THE ECONOMICS OF UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS

by

E. YEGIN CHEN

Submitted to the Sloan School of Management
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy
at the
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Abstract

This thesis investigates university-industry research relationships using a new, unique data set on the academic research sponsorship of over 5000 business entities at 65 universities covering the period 1975-90. In Chapter I, I introduce key issues, present a framework of explanations for these university-industry interactions, and review the literature.

In the next chapter, I describe and explore the new sponsored research data set. Among the findings are that sponsored research primarily involves industries and academic fields of high technological opportunity, particularly in drugs and electronics. Contract sponsored research is also a concentrated phenomenon, with extensive funding by a few corporations across many universities, combined with the limited involvement by numerous other firms.

In Chapter III, I examine why profit-seeking firms sponsor nonproprietary academic research, an examination that delves into some key issues involving R&D incentives and appropriability. I find econometric evidence supporting hypotheses that firms sponsor university research because they mitigate appropriability disincentives through size, diversity, and technical capability. Technological factors related to the firm's industry also play a role in determining sponsorship amounts.

I explore the economic geography of university-industry research interactions in Chapter IV. I present a conceptual framework of how firms receive non-uniform benefits from academic research. Through econometric analysis, I find that a university department's faculty size, rather than its excellence, to be a determinant of its research interaction volume with local firms. Also, small firms sponsor a greater proportion of academic research locally. Industry effects are important, with utilities sponsoring a greater percentage of academic research locally, but drug and R&D firms a smaller percentage.

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Chapter I : Introduction to Thesis

I.1 Overview
I.2 Why Study University-Industry Research Relationships?
I.3 Framework of Explanations
I.4 Evidence from the Literature

I.1 Overview

University-industry research relationships are a common means of interaction between academic and industrial researchers. This thesis investigates university-industry research relationships using a new, unique data set on the research sponsorship of 5604 business entities at 65 universities covering the period 1975-90. This data set covers firms in all industries interacting with academia, including the technology-intensive, the service-related, and the agricultural. In addition, it includes information on academic research in all fields of science and engineering.

In Chapter I, I introduce issues raised by these relationships and present a framework of explanations. Through a literature review, I shows that we know little about some key issues raised by the relationships, issues relating to appropriability and geographic effects.

At the outset of the thesis, it became clear that the detailed data needed to analyze issues involving appropriability and geography did not exist in a readily-accessible form. As such, Chapter II describes an important form of these relationships, sponsored research. It also chronicles the process of collecting detailed data on sponsored research, as well as the process of constructing a new data set. The chapter then overviews the composition of universities and firms involved in sponsored research at a level of detail not possible before. Among my findings are that sponsored research interactions primarily involve industries and academic fields of high technological opportunity, particularly in drugs and electronics. Sponsored research is also a highly skewed phenomenon, with extensive funding by a few corporations across many universities, combined with limited involvement by numerous entities at a single campus.

In Chapters III and IV, I use the data set to examine two key questions posed by sponsored research. First, why do profit-seeking firms sponsor nonproprietary academic research? This question delves into some of the key issues involving R&D incentives and appropriability. I find evidence that firms sponsor university research because they mitigate appropriability problems through advantages conferred by size, diversity, and technical absorptive capability. This technical capability interacts positively with firm size in determining academic research sponsorship, suggesting that university research complements internal R&D for large firms.

In Chapter IV, I examine the economic geography of university-industry research interactions. The main question here is the following: what determines the extent to which universities interact with local firms? I test two sets of hypotheses involving the determinants of a university department's industrial funding and a firm's local research funding. I find evidence that a university department's faculty size, rather than its excellence, determines the volume of its research interaction with local industry. In addition, I find evidence consistent with the hypotheses that small firms sponsor a greater proportion of their academic research locally. Industry effects are also significant, with electric utilities likely to sponsor locally, but pharmaceutical firms and R&D laboratories likely to sponsor globally.

I.2 Why Study University-Industry Research Relationships?

