefore unavailable for sampling. We provide an analysis of the reasons for early termination in the next section, as they are of substantive interest. The second filter was a requirement that each project must be active and must have been so for at least one year. *A priori*, we reasoned that these constraints would help to ensure the respondent's capability to rely on a research project history when answering the questions. These two filters reduced the population of 352 projects to 192 projects.

These 192 projects were then grouped according to the six types of projects with/without university involvement listed in Table 2 (column 3). From each of the categorical groupings, a sample of nine projects was selected (column 4). Attention was also given in the selection of nine projects to technology areas, size of lead participant, length of time the project had been active, and the total

[12] Expected project duration is agreed upon at the time ATP funds the project.

proposed research budget of the projects. Also reported in Table 2 are the sampling probabilities by type of university involvement.[13] This process of random stratified sampling yielded 54 projects.

Separate and distinct survey instruments were designed to obtain information about the nine projects selected in each of the six categories of type of university involvement.[14] The surveys were pre-tested with at least one lead participant of a project that could in principle have been included in the sample of nine but was not.

The ATP provided the name of a contact person in each of the 54 companies. This individual was contacted by telephone, explained the nature of the study, asked to participate in a survey, and assured that his/her specific responses would remain confidential and reported only in summary form. Each of the contact individuals agreed to participate in the survey under these conditions. The respective category-specific survey was sent by facsimile to each respondent. After a one week period, each non-respondent was re-contacted up to three times on a weekly basis and urged on each occasion to complete and return the survey. Table 2 (column 6) shows the number of surveys received, by category of university involvement.[15] With 7 non-respondents, our sample for analysis is 47, as shown at the bottom of Tables 1 and 2.

We emphasize that we are aware of the limitations of the self-reported data that will be analyzed below. While our survey instruments were pre-tested, the possibility that our primary data reflect the personal attitudes of the respondents as well as objective characterizations of their program is still present. As such, while this study is one of the first of its kind in attempting to quantify the role of universities in research partnerships, efforts to generalize from our findings should be made with the utmost caution.

D. Analysis of Terminated Projects in the Population

As an initial investigation of the role of universities in ATP-funded research projects, we investigated the reasons for the early termination of the 21 projects noted just above. These reasons ranged from the financial health of the participant(s) to lack of research success in the early part of the project.

---

[13] Variability in these probabilities reflects the fact that the sample size is constant at nine and that the size of the population of appropriate projects to sample, by category type, varies (column 3).

[14] Copies of the survey instruments are available upon request from the authors.

[15] Because there are multiple dimensions of ATP-funded projects, we do not claim that our sample of 47 respondents is representative of the filtered population or of the whole population in all dimensions. We offer our sample as one sample to consider, and possibly to generalize about, given the stated filtering and selection process. More detailed information about the representativeness of the sample by other characteristics of ATP-funded projects is available upon request from the authors.

Of the 21 terminated projects, 11 were joint ventures and 10 were single participants. Based on the representation of joint ventures in the 352 funded projects, joint ventures are 34 percent of the population of ATP-funded projects but they are 52 percent of terminated projects. Thus, joint ventures appear to have a higher probability of termination than single participants. Of the 11 joint ventures that were terminated, three included a university as a research partner and two others included a university as a subcontractor. Four of the single participants included as university as a subcontractor. Thus, nine of the 21 terminated projects involved a university in some research capacity.

To consider in a more systematic manner the relationship between university involvement in an ATP-funded project and the probability that the project will terminate early, we estimated a probit model of termination probability conditional on ATP's share of funding, involvement of a university, type of project, size of the lead participant, and technology area.[16] A time variable denoting the year in which each project was initially funded was also included.

The probit estimates from alternative specifications of equation (1) are reported in Appendix A (Table A-1) and the predicted probabilities as a function of our key variables are shown in Table 3. Our particular interest is the nature of the relationship between university involvement and termination. The results imply that the projects with university involvement as either a research partner or subcontractor have a lower probability of early termination. Also, the probability of early termination decreases as ATP's share of funding increases, although the effect is barely significant, and only for the specialization to simulate the results shown in Table 3. The termination rate does not vary across technology area,[17] but projects where the lead partner is of medium size are more likely to terminate early than the others.

The upper portion of Table 3 presents the calculated probabilities for a project terminating early, by size of the lead participant. For this example (information technology projects begun in 1991), the calculated probability of early termination is lower for each size category when a university is involved in the project. Similarly (lower portion of Table 3), the calculated probability of early termination is lower for each discrete level of ATP's share of funding when a university is involved in the project.[18] In the

---

[16] To be precise, we estimated the following model:

(1) $Pr(\text{project } i \text{ terminates early}) = F(\boldsymbol{X}_i \boldsymbol{\beta})$

where F is the cumulative normal probability function and $\boldsymbol{X}_i$ is a vector of variables that characterizes project i.

[17] This conclusion needs to be qualified slightly: because no projects in other manufacturing terminated early, these projects could not be included in the models estimated in the first 2 columns of Table A-1 (where we use technology dummies). Clearly projects in this technology area have a lower early termination rate than projects in the other technology areas.

[18] Similar relationships exist across other research technology areas, and this information is available from the authors.

population of ATP projects, university involvement is clearly associated with a lower probability of early termination.[19]

E. Estimating the Probability of Response to the Sample Survey

Only two of the six categories of university involvement listed in Table 2 (column 6) had a 100 percent response rate. Contact persons in joint ventures were less likely to respond, with the least responsive category being joint ventures with universities as both partners and subcontractors—only five of nine surveys were returned. We examined the probability of survey response using a probit model.

The probit estimates for a model of the probability of responding are reported in Table A-2 of Appendix A. When we include all of the right hand side variables, nothing is very significant. The only variable that is even marginally informative about the probability of survey response is the dummy for joint ventures with universities as both partner and subcontractor (JVUS), which are arguably the most complex arrangement contractually. Other factors held constant, contact persons in joint ventures with universities as research partners and as subcontractors have a lower probability of response than other contact persons. The associated predicted probabilities of response by selected technology areas and type of university involvement are reported in Table 4.[20]

[19] The information in Table A-1 is used to calculate a hazard rate for the probability that a project does not terminate early for use in the subsequent statistical analyses of a sample of ATP-funded projects to control for possible sample selection bias. To anticipate the use of this variable in later survey question equations, it is important to note that its inclusion in an ordered probit or tobit is not really econometrically correct if it actually enters. That is, if the probability distribution in the termination equation and the distribution in the survey question equation are dependent, then the appropriate method is to specify a full maximum likelihood model for the two random variables and estimate jointly (such a model is outlined in Appendix B). In fact, we found that the termination hazard and the sample response hazard never entered significantly, and that joint maximum likelihood estimates did not differ significantly from our single equation estimates, which implies that sample selection is unlikely to produce significant bias in our estimates. However, our sample size is small, so the power of all these tests is low.

[20] The sample size in Tables A-2 and Table 4 is quite small (only 29 observations), because all projects with large lead participants or whose technology area was electronics, biotechnology, chemicals, energy, or the environment responded to the survey and hence these projects could not be used to estimate the probability equation (they had one or more variables that were perfect predictors). In our later estimations, we used a response probability equation that does not depend on technology and is therefore defined for the whole sample.

In the results presented later, we will correct for response bias in two ways: 1) by simply including the JVUS dummy in our estimations to test for response bias;[21] and 2) estimating a full two equation model using maximum likelihood, where one equation is the equation of interest, and the other is the equation for response probability. The implication of the first strategy will be that we cannot identify the direct effects of being a joint venture with a university participating as a partner and as a subcontractor separately from the impact on the probability of survey response.

III. Role of Universities in ATP-Funded Projects

Three general questions about the roles of universities as research partners are posed in this section, and then they are answered with reference to the role of universities in ATP-funded projects. These questions are:

1. What roles do universities play in research partnerships in general?
2. Do universities enhance the research efficiency of research partnerships?
3. Do universities affect the development and commercialization of industry technology?

A. Role Played by Universities in ATP-Funded Projects

What research role do universities play in ATP-funded projects? At one level, the answer to this question comes from the organizational or administrative role that universities have in various projects. In a joint venture, the research role of a university is either as a research partner in the joint venture or as a subcontractor to the joint venture. In single applicant projects, the research role of a university is only as a subcontractor by definition of the project being a single applicant project.[22]

---

[21] As with our analysis of the probability of early termination, the results in Table A-2 could be used to calculate a survey hazard rate to used in the statistical analyses that follow. The survey hazard rate is the conditional probability density of responding to the survey. However, in practice, the only variable that predicted response or non-response in a simple probit model was JVUS (whether the project was a joint venture with a university as a partner). We therefore used a simpler and more robust method to correct for response bias, by including the JVUS dummy directly in our estimated model. Unlike the use of a hazard rate, this correction does not require normality of the response probability equation to be valid. In the case of a single dummy variable predictor, of course, the two approaches for converting any response bias would be equivalent if normality held.

[22] Related to this organizational or administrative research role that universities have is another level at which to answer the first research question. Four of the six groups of contact persons for the survey were asked why the university subcontractors on this project were selected. In the case of joint ventures where a university is only involved as a subcontractor (jvs) and in the case of single participants where the university is only involved as a subcontractor (ss), the most frequent response was that the subcontractor was selected to gain access to eminent researchers. Joint ventures in which the university is only involved as a research partner (jvu) reported that the university was invited to participate most commonly because of previous research interactions with other members of the joint venture. And, finally, the dominant response when universities are involved in a joint venture as research partners and as subcontractors (jvus) is that each was selected based on their overall research reputation.

At a second level, we explored the research role played by universities by asking each contact person to respond to the following statement using the 7-point Likert scale noted below:

> *This research project has experienced difficulties acquiring and assimilating basic knowledge necessary for the project's progress.*
>
> strongly agree…………………………….………………....strongly disagree
>
> 7 6 5 4 3 2 1

Respondents in general disagreed with this statement (e.g., responded to the statement with a 1 or a 2), but those who agreed with the statement (e.g., responded to the statement with a 6 or a 7) most frequently were involved in single applicant projects with no university involvement.[23] To examine this issue of the research role that universities play in ATP-funded projects more systematically, ordered probit models were estimated to explain inter-project differences in responses by the contact person to the statement above. Held constant in these models are several characteristics of the project as determined from ATP information about the project and from responses to survey questions.

The estimates are shown in Table 5. In column 1 we include the hazard rate for non-termination (the conditional probability density that the project will go forward to completion) and the proxy for the survey response hazard (JVUS) in the model. Neither of these enters into the equation significantly, implying that selection bias is unlikely to be a problem for our estimates. However, the full model for sample selection (an ordered probit equation plus an equation for the probability that the survey was returned) is barely identified in these data, with a correlation coefficient between the disturbances near minus one with a large standard error.

Four observations about the estimates in Table 5 seem relevant:

1. Respondents with a university participant (as a research partner or as a subcontractor) systematically agreed that the project has experienced difficulties acquiring and assimilating basic knowledge necessary for progress toward completion (a relationship opposite to that seen from the descriptive data in Table A-4 in the data appendix, because now we have controlled for project size, and prior experience). Joint venture projects are larger than others, which tends to lower difficulty in general but raise it if a partner is a university. This is probably also consistent with such projects being more "difficult" or closer to "new" science than are others and hence the university partner was chosen in

[23] See Table A-4 in the data appendix. In estimation, categories 1 and 2 and categories 6 and 7 were combined because of the small number of responses in those categories.

anticipation of this. Or, the university's presence may create a greater awareness that such difficulties exist.

2. Prior experience working with a university as a research partner or as a subcontractor is a very significant factor in decreasing the difficulty of acquiring and assimilating basic knowledge.
3. Acquisition and assimilation difficulties with basic knowledge decrease slightly as overall project size increases.
4. Projects in the electronics area have substantially more difficulty in acquiring and assimilating basic knowledge than do projects in other technology areas.

B. Research Efficiencies from Universities in ATP-Funded Projects

Are there systematic differences in the research efficiency of ATP-funded projects that have universities involved and those that do not? We addressed this question of research efficiency by asking each contact person to respond to a series of five statements. The first three of these statements investigate unexpected research problems encountered to date relative to when the project began. The last two statements relate to the productive use of complementary research resources.

The first three statements were of the following form:

> *The number of [conceptual / equipment-related / personnel] research problems encountered in this project have been _____ (please select one response—more than / less than / about the same as) expected when the project began.*

From the univariate statistics, it appears that unexpected conceptual and personnel research problems occur more frequently among single applicants than among joint ventures, whereas equipment-related problems are more common among joint ventures.[24] There is no clear response pattern that relates to the involvement of a university in the project with the exception that projects with universities involved as subcontractors in joint ventures reported the greatest number of unexpected personnel-related research problems.

To examine responses to this statement more systematically, ordered probit models were estimated. Held constant in these models are several characteristics of the project as determined from ATP information about the project and from responses to survey questions. Also held constant is the survey response hazard rate variable as discussed above.[25] As seen in the specifications in Table 6 (columns 1 and 2), none of the individual variables is significant in explaining the existence of unexpected conceptual or equipment-related research problems. Because only a very few projects had fewer problems of any type than expected, the three categories *of less than/about the same as/more than* were collapsed into two; more than expected, or about the same as or less than expected. Even when re-estimated in this form in probit models (results not shown), essentially no identifiable individual variable effects explained the existence of unexpected research problems. Thus, we suggest that the presence of unexpected problems is perhaps random or a complex result of many factors that we cannot disentangle, that is, that they are truly "unexpected" given the information available to the firm (and to us).

The estimates in column 3 of Table 6 do suggest that the presence of "unexpected" personnel-related problems are associated mainly with the technology field, being more prevalent in those technology areas closer to the "frontier," such as information technology, electronics, and biotechnology. Project budget size is a marginally significant explanatory variable in explaining the present of unexpected personnel problems; projects with non-profit lead partners are less likely to experience this kind of problem. As we saw above, joint ventures with university partners are both more likely to have personnel-related problems and also less likely to respond to the survey, so we cannot disentangle these two effects.

The fourth and fifth statements addressed aspects of research efficiency that are related to the productive use of complementary research resources. These statements were:

> *To date, approximately ___ percent of the research time devoted to this project has, in retrospect, been unproductive.*
>
> *To date, approximately ___ percent of the financial resources devoted to this project has, in retrospect, been unproductive.*

These two statements are analyzed together because of the high correlation between responses. Twenty-two of 42 contact persons responded to both questions with the same percentage.

---

[24] See Tables A-5, A-6, and A-7 in Appendix A. In estimating the models for the presence of unexpected conceptual, equipment, or personnel problems, categories 1 and 2, categories 3, 4, and 5, and categories 6 and 7 were combined because of the small number of responses.

[25] Ordered probit models that allowed for sample selection were also estimated, but proved to be very difficult to identify because of the small sample. Therefore we rely mainly on the ad hoc correction terms discussed in footnotes 19 and 21 above.

According to the raw statistical data, the least amount of unproductive research time and cost is being reported for single applicant projects with a university as a subcontractor.[26] However, our Tobit estimates (Table 6) reveal that this is because the technology mix varies across project type.[27] Although we originally included all variables in the estimation, only the size of the lead partner and the technology variables were significant in either equation. Unproductive time and cost seems to be most associated with electronics projects and least associated with information technology and manufacturing projects.