Industrial firms have sponsored research in university laboratories for over a century. National Science Foundation (NSF) data (NSF 1990) suggest that university-industry research relationships are a broad phenomena which have been steadily increasing over the last two decades, in both nominal and real terms (the top graph in Figure 1). In 1989, industry support of campus R&D by means of grants and contracts totalled $983 million. This amount went to over 200 academic research institutions, both public and private, in every state.

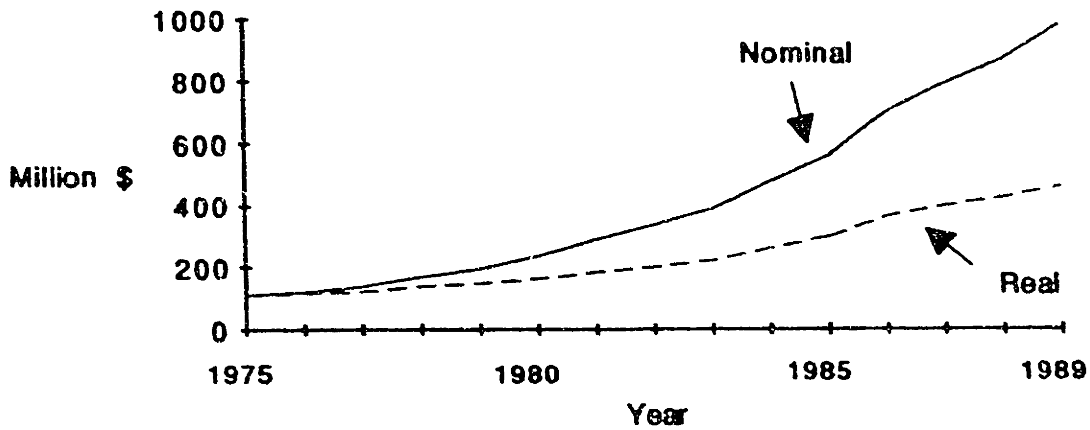
In recent years, the dollar volume of industry-supported research has not only steadily increased in both nominal and real terms, but has also grown at a faster rate than all other university research funding sources (the bottom graph in Figure 1). This research expenditure at universities constitutes over a quarter of industry -financed R&D contracted to outside organizations, though only 6% of all university research (NSF 1989). If most industrially-sponsored academic research can be classified as "basic research", then industry conducts approximately one-third of its basic research through universities. Despite the widespread presence and growth of these university-industry research relationships, the economics literature has not fully explored research relationship issues regarding firm incentives, appropriability, and regional economic benefits. We know very little on a systematic basis about academic-industrial research connections; even basic questions, such as what sorts of industries and firms fund campus research, remain unanswered.

Exploring these research interactions sheds light on key issues involving the economics of technological change and provides a piece of the puzzle to the story of firms and innovation. The primary issue arises from the non-proprietary nature of university research results. With very few exceptions, the results of university research become public knowledge through wide dissemination in conferences, papers, thesis, and journal articles. In addition, the rights to any patents resulting from the research are retained by the university, which may not necessarily license them to the sponsor firm (Sponsored research and the non-proprietary nature of results are described in Chapter II).