Comparing the estimates in Tables 8 and 9, projects in electronics have the largest share of time and money that is unproductively used whereas projects in manufacturing have the least. Unproductive research time and money in electronics may be related to the fact that projects in this field also have difficulty acquiring and assimilating the basic research they need. It is noteworthy that biotechnology projects have relatively little unproductive research expenditure, although somewhat more unproductive research time. It is also the case that larger (profit-making) lead partners seem to be better at making productive use of research time and expenditure, or at least they perceive that to be the case.

C. Accelerated Development and Commercialization of Technology from Universities in ATP-Funded Projects

Are there systematic differences in the ability of ATP-funded projects to accelerate the development and commercialization of technology when universities are involved in the project and when they are not? We addressed this question by asking each contact person to respond to two statements.

The first statement posed to the lead participant was:

Potential new applications of the technology being developed have been recognized over the course of the project.

strongly agree…………………………….………………....strongly disagree

7 6 5 4 3 2 1

A much larger percentage of joint venture projects with a university involved as a research partner reported agreement to this statement than did joint venture projects with no university or with only a

[26] See Tables A-8 and A-9 in Appendix A.

[27] Note that this survey statement addresses realized unproductive research time and not expected unproductive research time. The same is true for the unproductive use of financial resources.

university serving as a subcontractor. On average, though, respondents from single applicants agreed more often to the statement than did respondents from joint ventures.[28]

Ordered probit estimates for this question (corrected for response probability) were for the most part insignificant; column 1 of Table 8 shows a minimal specification of the model. It may be that the generation of new applications from a technology project in process cannot be attributed to any particular individual project characteristics and is essentially unpredictable regardless of the technology area. The results do however suggest that projects with a higher ATP share are more likely to develop unanticipated applications for the technology. Perhaps a higher ATP share brings greater resources for ATP monitoring or imparts on the research performers a greater leveraging effect to search for or to recognize new applications of the technology. It is noteworthy that university participation seems to have no impact on the generation of new applications of the technology.

The second statement was:

At this stage of the research, it appears that the technology will be developed and commercialized sooner than expected when the project began.

strongly agree……………………………..………………....strongly disagree

7 6 5 4 3 2 1

Single applicant respondents were more optimistic than joint venture respondents about completing the research and commercializing the results sooner than expected, and the most optimistic of all were single applicants with no university involvement.[29]

The response-corrected ordered probit estimates for this question are shown in column 2 of Table 8. A number of variables are significant leading to four interesting conclusions.

1. Projects involving universities as partners are less likely to develop and commercialize technology sooner than expected. This association perhaps reflects the fact that universities are involved in more difficult projects to begin with, namely projects with a lower probability of early completion.
2. Large projects and/or projects with large lead participants are less likely to expect to develop and commercialize their technology sooner than expected compared to projects with non-profit or medium-sized lead participants. Perhaps it is the case that such larger projects reveal a whole new set of research insights. To the extent that larger research budgets are associated with research projects

[28] See Table A-10 in the data appendix.
[29] See Table A-11 in the data appendix.

that can stretch the frontiers of knowledge then less time will be devoted toward looking for early-on commercialization opportunities of the technology.

3. It is also the case that projects with a small lead participant are less likely to expect to develop and commercialize technology sooner than expected. Recall that this group is very small firms, and this may reflect resource constraints they face in development when the project budget does not cover the full cost of making the technology commercially viable.
4. Lack of experience with a university partner reduces the expectation of early commercialization, as does university involvement, perhaps because of lack of market pressure and focus on the particular project by the university participant, or perhaps simply because some adjustment costs are included as the participants learn to work with a university.
5. Projects in information technology, chemicals, energy, and the environment, and materials are significantly more likely to commercialize earlier than expected than projects manufacturing, electronics, and biotechnology.

IV. Concluding Observations

The focus of this survey-based study of ATP-funded research projects is on universities as research partners. Our analyses of the survey data allow us to set forth in this concluding section a consistent and very illuminating story about their research role.

Before offering our concluding observations we emphasize that all of the results from the descriptive analyses and qualitative choice models presented and discussed in the previous sections should be interpreted cautiously. First, to emphasize yet again, the general topic that we have investigated has not previously been studied by academic scholars or professionals in sufficient detail for us to have a theoretical foundation against which to base our inquiry, and as such many of the concepts we attempted to quantify are new and certainly the survey questions posed to address them are exploratory in construction. Second, our analytical tools are not sufficiently sophisticated to make conclusions about directions of causality. The statistical associations that were emphasized in the previous sections are just that, statistical associations (albeit robust associations) and not evidence of independent and dependent relationships. More research will certainly need to be done on the general subject of universities as research partners before such inferences can be made. And third, our analyses are based in some cases on very small sample sizes (e.g., when we control for technology field) so that they are in many cases subject to substantial sampling error (reflected in the standard errors) and some effects are difficult to identify due to the sparseness of the relevant covariates.

Given these caveats, we conclude the paper by emphasizing two themes that seem to be consistent with the data that we have analyzed, the first of which related specifically to the research role of universities.

Universities Create Research Awareness in ATP-Funded Projects. Our first conclusion is that universities create research awareness among the research partners in the ATP-funded projects studied. The qualitative models estimated suggest that projects with university involvement, either as a research partner or as a subcontractor, are one, experiencing difficulties acquiring and assimilating basic knowledge for the project's progress (Table 5); and two, not anticipating being able to develop and commercialize technology sooner than expected when the project began (Table 8).

At one level, these two findings could be interpreted to mean that university involvement is creating research problems in these two dimensions. We eschew that interpretation and conclude, albeit cautiously, that university involvement is creating a greater awareness of research problems than would otherwise be the case. We base our interpretation on the fact that ATP-funded projects with university involvement are less likely to terminate early compared to projects without university involvement (Table 3 and Table A-1).

Thus, we offer a possible interpretation of the research role of a university.[30] Universities are included (e.g., invited by industry) in those research projects that involve what we have called "new" science. As such, it is the collective perception of the other research participant(s) that the university could provide a research insight that is more anticipatory of future research problems that might be encountered and could thus take on the role of an ombudsman to anticipate and translate to all concerned the complex nature of the research being undertaken. Thus, one finds universities purposively involved in projects that are characterized as problematic with regard to the use of basic knowledge. And, because of the type of project for which a university is likely to be invited to partner it is logical that such research will not move faster than expected toward a commercial application of the resulting technology.

Research Funding Influences the Scope of the Research. We infer from several findings that projects with larger research budgets seem to be undertaking research of a broader scope than that considered by other projects, as opposed to researching a narrow project in greater detail. We posit this conclusion based on the following observations: larger budgeted projects are encountering more unexpected personnel-related problems (Table 6), and larger budgeted projects are less likely to commercialize their technology ahead of schedule (Table 8). These statistical associations are not

[30] Absent baseline information about the technical difficulty of the projects or their closeness to "new" science other than technology field, this interpretation is offered cautiously.

inconsistent with such projects attempting to foster newer frontiers of research. It is, however, also true that larger budgeted projects have fewer problems acquiring and assimilating basic knowledge. Thus, if the larger budgeted projects are broader, the scope and breadth would appear to address new applications (new generic technology across many industries for example) rather than fundamental basic research.

We do not speculate as to the extent to which our findings can be generalized to either other projects that are partially publicly funded, or to private sector joint ventures with and without university research interactions. As more research is conducted on this topic, the wider applicability of the observations we set forth in this concluding section will and should be tested.

References

Adams, James D. "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, vol. 98, 1990, pp. 673-702.

Baldwin, William, L and Albert N. Link. "Universities as Research Joint Venture Partners: Does Size of Venture Matter?" *International Journal of Technology Management*, vol. 15, 1998, pp. 895-913.

Berman, Evan M. "The Economic Impact of Industry-Funded University R&D," *Research Policy,* vol. 19, 1990, pp. 349-355.

Blumenthal, David, Michael E. Gluck, Karen S. Lewis, Michael A. Stoto, and David Wise. "University Industry Research Relationships in Biotechnology: Implications for the University," *Science,* vol. 232, 1986, pp. 1361-1366.