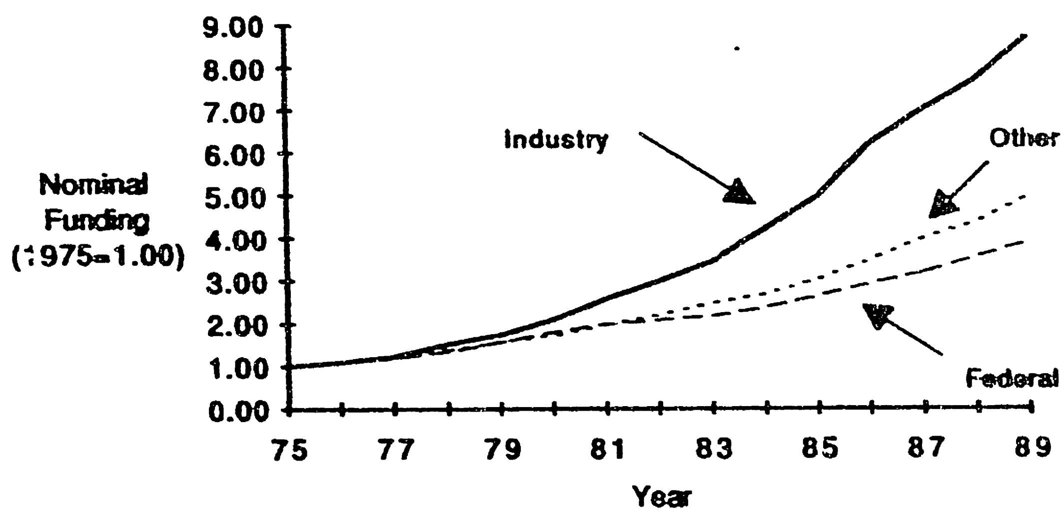
Even for R&D that the firm conducts internally and attempts to keep proprietary, imperfections in the market for knowledge can produce sub-optimal private investment in research and development (Arrow 1962). As

FIGURE 1

Growth In Industry Funding of University Research



Relative Growth of University Funding Sources



one of these market imperfections, the presence of spillovers means that the gains from R&D efforts accrue to competitor firms. A cursory analysis of the spillover disincentive to private R&D investment (Levin & Reiss 1984, Spence 1984) implies that firms facing competition would be irrational to sponsor university research; the broad dissemination of academic research results means that spillover problems may be especially acute. This suggests that traditional appropriability-based explanations for R&D incentives may need to be modified or supplemented.

This industrial-sponsored research cannot be explained away as corporate philanthropic support of higher education. In contrast to interactions in which firms basically just send money to universities, such as unrestricted grants and fellowships, firms sponsoring research are often intimately involved in defining and monitoring the funded campus scientific endeavors. Also, unlike corporate giving motivated primarily by philanthropy, company funds support a specific research project with a budget and timeframe investigating technical matters of interest to the firm. Thus, to the extent that corporate funding of academic research is more than just another form of philanthropy, the widespread occurrence of these university-industry relationships poses a fundamental question to economists: why do private corporations sponsor non-proprietary research at universities?

In addition, understanding these cooperative research links proves important as a basis for sound policy-making. Throughout the 1970s and early 1980s, policy-makers seized upon enhanced university-industry interactions as part of the prescription for greater national and local competitiveness. Inspired by the role of Stanford University in starting Silicon Valley, policy-makers at both the federal and state levels have put forth initiatives facilitating greater university and industry research interactions. These federal, state, and local initiatives sought to boost innovation and spur regional economic growth in part through university-industry interactions.

However, by the mid 1980s, this enthusiasm about research cooperation had been tempered. Business executives (Business-Higher Education Forum 1988) and academic observers (Feller 1990) faced the need to evaluate critically earlier efforts at university-industry technology transfer. Further, even the industry presence on academic campuses caused serious strains in the academic community over conflict-of-interest and nature-of-research issues (Tippie 1989). In the 1990s, the previously sacrosanct institution of university research itself was receiving unprecedented scrutiny, as the government launched investigations into accounting practices as well as charges of research fraud. These developments suggest that an improved understanding of the university's relation to society seems overdue.

University-industry research relationships are also interesting because of their strategic possibilities for the firm. Business managers facing increasing pressures to innovate have been evaluating the benefits and challenges of academic research relations (Business Higher Education Roundtable 1988). Academia is viewed as a "window" on future technological developments, an underutilized resource in the competitive struggle. Also, recent R&D literature (Harhoff 1991) offers some hints that firms can exploit the spillovers from university research for competitive advantage.

From the previous discussion, we can see that an understanding of university-industry research relations can play an important role in economics, business, and policy. Ideally, a fairly comprehensive understanding of university-industry research relations would include several theoretical and empirical elements. We would first like to understand who participates in university research relations, what sorts of industries and companies establish links with academia. Ultimately, we would also like to further our knowledge of the effect of university research on economic growth and productivity. The next section presents a framework of explanations for these research relationships.