Bonaccorsi, Andrea and Andrea Piccaluga. "A Theoretical Framework for the Evaluation of University-Industry Relationships," *R&D Management*, vol. 24, 1994, pp. 229-247.

Burnham, James B. "Evaluating Industry/University Research Linkages," *Research-Technology Management*, vol. 40, 1997, pp. 52-55.

Campbell, Teresa Isabelle Daza. "Public Policy for the 21st Century: Addressing Potential Conflicts in University-Industry Collaboration, *The Review of Higher Education,* vol. 20, 1997, pp. 357-379.

Cockburn, Iain and Rebecca Henderson. "Public-Private Interaction and the Productivity of Pharmaceutical Research," NBER Working Paper 6018, April 1997.

Cohen, Wesley M. and Daniel A. Leventhal. "The Implications of Spillovers for R&D and Technology Advance," in *Advanced in Applied Micro-Economics* (V.K. Smith and A.N. Link, editors), JAI Press, Greenwich, CT, 1990.

Cohen, Wesley M., Richard Florida, Lucien Randazzese, and John Walsh. "Industry and the Academy: Uneasy Partners in the Cause of Technological Advance," in *Challenge to the University* (R. Noll, editor), Brookings Institution Press, Washington, DC, 1997.

Council on Competitiveness. *Endless Frontiers, Limited Resources: U.S. R&D Policy for Competitiveness,* Council on Competitiveness, Washington, DC, 1996.

Estrella, Arturo. " A New Measure of Fit for Equations with Dichotomous Dependent Variables," *Journal of Business and Economic Statistics*, April 1998, pp. 198-205.

Feller, Irwin. "Universities as Engines of R&D-Based Economic Growth: They Think they Can," *Research Policy,* vol. 19, 1990, pp. 349-355.

Hagedoorn, John, Albert N. Link, and Nicholas Vonortas. "Research Partnerships," *Research Policy*, forthcoming.

Henderson, Rebecca, Adam B. Jaffe, and Manuel Trajtenberg. “Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting 1965-1988,” NBER Working Paper No. 5068, 1995.

Jaffe, Adam. “Real Effects of Academic Research,” *American Economic Review*, vol. 79, 1989, pp. 957-978.

Klevorick, Alvin K., Richard C. Levin, Richard R. Nelson, and Stanley G. Winter. “On the Sources and Significance of Interindustry Differences in Technological Opportunities,” *Research Policy*, vol. 24, 1994, pp. 195-206.

Leyden, Dennis P. and Albert N. Link. *Government’s Role in Innovation*, Kluwer Academic Publishers, Norwell, MA, 1992.

Link, Albert N. *A Generosity of Spirit: The Early History of Research Triangle Park*, University of North Carolina Press for the Research Triangle Park Foundation, 1995.

Link, Albert N. “Research Joint Ventures: Patterns from Federal Register Filings,” *Review of Industrial Organization*, vol. 11, 1996, pp. 617-628.

Mansfield, Edwin. “Academic Research and Industrial Innovation,” *Research Policy*, vol. 20, 1991, pp. 1-12.

Mansfield, Edwin. “Academic Research and Industrial Innovation: A Further Note,” *Research Policy*, vol. 21, 1992, pp. 295-296.

Mansfield, Edwin and Jeong-Yeon Lee. “The Modern University: Contributor to Industrial Innovation and Recipient of Industrial R&D Support,” *Research Policy*, vol. 25, 1996, pp. 1047-1058.

Morgan, Robert P. "University Research Contributions to Industry: The Faculty View," in *Trends in Industrial Innovation: Industry Perspectives & Policy Implications* (edited by Peter D. Blair and Robert A. Frosch), Research Triangle Park: Sigma Xi,, The Scientific Research Society, 1998, pp. 163-170.

Mowery, David C. and David J. Teece. "Strategic Alliances and Industrial Research, in *Engines of Innovation: U.S. Industrial Research at the End of an Era* (edited by Richard S. Rosenbloom and William J. Spencer), Boston, Harvard Business School Press, 1996, pp. 111-129.

National Science Foundation/SRS. *Academic Research and Development*, U.S. Government Printing Office, Washington, D.C., 1997 and later editions.

Poritt, Keith. “The Social Shaping of the National Science Base,” *Research Policy*, vol. 27, 1998, pp. 793-305.

Rosenberg, Nathan and Richard R. Nelson. “American Universities and Technical Advance in Industry,” *Research Policy*, vol. 23, 1994, pp. 323-348.

Siegel, Donald, David Waldman, and Albert N. Link. "Assessing the Impact of Organizational Practices on the Productivity of University Technology Transfer Offices: An Exploratory Study," NBER Working Paper No. 7256, 1999.

Van de Ven, Andrew H. "A Community Perspective on the Emergence of Innovations," *Journal of Engineering Technology Management*, vol. 10, 1993, pp. 23-51.

Zeckhauser, Richard. "The Challenge of Contracting for Technological Information," *Proceedings of the National Academy of Science*, vol. 93, 1996, pp. 12743-12748.

Zucker, Lynne G., Michael Darby, and Jeff Armstrong. "Intellectual Capital and the Firm: The Technology of Geographically Localized Knowledge Spillovers," NBER Working Paper No. 4946, 1994.

Table 1
Selection of the Sample of Projects

	Number	Type of Selection
Total Number of Projects	352	
# terminated very early	-1	
	351	
# terminated early	-20	non-random
	331	
# inactive or active less than one year	-139	mostly random
	192	
# not sampled	-138	stratified (random)
# sampled	54	
# not responding	-7	non-random
# good survey responses	**47**	

Table 2
Distribution of ATP-Funded Projects by Type of University Involvement

Type of University Involvement	Number of Projects	Filtered Projects	Sample Projects	Sampling Probability	Number Responding
Joint Venture	118	81	36	44.4%	29
No university involvement (jv)	47	31	9	29.0%	8
Universities involved as subcontractors (jvs)	42	28	9	32.1%	8
Universities involved as research partners (jvu)	16	11	9	81.8%	8
Universities involved as both partner and sub. (jvus)	13	11	9	81.8%	5
Single applicant	234	111	18	16.2%	18
No university involvement (s)	106	45	9	20.0%	9
Universities involved as a subcontractor (ss)	128	66	9	13.6%	9
Total	352	192	54	28.1%	47

Filtered projects are projects that have been active one year or more and are still active in the beginning of 1998.
Sampled projects were selected from the filtered project universe to ensure an equal number in each category.

Table 3
Simulation of Probability of Termination
ATP Information Technology Projects Begun in 1991

	University Involved	No University Involved
Size of Lead Participant (50% ATP share)		
Small	0.036	0.094
Medium	0.189	0.344
Large	0.042	0.106
Not-for-profit	0.081	0.179
ATP Share of funding (Medium Lead Part.)		
Zero	0.423	0.612
25 percent	0.296	0.477
50 percent	0.189	0.344
75 percent	0.111	0.228
100 percent	0.059	0.138

This simulation is based on specification (1) in Table A-1.

Table 4
Predicted Probability of Survey Response

Project Type	Predicted Probability	Sample Probability	Number in Sample	Number of Responses
JVUS in materials or info. tech.	0.16	0.25	4	1
JVUS in manufacturing	0.60	0.50	2	1
non-JVUS in materials or info. tech.	0.78	0.80	15	12
non-JVUS in manufacturing	0.98	1.00	5	5
All other projects	1.00	1.00	28	28

The predicted probabilities are based on specification (1) in Table A-2.