I.3 Framework of Explanations

Having seen evidence of the sizable and growing volume of industry-supported research at universities, we do not currently have a satisfactory, integrated explanation for these research relationships. Instead, there are several lines of reasoning that each shed light on part of the story. This section describes a framework encompassing the varied explanations for industry-sponsored research at universities.

Though some explanations can be assigned to more than one category, I propose two meta-groupings of explanations based on the supply of and demand for research funds. Within the realm of supply-side explanations, I first review the traditional economics literature, focusing on appropriability, cost sharing, and cost minimization. Subsequently, I examine strategic motivations, and the extent to which these research relationships are an outgrowth of how firms and institutions are organized. Finally, a firm's incentive to enhance its infrastructure is explored. Throughout the following discussion, the question being asked is "Why do rational firms sponsor research *at universities?*" On the demand-side, I only highlight the key explanations, for these explanations are not as well grounded in the literature.

This section serves as a foundation for the discussions in Chapters III and IV, providing a broad view of the issues. Those chapters will focus on more targeted portions of the literature relating to appropriability and geographic effect, though some overlap is inevitable.

I.3.1 ECONOMIC

This section begins with the insights from the economics literature on university research supported by companies. This body of work has offered explanations for *why* a firm conducts R&D, focusing on appropriability, technological opportunity, and demand pull factors (see Cohen and Levin 1989 for a good overview) as well as *who* conducts R&D more effectively (see Scherer 1989 for a summary). However, the economics literature offers very little explicit exploration of *where* a firm conducts research, whether the R&D efforts are conducted internally or contracted to other parties.

Appropriability Explanations

Though economists have not always agreed as to what constitute the "Schumpeterian hypotheses", Schumpeter (1943) is generally credited with two claims: that appropriating the fruits of R&D in the form of monopoly rents present a powerful spur to conduct R&D, and that "large" firms are better suited to conduct R&D. The first claim contributed to a focus on appropriability of results as an incentive for R&D. However, these appropriability explanations for R&D face serious shortcomings because of the special nature of technical knowledge (Arrow 1962, Nelson 1959) and break down in the face of industry-sponsored research in academia.

Arrow (1962) and Nelson (1959) note limitations to the ability of firms to appropriate R&D results, which produces societally sub-optimal R&D incentives. In addition to traditional investment concerns with risk, these limitations stem from two specific characteristics of investment in technical knowledge: spillovers and imperfect markets for knowledge. As one examines research that is more "basic", these problems become more acute.

Compared with development or applied research, basic research carries greater uncertainty about the existence or applicability of results. Research toward the basic end of the spectrum tends to be at the frontiers of knowledge, prompting the possibility of many dead-ends and false trails. Even when potentially applicable results are discovered, these results are often several years away from commercial introduction. The possibilities of appropriating these research gains often exist in the hazy, distant future.

In addition, while the generation costs involved with basic research can be quite high, duplication costs for basic research results are relatively low. Greater ease of transmission coupled with the potentially larger audience for fundamental research results means a more serious spillover problem in basic research. As such, a greater tendency towards spillovers means a potentially greater free-rider problem.

Finally, imperfections in the market for knowledge may also dampen a firm's incentives to conduct basic research. A firm attempting to sell the results of research that it can't use (which is more likely given the wider range of outcomes from basic research efforts) has to convince potential buyers of the quality of the result; the only way to do so is to reveal the actual result, in which case the buyer then has no incentive to pay for it.

These three factors limiting ability to appropriate R&D results – uncertainty, spillovers, and imperfections in the knowledge market – are especially acute in the case of industry-sponsored research at universities. Economists have found evidence supporting the view that university research output is more basic than industry research output (Henderson, Jaffe, and Trajtenberg 1990a), compounding the uncertainty and spillover problem.

To the extent that some academic laboratories undertake more radical, unproven approaches, the uncertainty of ever seeing a return on research expenditures is increased. Also, spillovers are a *goal* of the university environment. University researchers freely disseminate results via seminars, conferences, theses, and publications. Competitor firms have access to all these information sources, and may also establish research links with the same researchers themselves! Finally, the firm cannot even *try* to market the output of sponsored research closest to commercial application–patents. Title to any patents resulting from sponsored research resides not with the sponsor, but with the university.[1]

Thus, the factors noted by Arrow and Nelson as limitations to appropriability are especially severe in the case of university research. Thus, other explanations for these relationships need to be examined. The next section turns to economic theories developed to explain a related

[1] Chapter II describes the non-proprietary nature of sponsored research in more detail.

phenomenon, that of firms sponsoring research where the results may accrue to competitors.

Cost Sharing

University-industry research relationships may represent a means for firms to share research costs with other sponsors, particularly the government, tap into spillovers from this other university research, and reduce problems with researcher shirking (Industrial Research Institute 1991). Further, cooperating with a university offers the benefit that the university does not compete in the product market. It also provides the means to monitor industry R&D expenditures.

These considerations extend economic theories explaining the firm's incentives to participate in cooperative research endeavors, research joint ventures, research consortia, and similar arrangements, in which the research results are also readily disseminated. Economic explanations for why a firm would join cooperative arrangements generally involve the large fixed-cost element of some R&D projects, imperfect appropriability, high risk, and imperfections in the market for knowledge stemming from moral hazard.

Cooperative arrangements represent a means to overcome moral hazard problems that constrain a firm's ability to raise sufficient capital. They allow the sharing of costs (Kamien and Schwartz 1982, Katz 1986), a key factor in cases when universities possess equipment not readily available in industry (National Science Board 1982). In addition, if spillovers among cooperative research group members are high, the internalization of spillovers can boost a firm's effective R&D level (Katz 1986). This greater exchange of information for members means that the net benefits of greater effective R&D and lower cost outweigh the advantages of undertaking R&D alone and free-riding on the lower non-member spillover rate.

University and cooperative research may also reduce the risk of research projects by enabling organizations to pool complementary research skills. In the presence of limited labor mobility, the ability to assign researchers temporarily to extramural projects may enhance the probability of project success (Cusumano and Sinha 1990).

Also, firms that sponsor research at universities can use the research cooperatively to monitor each other's R&D inputs. Firms may face a prisoner's dilemma in the conduct of basic research. A firm has incentives to perform research in several areas, but a broad research effort by every firm duplicates effort within the industry. If there are economies of scale in research, this dispersion of resources may hinder both the firm's and the industry's progress. Statements by firms about their research portfolios face credibility problems. What the industry would like is a mechanism to verify credibly each firm's research portfolio (Katz 1986). Cooperative research endeavors allow firms in an industry to ensure that research topics of common interest are being worked on, freeing the resources of individual companies for more specific endeavors. In the case of university research, some industries have used an industry trade organization to coordinate sponsorship of generic research at universities.[2] Firm's inputs can be readily verified because records of these contracts are kept by an impartial third-party and are generally part of the public record.

In addition, as firms need to consider the product market effects of research market cooperation (Katz 1986, Cusumano and Sinha 1990), universities represent an ideal partner because they will not compete on the product market with sponsoring firms. University research may also reduce the problem of researcher shirking that may plague industry cooperative efforts, where free-rider temptations may prompt other firms to send low quality researchers to the endeavor and also prompt the competitor's researchers not to work hard. In a university setting, the firm knows to a large extent the quality of the researchers and knows that they have every incentive to work hard. For graduate students striving to graduate, the incentive is clear. For professors striving for tenure, the incentive to

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[2] For example, the pharmaceutical industry funds academic work of interest through the Pharmaceutical Manufacturers Association, while the electric utility industry does so through the Electric Power Research Institute. Firms in these industries also sponsor university work individually.

produce articles describing quality work is strong.[3] Other researchers may need to protect reputations and gain further industry support.