Table 5
Determinants of Difficulty Acquiring Basic Knowledge

Variable	(1) Ordered Probit Coefficient (s.e.)	(2) Ordered Probit Coefficient (s.e.)	(3) Ord. Probit/Sample Sel. Coefficient (s.e.)
Log of total project budget	-0.72 (0.36) **	-0.51 (0.30) *	-0.52 (0.27) *
ATP share (fraction)	-2.31 (5.38)		
D (university participant)	0.80 (1.38)	0.98 (0.51) *	0.90 (0.48) *
D (no prior experience)	1.14 (0.50) **	1.04 (0.50) **	0.99 (0.47) **
Log (revenue of lead part., $M)		0.08 (0.06)	0.09 (0.06)
Small lead participant	-1.39 (2.73)		
Large lead participant	-0.32 (2.49)		
Non-profit lead part.	-0.04 (1.49)		
Chi-square for 3 size vars. (prob.)	3.03 (0.388)		
Information Technology	0.08 (0.65)		
Manufacturing	-1.22 (1.01)		
Electronics	3.01 (1.06) ***	2.75 (0.84) ***	2.66 (0.80) ***
Biotechnology	0.00 (0.63)		
Chemicals, energy, and environ.	-1.04 (0.88)		
Chi-sqaure for 5 tech. vars. (prob.)	12.3 (0.030) **		
Non-termination hazard	0.71 (3.67)		
JVUS (survey response hazard)	-0.48 (0.81)		
Correlation coefficient			-0.99 (596)
Number of observations	47	47	54 (47)
Log likelihood	-44.09	-46.27	-62.39
Scaled R-squared	0.150	0.127	
Chi-squared (degrees of freedom)	23.90 (14)	17.54 (5)	

The categories have been collapsed from 7 to 5, using the groupings (1&2), 3, 4, 5, (6&7).
The excluded category is a project in materials with no university participant.
The excluded category in column 2 is a project where the lead participant is of medium size.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).
Estimates in column 3 are combined ordered probit/sample selection estimates.
The selection equation estimates are Pr(1.79 -1.28 (JV with Univ as partner) - 0.93 (Non-profit lead partner)).
The correlation coefficient is that between the disturbances in the two equations.

Table 6
Determinants of the Problems in the Project
Ordered Probit Estimates

Variable	Conceptual Coefficient (s.e.)	Equipment-related Coefficient (s.e.)	Personnel-related Coefficient (s.e.)
Log of total project budget	-0.10 (0.34)	0.46 (0.31)	0.61 (0.39) *
D (university participant)	0.03 (0.73)	-0.54 (0.56)	1.16 (0.79)
D (no prior experience)	0.61 (0.51)	0.23 (0.49)	0.65 (0.54)
Small lead participant	1.16 (1.55)	-0.32 (1.39)	-1.48 (1.64)
Large lead participant	0.91 (1.45)	-0.96 (1.31)	0.20 (1.55)
Non-profit lead part.	1.29 (1.11)	-0.90 (1.03)	-2.64 (1.35) **
Chi-square for 3 size vars. (prob.)	1.49 (0.684)	2.38 (0.498)	11.27 (0.010) ***
Information Technology	0.82 (0.67)	-1.07 (0.66)	1.77 (0.74) **
Manufacturing	0.06 (0.84)	-0.78 (0.85)	2.16 (0.97) **
Electronics	-0.96 (0.98)	-0.03 (0.99)	2.63 (1.21) **
Biotechnology	-0.13 (0.64)	-0.55 (0.63)	2.01 (0.76) ***
Chemicals	0.51 (0.78)	-0.25 (0.75)	0.47 (0.80)
Chi-square for 5 tech. vars. (prob.)	4.31 (0.506)	3.02 (0.697)	9.0 (0.110)
Non-termination hazard	0.13 (1.81)	0.62 (1.68)	0.26 (1.80)
JVUS (survey response hazard)	-0.84 (0.76)	-0.14 (0.69)	-1.90 (0.85) **
Number of observations	46	45	44
Log likelihood	-30.24	-33.02	-27.00
Pseudo R-squared	0.146	0.131	0.428
Chi-squared (degrees of freedom)	10.45 (13)	7.10 (13)	24.13 (13) **

The categories have been collapsed from 7 to 3, using the groupings (1&2), (3, 4, & 5), (6&7).
The excluded category is a project in materials or energy with no university participant
and where the lead participant is of medium size.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).

Table 7
Percentage of Unproductive Research Time and Cost
Sample Selection Estimates

Dependent Variable	(1) Research Time			(2) Research Cost		
Variable	Coefficient (s.e.)			Coefficient (s.e.)		
Log (revenue of lead part., $M)	-0.88	(0.30)	***	-0.84	(0.27)	***
Information Technology	-5.92	(2.89)	**	-5.76	(1.87)	***
Manufacturing	-10.54	(4.19)	**	-8.64	(4.72)	*
Electronics	11.08	(4.96)	**	13.99	(5.58)	**
Biotechnology	-0.85	(3.13)		-10.47	(3.23)	***
Chemicals, energy, and environ.	8.24	(3.58)	**	6.55	(1.13)	***
Chi-square for 5 tech. vars. (prob.)	28.6	(0.001)	***	26.7	(0.001)	***
Intercept	18.39	(3.21)	***	15.40	(3.12)	***
Standard error	6.32	(0.70)	***	7.40	(0.73)	***
	Probit for Sample Response					
Intercept	1.17	(0.26)	***	0.97	(0.20)	***
JVUS	-0.55	(0.50)		-0.77	(0.26)	***
Non-profit lead partner	-1.08	(0.46)	**	-0.30	(0.33)	
Rho (correlation btwn 2 eqs)	0.09	(0.57)		0.99	----	
No. of obs. (No. responding)	54 (42)			54 (42)		
Log likelihood	-151.34			-155.65		

The excluded category is a project in materials.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).

Table 8
Performance Determinants
Ordered Probit Estimates with Correction for Response Probability

Dependent Variable	(1) New applications of technology developed			(2) Commercialized sooner than expected		
Variable	Coefficient (s.e.)			Coefficient (s.e.)		
Log of total project budget				-0.91	(0.37)	**
ATP share (fraction)	3.29	(1.41)	**			
D (university participant)	-0.14	(0.42)		-0.78	(0.42)	*
D (no prior experience)				-0.94	(0.44)	*
Small lead participant				-1.34	(0.54)	**
Large lead participant				-1.73	(0.67)	***
Chi-square for size vars. (prob.)				8.43	(0.015)	**
Information Technology				1.08	(0.52)	**
Manufacturing						
Electronics						
Biotechnology						
Chemicals, energy, and environ.				1.21	(0.74)	*
Materials				1.64	(0.76)	**
Chi-square for tech. vars. (prob.)				6.92	(0.074)	*
	Probit for Sample Response					
Intercept	1.79	(0.40)	***	1.47	(0.34)	***
JVUNS	-1.39	(0.46)	***	-0.69	(0.49)	
Non-profit lead partner	-0.97	(0.48)	**	-1.21	(0.51)	**
Correlation coefficient	-0.96	(0.67)		-0.95	(0.28)	***
No. of obs. (number responding)	54 (47)			54 (47)		
Log likelihood	-79.72			-87.12		

The dependent variable takes on only six values because one of the cells (y=3) is empty.
The excluded category in column 2 is a project where the lead participant is of medium size.
The correlation coefficient is that between the disturbances in the two equations.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).

Appendix A

Table A-1

Determinants of the Probability of Early Termination

Probit Estimates: Dependent Variable = 1 if Project Terminated Early

Variable	(1) Coefficient (s.e.)	(2) Coefficient (s.e.)	(3) Coefficient (s.e.)
D (university involvement)	-0.434 (0.258) *	-0.537 (0.269) **	-0.478 (0.249) *
ATP share of funding	-1.783 (0.943) *	-1.472 (0.957)	-1.374 (0.899)
Time trend	-0.112 (0.082)	-0.112 (0.084)	-0.079 (0.075)
Small lead participant	-0.716 (0.317) **	-0.818 (0.326) **	-0.914 (0.302) ***
Large lead participant	-0.929 (0.348) ***	-0.943 (0.351) ***	-0.848 (0.335) ***
Non-profit lead part.	-0.401 (0.466)	-0.337 (0.467)	-0.516 (0.419)
Chi-square for 3 size vars. (prob.)	8.47 (0.037) **	9.47 (0.024) **	10.50 (0.015) **
Information Technology	0.025 (0.338)	-0.074 (0.347)	
Electronics	-0.488 (0.465)	-0.478 (0.389)	
Biotechnology	-0.533 (0.455)	-0.510 (0.569)	
Chemicals, Energy, & Environ.	-0.039 (0.387)	-0.022 (0.457)	
Chi-square for 4 tech. vars. (prob.)	2.90 (0.575)	2.16 (0.675)	
Intercept	0.738 (0.655)	0.662 (0.664)	0.285 (0.569)
Number of observations	313	312	351
Log likelihood	-67.33	-64.42	-67.89
Scaled R-squared	0.126	0.133	0.115
Chi-squared (DF)	19.38 (10)	19.75 (10)	17.67 (6)

Column (1) includes the full sample excluding projects in other manufacturing (none of which were terminated).
Columns (2) and (3) delete a single observation for a project that was terminated prior to starting.
The excluded category is a project in materials with no university participation and where the lead participant is of medium size.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).
The scaled R-squared is a measure of goodness of fit relative to a model with only a constant term, computed as a nonlinear transformation of the LR test for zero slopes (see Estrella 1998).

Table A-2

Probit Estimates for the Probability of Survey Response

Dependent Variable = 1 if Survey was Returned

Variable	(1) Coefficient (s.e.)	(2) Coefficient (s.e.)	(3) Coefficient (s.e.)
JV with university as partner	-0.08 (1.05)		
JV with univ. as subcontractor	-0.54 (1.23)		
JV with univ. as part. & sub.	-1.75 (0.95) *	-1.36 (0.65) **	-1.21 (0.53) **
Small lead participant	0.29 (1.10)		
Large lead participant			
Non-profit lead part.	-0.31 (1.23)	-0.34 (0.60)	-0.96 (0.52) *
Information Technology	0.42 (0.90)		
Manufacturing	1.24 (1.09)		
Intercept	0.76 (1.34)	1.16 (0.42) ***	1.78 (0.36) ***
Number of observations (#=1)	26 (19)	26 (19)	54 (47)
Log likelihood	-10.69	-12.12	-15.50
Scaled R-squared	0.294	0.229	0.213
Chi-squared (DF)	8.91 (7)	6.05(2)	10.66 (2)

The sample in columns 1 and 2 is joint ventures with small, medium or non-profit lead participants in the information technology, manufacturing, or materials areas. All other technologies predict perfectly.

The excluded category is a project in materials with no university participant and where the lead participant is of medium size.

Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).

The scaled R-squared is a measure of goodness of fit relative to a model with only a constant term, computed as a nonlinear transformation of the LR test for zero slopes (see Estrella 1998).

Table A-3
Overall Determinants of Sampling Probability
Probit Estimates: Dependent Variable = 1 if Project was sampled and responded

Variable	(1) Coefficient (s.e.)	(2) Coefficient (s.e.)	(3) Coefficient (s.e.)
JV with university partner	2.16 (0.52)***	1.74 (0.36)***	1.75 (0.36)***
JV with university partner and sub.	1.44 (0.46)***	1.74 (0.36)***	1.75 (0.36)***
JV with no university	0.632 (0.310)**	0.651 (0.210)***	0.563 (0.200)***
JV with university subcontractor	0.647 (0.322)**	0.651 (0.210)***	0.563 (0.200)***
Single with university	-0.434 (0.253)		
ATP share of funding	0.570 (0.792)		
Time trend	-0.071 (0.062)	-0.065 (0.060)	
Small lead participant	-0.118 (0.295)		
Large lead participant	0.194 (0.304)		
Non-profit lead part.	-0.838 (0.509) *	-0.704 (0.410) *	-0.693 (0.391) *
Chi-square for 3 size vars. (prob.)	5.20 (0.158)		
Information Technology	0.064 (0.297)	-0.024 (0.280)	
Manufacturing	0.155 (0.366)	0.045 (0.352)	
Electronics	-0.293 (0.398)	-0.393 (0.372)	
Biotechnology	0.447 (0.323)	0.323 (0.298)	
Chemicals, Energy, & Environ.	-0.004 (0.344)	-0.016 (0.338)	
Chi-square for 4 tech. vars. (prob.)	4.51 (0.479)	4.04 (0.543)	
Intercept	-1.59 (0.60) ***	-1.25 (0.30) ***	-1.42 (0.12) ***
Number of obs. (Number=1)	351 (47)	351 (47)	351 (47)
Log likelihood	-118.82	-120.67	-122.98
Scaled R-squared	0.112	0.101	0.088
Chi-squared (DF)	38.78 (15)	35.06 (9)	30.44 (3)

A single observation for a project that was terminated prior to starting has not been used.
In column 1, the excluded category is a single participant project in materials with no university participation and where the lead participant is of medium size.
Coefficient significance levels are denoted by * (10 percent) ** (5 percent) *** (1 percent).

Table A-4
Difficulties Acquiring and Assimilating Basic Knowledge

Type of University Involvement	Number Responding	disagree 1,2	somewhat 3,4,5	agree 6,7	Percent 6,7
Joint Venture	29	19	8	2	6.9%
No university involvement (jv)	8	7	0	1	12.5%
Universities involved as subcontractors (jvs)	8	4	4	0	0.0%
Universities involved as research partners (jvu)	8	5	2	1	12.5%
Universities involved as both partner and sub. (jvus)	5	3	2	0	0.0%
Single applicant	18	9	7	2	11.1%
No university involvement (s)	9	5	2	2	22.2%
Universities involved as a subcontractor (ss)	9	4	5	0	0.0%
Total	47	28	15	4	8.5%

Table A-5
Conceptual Research Problems versus Expectations

Type of University Involvement	Number Responding	Less than	About the same as	More than	Percent More than
Joint Venture	28	0	18	10	35.7%
No university involvement (jv)	7	0	5	2	28.6%
Universities involved as subcontractors (jvs)	8	0	6	2	25.0%
Universities involved as research partners (jvu)	8	0	3	5	62.5%
Universities involved as both partner and sub. (jvus)	5	0	4	1	20.0%
Single applicant	18	1	8	9	50.0%
No university involvement (s)	9	1	3	5	55.6%
Universities involved as a subcontractor (ss)	9	0	5	4	44.4%
Total	46	1	26	19	41.3%

Table A-6
Equipment-Related Research Problems versus Expectations

Type of University Involvement	Number Responding	Less than	About the same as	More than	Percent More than
Joint Venture	27	1	13	13	48.1%
No university involvement (jv)	6	0	2	4	66.7%
Universities involved as subcontractors (jvs)	8	0	5	3	37.5%
Universities involved as research partners (jvu)	8	1	2	5	62.5%
Universities involved as both partner and sub. (jvus)	5	0	4	1	20.0%
Single applicant	18	1	14	3	16.7%
No university involvement (s)	9	0	7	2	22.2%
Universities involved as a subcontractor (ss)	9	1	7	1	11.1%
Total	45	2	27	16	35.6%

Table A-7
Personnel-Related Research Problems versus Expectations

Type of University Involvement	Number Responding	Less than	About the same as	More than	Percent More than
Joint Venture	27	3	14	10	37.0%
No university involvement (jv)	6	1	5	0	0.0%
Universities involved as subcontractors (jvs)	8	1	1	6	75.0%
Universities involved as research partners (jvu)	8	1	3	4	50.0%
Universities involved as both partner and sub. (jvus)	5	0	5	0	0.0%
Single applicant	17	0	9	8	47.1%
No university involvement (s)	8	0	4	4	50.0%
Universities involved as a subcontractor (ss)	9	0	5	4	44.4%
Total	44	3	23	18	40.9%