In summary, firms that participate in university research can enjoy the cost sharing, risk-reducing, spillover internalizing, and industry monitoring aspects associated with cooperative industry endeavors. They also derive additional benefits from no product market competition and (in theory at least) greatly reduced problems with shirking by researchers. The next three sections describe why university research may be seen by a firm as less costly than internal research for three reasons: transaction costs, wage differentials, and taxes. Each of these three will be discussed in the sections that follow.

Minimization of Transaction Costs

If firms establish their boundaries to minimize transaction costs, they should extend this behavior to include minimizing R&D transaction costs (Williamson 1975, Pisano 1990). Assuming that gross research benefits are roughly equal in both university and industry laboratories, sponsored research at a university offers a firm several advantages over internal R&D in terms of transaction cost savings. Industry support of university research can be viewed as industry's using research spot markets.

Transaction costs pertinent to R&D stem from three main sources: hold-up problems, investments in specific assets, and contract costs. Firms using university research can have lower transaction costs. For example, hold-up problems with research results are alleviated by the academic incentive structure which rewards researchers who disclose results first and fully (Dasgupta and David 1991). In addition, small-numbers problems are alleviated by the large number of universities, implying a sizable, unsated spot market for research funds. Second, the more general nature of basic research work means that the parties generally do not invest in specialized

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3 Though incentives for tenured faculty to expend effort may be reduced, the observation that many faculty remain highly productive after tenure suggests that intellectual curiousity, as well as professional and pecuniary motivations, still remain.

assets for the relationship. Issues of researcher quality and researcher availability aside, a firm supporting research at one university can direct its efforts to work at another institution with little additional cost.

Finally, contract costs involving specification and monitoring are reduced in the sponsored work. Universities tend to have standard contracts with clearly specified procedures to handle most outcomes; this institutionalization of the research contract function likely reduces the costs of drawing up a contract to cover a variety of situations. The monitoring of a professor's research is conducted by academic peers at open meetings, thereby relieving corporate sponsors of the need to expend substantial resources to monitor research.

Thus, with certain assumptions about the benefits to research at different locales, transaction cost economics offer an explanation for why firms would utilize the "spot market for research" of university laboratories, rather than integrating that research function in-house.

Minimization of Wages

Cost-minimization stories of industry sponsored research feature firms taking advantage of lower labor costs at universities. Casual empiricism suggests that university research labor costs are lower than industry research labor costs, due in part to low graduate student stipends and less-than-stratospheric faculty salaries. A sizable number of observers mention these factor price differentials as an explanation for industrial contract research.

This explanation requires immobile factors of research (faculty, graduate students, and technical staff) in the face of long-run wage disparities between academia and industry. Such labor immobility may persist because academic researchers stay in academia because they have utility functions incorporating elements other than salary, such as lifestyle (Dasgupta and David 1991).

A second possible set of conditions for wage minimization states that even if rough salary parity between top level researchers exists, firms may still save by contracting the work to the higher education sector. The savings in this case result from large numbers of research hours from graduate students, who are paid less and do not yet enjoy labor mobility.

This wage minimization story does not consider issues involving researcher quality, nor does it consider the total cost of utilizing graduate students and professors. The story usually implies that companies are able to use university researchers at least as skillful as private ones at less expense. If wages signal quality in even some aspects of the market for researchers, low wages may mean low quality and hence no real savings at all. Furthermore, as research overhead costs have steadily climbed at universities, the total cost savings involved with academic research may have been reduced in recent years.

Minimization of Taxes

To the extent that firms treat R&D as an investment, one would expect tax policies affecting R&D to affect R&D levels and locales. However, though empirical evidence suggests that the effect of taxes on the amount of industrial R&D performance within an international arena can be significant (Hines 1991), the effect on R&D by a firm within a country has been found to be modest, at best (Collins 1986). The evidence is even weaker concerning the locale where the research is conducted. Surveys on factors influencing industrial location decisions tend to rate taxes as a determinant, but not a crucial one (OTA 1984). Surveys on reasons that firms sponsor university research rank tax savings as a very low priority for the firms involved (NSB 1982, Link and Rees 1991). In summary, it appears that firms enjoy easier ways of obtaining tax benefits than going through sponsored research at universities.

First Mover Advantages

Another explanation for firms sponsoring non-proprietary work is the importance of lead-time. Sponsoring research often provides the sponsor advance notice of results through regular progress reports and first access to proposed publication articles. To the extent that this notice provides Stackelberg first-mover advantages, lead-time may be part of the explanation. However, as Rosenberg (1990) notes, there may be "substantial first-mover disadvantages as well as late-mover advantages" in the race to introduce new, unproven technologies to market. However, his assertion that first-mover advantages may "serve as a significant incentive for the performance of basic research" begs the question of how much lead-time is obtained. Since basic research fruits are typically several years removed from market, it is not at all clear that a few months advance notice make a large difference.

1.3.2 STRATEGIC EXPLANATIONS

The strategic group of explanations is highly related to the economics group of explanations, but features slightly different factors at work. These factors include building learning capacity, strategic spillovers, and shutting out competitors.

Technical Capacity

A firm may choose to be involved with university research to maintain its technical capability and to have access to the scientific community. These explanations posit that university research has multiple outputs, direct ones in the form of learned information and knowledge, along with indirect ones in the form of embodied knowledge and access.

The technical capability of a firm resides not just in technical information embodied in patents, products, processes, and publications, but also in the skills and knowledge possessed by its employees. Performing R&D results not only in technical information printed in reports, but also knowledge embodied in its researchers. Researchers learn while doing. In establishing research links at universities, the firm acquires the capability to monitor and learn from external technical developments, with the research expenditures representing a payment toward the substantial long-run costs of learning (Cohen and Levin 1989). Doing so keeps the firm's knowledge base close to the cutting edge, even if no direct expected monetary benefit results from the work. The importance of the academic setting stems from cutting-edge university research in many areas.

In addition, if basic research leads to better decision-making regarding applied research methods and areas as well as to better evaluation of R&D results (Rosenberg 1990), firms may interact with universities to receive advice on more applied matters from experts in basic research. The pervasiveness of faculty consulting arrangements may reflect the advantages of having impartial, outside experts assist the firm.

Finally, another benefit of basic research, particularly at universities, is what Rosenberg (1990) dubs the receipt of a "ticket of admission to an information network." Extending the reasoning of Nelson (1990), I suggest that firms supporting campus research have access not just to the one researcher contracted with, but also to his colleagues and peers at other institutions. The firm learns about research being conducted elsewhere by these colleagues, benefits from conferences and meetings that the sponsored research attends, and may find it easier to establish relations with other researchers. In short, involvement with university research allows a firm to participate more fully in the academic research community.

Strategic Spillovers

Whereas we have previously treated the high level of spillovers from university laboratories as a problem for appropriability, some firms may see spillovers as a strategic opportunity, a choice variable (Harhoff 1991). In extending the strategic spillover story, a firm sponsors university laboratories in order to provide technical knowledge to those in related industries as a public good, without licenses or payments. Despite funding research that it cannot use itself, the firm then earns a return on its university research expenditures from an externality effect caused by vertical interdependencies between industries. For example, these spillovers may result in reduced supplier costs. The sponsor needs special ties or market power with these firms in order to reap the benefits.

Research conducted in campus laboratories may thus be particularly attractive because of the greater dissemination of results (Henderson, Jaffe, and Trachtenberg 1990a), freedom from antitrust complaints by competitors, and the potential for market entry. As previously noted, the university strives to disseminate knowledge; a profit-seeking firm trying to broadcast its research results would run into opposition from managers within and stockholders without. A firm sharing results from its own laboratories with upstream or downstream firms on a proprietary basis may encounter charges of anti-competitive practices by rivals. Thus, one would expect to see firms sponsoring research in areas unrelated to its product line if those research areas could be used by upstream or downstream firms.