Table A-8
Percent Unproductive Research Time on Project

Type of University Involvement	Number Responding	<10%	10-19%	>19%	Percent >19%
Joint Venture	25	4	13	8	32.0%
No university involvement (jv)	6	2	2	2	33.3%
Universities involved as subcontractors (jvs)	8	0	5	3	37.5%
Universities involved as research partners (jvu)	6	1	3	2	33.3%
Universities involved as both partner and sub. (jvus)	5	1	3	1	20.0%
Single applicant	17	6	7	4	23.5%
No university involvement (s)	8	3	2	3	37.5%
Universities involved as a subcontractor (ss)	9	3	5	1	11.1%
Total	42	10	20	12	28.6%

Table A-9
Percent Unproductive Financial Resources for Project

Type of University Involvement	Number Responding	<10%	10-19%	>19%	Percent >19%
Joint Venture	25	7	12	6	24.0%
No university involvement (jv)	6	2	3	1	16.7%
Universities involved as subcontractors (jvs)	8	1	5	2	25.0%
Universities involved as research partners (jvu)	6	3	1	2	33.3%
Universities involved as both partner and sub. (jvus)	5	1	3	1	20.0%
Single applicant	17	7	9	1	5.9%
No university involvement (s)	8	5	2	1	12.5%
Universities involved as a subcontractor (ss)	9	2	7	0	0.0%
Total	42	14	21	7	16.7%

Table A-10
Potential New Applications of the Technology Have Been Recognized

Type of University Involvement	Number Responding	disagree 1,2	somewhat 3,4,5	agree 6,7	Percent 6,7
Joint Venture	29	3	9	17	58.6%
No university involvement (jv)	8	0	5	3	37.5%
Universities involved as subcontractors (jvs)	8	3	2	3	37.5%
Universities involved as research partners (jvu)	8	0	2	6	75.0%
Universities involved as both partner and sub. (jvus)	5	0	0	5	100.0%
Single applicant	18	1	2	15	83.3%
No university involvement (s)	9	0	1	8	88.9%
Universities involved as a subcontractor (ss)	9	1	1	7	77.8%
Total	47	4	11	32	68.1%

Table A-11
Technology to be Commercialized Sooner than Expected

Type of University Involvement	Number Responding	disagree 1,2	somewhat 3,4,5	agree 6,7	Percent 6,7
Joint Venture	27	12	12	3	11.1%
No university involvement (jv)	7	3	4	0	0.0%
Universities involved as subcontractors (jvs)	8	4	2	2	25.0%
Universities involved as research partners (jvu)	7	3	3	1	14.3%
Universities involved as both partner and sub. (jvus)	5	2	3	0	0.0%
Single applicant	18	2	12	4	22.2%
No university involvement (s)	9	2	3	4	44.4%
Universities involved as a subcontractor (ss)	9	0	9	0	0.0%
Total	45	14	24	7	15.6%

Appendix B: Ordered Probit and Sample Selection

February 22, 2000

0.1 The ordered probit model[1]

This model is used when the dependent variable takes on ordinal values, such as 1,2,3. These are assumed to represent ranges of an unknown latent variable with unknown cutoffs. The latent variable is determined by a linear regression function plus a random error that is normally distributed. That is,

$$\begin{aligned} y_{1i}^* &= X_i\beta + \nu_{1i} && i = 1, ..., N \\ y_{1i} &= j && \text{if } \alpha_{j-1} < y_{1i}^* \leq \alpha_j && j = 1, ., J \end{aligned}$$

The latent variable is assumed to have infinite support, so $\alpha_0 = -\infty$ and $\alpha_J = \infty$. Thus there are $J-1$ cutoffs to be estimated. Because y_{1i} is observed only as an indicator, the coefficients are only identified up to scale, and the disturbance is therefore assumed to have a unit normal distribution. The equations defining y_{1i} can be rewritten in the following way:

$$y_{1i} = j \qquad \text{if } \alpha_{j-1} - X_i\beta < \nu_{1i} \leq \alpha_j - X_i\beta \qquad j = 1, ., J$$

For illustration, a graphical representation of the distribution of ν_1 for an ordered probit model with 3 values for y is shown below.

Under the normality assumption, the likelihood function for observation i is given by the following expression:

$$\begin{aligned} \Pr(y_{1i} &= j|X_i) = \Pr(\alpha_{j-1} - X_i\beta < \nu_{1i} \leq \alpha_j - X_i\beta) \\ &= \Pr(\nu_{1i} \leq \alpha_j - X_i\beta) - \Pr(\nu_{1i} \leq \alpha_{j-1} - X_i\beta) \\ &= \Phi(\alpha_j - X_i\beta) - \Phi(\alpha_{j-1} - X_i\beta) \end{aligned}$$

Note that in the special cases where j=1 or j=J, this expression simplifies to

[1] These notes are solely for the purpose of clarifying what is being estimated in the body of the paper. They cover well-trodden ground, and no claim to novelty is impled. Some textbook references are to Greene (*Econometric Analysis*, Prentice-Hall, 1999) and Maddala (*Limited Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, 1983).

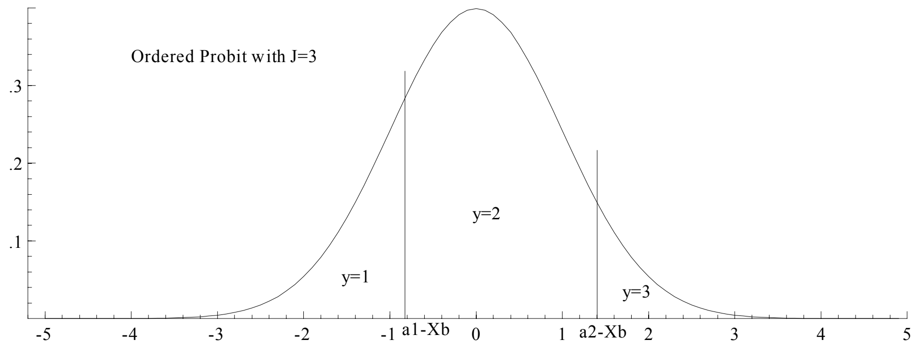

Figure 1: Distribution of Ordered Probit Latent Variable

$$\begin{aligned} \Pr(y_{1i} &= 1|X_i) = \Phi(\alpha_1 - X_i\beta) \\ \Pr(y_{1i} &= J|X_i) = 1 - \Phi(\alpha_{J-1} - X_i\beta) \end{aligned}$$

Combining the N observations, we can estimate the ordered probit model by maximizing the following log likelihood function:

$$\log L(\beta, \alpha_1, \alpha_2, .., \alpha_{J-1}) = \sum_{i=1}^{N} \sum_{j=1}^{J} I(y_{1i} = j) \bullet \log[\Phi(\alpha_j - X_i\beta) - \Phi(\alpha_{j-1} - X_i\beta)]$$

where $I(y_{1i} = j)$ is an indicator function (dummy variable) that specifies whether the current observation of the dependent variable takes on the value j. Starting values for the unknown cutoffs (the αs) can be obtained by maximizing this likelihood with β set to zero. This yields the following intuitive relationship between the observed number for each value of j (denoted N_j) and the estimated αs:

$$\frac{\sum_{k=1}^{j} N_k}{N} = \Phi(\alpha_j)$$

That is, the starting values for the unknown αs can be determined by inverting the empirical distribution function.

0.2 Ordered Probit Model with Sample Selection

Now suppose that the data for y and X are observed only part of the time (either because of non-random sampling, or non-random non-response to a survey). Then we might want to estimate the model above while controlling for selection into the sample. The most straightforward way is to posit a second equation with a disturbance that is jointly distributed with that from the first equation (accommodating the possibility of non-random selection, and hence bias in uncorrected estimates). The augmented model becomes

$$\begin{aligned}
y_{1i}^* &= X_i\beta + \nu_{1i} \qquad\qquad i = 1, ..., N \\
y_{2i}^* &= Z_i\delta + \nu_{2i} \\
y_{1i} &= j \qquad\qquad \text{if } \alpha_{j-1} < y_{1i}^* \leq \alpha_j \text{ and } y_{2i}^* > 0 \qquad\qquad j = 1, ., J \\
y_{1i} &= 0 \text{ (i.e.,not observed)} \qquad\qquad \text{if } y_{2i}^* \leq 0
\end{aligned}$$

The disturbances (ν_{1i}, ν_{2i}) are assumed to have a joint normal distribution with means zero, variances one, and covariance ρ. There is no loss in generality in constraining the means to be zero (if the Zs include an intercept) and the variances to be one (since the scale of both dependent variables is undefined). We can write the likelihood for this model in the following way:

$$\begin{aligned}
\Pr(y_{1i} &= j|X_i, Z_i) = \Pr(\alpha_{j-1} - X_i\beta < \nu_{1i} \leq \alpha_j - X_i\beta, \nu_{2i} > -Z_i\delta) \qquad (1) \\
&= \Pr(\nu_{1i} \leq \alpha_j - X_i\beta, \nu_{2i} > -Z_i\delta) - \Pr(\nu_{1i} \leq \alpha_{j-1} - X_i\beta, \nu_{2i} > -Z_i\delta) \\
&= \Phi_2(\alpha_j - X_i\beta, Z_i\delta, \rho) - \Phi_2(\alpha_{j-1} - X_i\beta, Z_i\delta, \rho) \\
\Pr(y_{1i} &= 0|X_i, Z_i) = \Pr(\nu_{2i} \leq -Z_i\delta) \\
&= \Phi(-Z_i\delta)
\end{aligned}$$

where $\Phi_2(a, b, \rho)$ is the cumulative unit bivariate normal distribution with correlation coefficient ρ evaluated at cutoff points a and b. The log likelihood for all the data (observations where y, X, and Z are observed plus observations where only Z is observed) is given by combining the logarithms of these probabilities:

$$\begin{aligned}
\log L(\beta, \delta, \alpha_1, \alpha_2, .., \alpha_{J-1}; \rho) &= \sum_{i=1}^{N} \{I(y_{1i} = 0) \bullet \log \Phi(-Z_i\delta) \\
+ \sum_{j=1}^{J} I(y_{1i} &= j) \bullet \log[\Phi_2(\alpha_j - X_i\beta, Z_i\delta, \rho) - \Phi_2(\alpha_{j-1} - X_i\beta, Z_i\delta, \rho)]\}
\end{aligned}$$

Although the sum is over all the observations, the data for y and X will be used only when $j > 0$, that is, when y and X are observed. Unfortunately, this likelihood is not globally concave, and may be difficult to estimate, both because starting values are hard to obtain, and because the dependent variables are typically rather coarse and do not provide much identifying power for the coefficients.

It is worth noting that when the correlation ρ between the two disturbances is zero, the bivariate normal term becomes the following:

$$\begin{aligned}
&\Phi_2(\alpha_j - X_i\beta, Z_i\delta, 0) - \Phi_2(\alpha_{j-1} - X_i\beta, Z_i\delta, 0) \\
= &\Phi(\alpha_j - X_i\beta) \bullet \Phi(Z_i\delta) - \Phi(\alpha_{j-1} - X_i\beta) \bullet \Phi(Z_i\delta)
\end{aligned}$$

so that the log likelihood function reduces to the following:

$$
\begin{aligned}
\log L(\beta, \delta, \alpha_1, \alpha_2, .., \alpha_{J-1}) &= \sum_{i=1}^{N} \{I(y_{1i} = 0) \bullet \log \Phi(-Z_i\delta) \\
+ \sum_{j=1}^{J} I(y_{1i} &= j) \bullet [\log[\Phi(\alpha_j - X_i\beta) - \Phi(\alpha_{j-1} - X_i\beta)] + \log \Phi(Z_i\delta)]\} \\
&= \sum_{i=1}^{N} \{I(y_{1i} = 0) \bullet \log \Phi(-Z_i\delta) + I(y_{1i} \neq 0) \bullet \log \Phi(Z_i\delta)\} \\
+ \sum_{i=1}^{N-N_0} \sum_{j=1}^{J} I(y_{1i} &= j) \bullet \log[\Phi(\alpha_j - X_i\beta) - \Phi(\alpha_{j-1} - X_i\beta)]
\end{aligned}
$$

which is simply the sum of the probit for selection (the first term) and the ordered probit that was derived before, estimated only over the observed sample of data.

0.3 Sequential selection

As we discussed in the body of the paper, selection into the sample analyzed from the universe of projects can be broken down into a series of steps, some of which are either known or "ignorable." Under the assumption that the steps are conditionally independent, we can write the selection sequence schematically in the following way:

$$\Pr(y_{1i}\ observed) = \Pr(R|S, Z) * \Pr(S|P, Z) * \Pr(P|notT, Z) * \Pr(notT|Z)$$

where Z are the observed conditioning variables. The sets R, S, P, $notT$, and T are the respondents ($N = 47$), the sample ($N = 54$), the sampling universe ($N = 192$), the non-terminated projects ($N = 331$), and the terminated projects ($N = 21$) respectively. The first and the fourth terms in this probability are the ones analyzed in Tables A-1 and A-3 of Appendix A. The second and third terms are determined by known sampling probabilities:

$$
\begin{aligned}
P_S &= \Pr(S|P, Z) = .29 * jv + .321 * jvs + .818 * jvu + .818 * jvus + .2 * s + .136 * ss \\
P_P &= \Pr(P|notT, Z) = 192/331 = 0.58
\end{aligned}
$$

Incorporating this complex selection sequence into the likelihood given in equation (1) is straightforward under the condition that the disturbance in the equation for termination probability is uncorrelated with the disturbances in the response probability equation and the ordered probit (or other regression of interest). In fact, the analysis in the previous section goes through with no changes under that condition, although it must be carried out only for the sampled observations (S) and uses no information from the terminated projects. For the sake of completeness, we show the full log likelihood function here::

$$
\begin{aligned}
\Pr(y_{1i} &= j|X_i, Z_i) = \Phi_2(\alpha_j - X_i\beta, Z_i\delta, \rho) - \Phi_2(\alpha_{j-1} - X_i\beta, Z_i\delta, \rho) * P_{\text{Si}} * P_{Pi} * \Phi(-Z_i\gamma) \quad (2)\\
\Pr(y_{1i} &= 0, S|X_i, Z_i) = \Phi(-Z_i\delta) * P_{\text{Si}} * P_{Pi} * \Phi(-Z_i\gamma)\\
\Pr(y_{1i} &= 0, notS, P|X_i, Z_i) = \Phi(-Z_i\delta) * (1 - P_{\text{Si}}) * P_{Pi} * \Phi(-Z_i\gamma)\\
\Pr(y_{1i} &= 0, notP, notT|X_i, Z_i) = \Phi(-Z_i\delta) * (1 - P_{\text{Si}}) * (1 - P_{Pi}) * \Phi(-Z_i\gamma)\\
\Pr(y_{1i} &= 0, T|X_i, Z_i) = \Phi(-Z_i\delta) * \Phi(Z_i\gamma)
\end{aligned}
$$

Clearly the multiplicative terms will not affect the maximization of the log likelihood unless the two probabilities are not independent. In that case, the first probability will become a trivariate normal, which greatly increases the complexity of estimation. Because our sample of terminations was small, and in practice we never observed a significant coefficient for a termination probability correction (the hazard rate from $\Phi(Z_i\gamma)$), we did not pursue estimation using this rather complicated likelihood function.