Market Foreclosure

A more sinister tale involves a large firm's funding university researchers to block the access of smaller firms to those researchers. While the smaller firms still learn from the papers resulting from research, direct access and the means to influence research project choice are enjoyed only by the large firm. This foreclosure story requires a very inelastic supply of researchers and is not borne out by casual observation of the large unmet university demand for research funds. However, theory warns that firms may use cooperative arrangements to collusively restrict the level of R&D (Katz 1986).

I.3.3 INSTITUTIONAL EXPLANATIONS

This branch of explanations explores the characteristics and relationships among organizations promoting technological progress to explain who performs what sort of R&D. University-industry relations are therefore an institutional phenomenon stemming from the way that society has organized its R&D performing entities. From these considerations, two main explanations for academic-industrial research connections focus on the firm's desire to tap into the university's technological locus and the behavior of firms.

Technological Locus

Industry involvement in university research may occur simply because the research of interest to the firm occurs nowhere else, or because the leading edge developments are occurring in academia. Having the locus of technology residing at universities provides firms with a strong incentive to establish research links to keep abreast of new developments, a "window" on new technology (National Science Board 1982, Blanchard 1990, Link & Rees 1991). These links then serve as insurance against the catastrophe of being left behind the wave of technological progress or as an option on an underlying technology with commercial potential. To be complete, these explanations require a description of why the laboratories of universities and firms differ, as well as why industry cannot readily duplicate academic research.

Unique Aspects of Academic Laboratories

University laboratories can produce cutting-edge work with the potential to produce not just new products, but whole new industries. As a result, firms may seek to maintain their technological currency by establishing links with professors at the forefront of potentially marketable technologies. A cursory review of the important advances emanating from industrial R&D laboratories suggests that academic laboratories are not necessarily "better" than industrial ones. Rather, academic laboratories may be important to industry because they are *different*. Recent work (Dasgupta and David 1991) on the "socio-economic rule structures" governing the conduct of research and the disposition of research results offers insight into why university research may be at the forefront of basic knowledge more often than industrial laboratories. In particular, academic research may have strengths in the areas of encouraging effort and risk-taking, having a larger pool of knowledge base, and attracting top talent.

University laboratories may be the site of discovery because of the nature of university research, which tends to be more basic, unproven, and further from the market than industrial R&D. If truly revolutionary discoveries are those of a very fundamental nature, then risk-taking in the form of questioning fundamental assumptions is a necessity. The rules under which university laboratories operate may encourage this risk-taking to a greater extent. Races in the scientific community place a premium on being the first to announce results, providing some incentive for risky R&D strategies. In contrast, though being first to introduce a product is important in industry, there are sometimes benefits to being a close second.

In addition, the importance that academia places on adding to the stock of knowledge contrasts with industry's emphasis on using existing stock for the attainment of profit. Academic researchers build their reputations by pushing back the frontiers of knowledge, not by refining existing processes. Thus, all else equal, one would expect university researchers to expend more effort probing new ideas.

But do university experts actually expend the effort to probe new ideas? Academic researchers in the early part of their careers face strong incentives to expend effort in research due to the "publish-or-perish" syndrome. In addition, this effort may be more readily monitored because of the open dissemination of results and the greater share of individual (versus project team) work. Finally, the academic institution of tenure may grant researchers the career security to pursue long term, extremely risky projects.

In addition to the stories above which focus on differences in the institutions, Dasgupta and David (1991) posit a model focusing on differences in researchers. In their model, science and technology continually compete to attract the best minds. Top talent tend to join science because science's rule of results dissemination allows them to signal quality to a broader audience so long as these signalling costs are not too high. The benefits of signalling include psychic rewards and possible funds later on from industry. This model implies that university-industry research relations occur (under the rules of science) because firms seek to learn from researchers who have signalled their quality and research interests. In addition, a dearth of top talent in industry means that firms seeking the catalytic role of science need to draw on university resources. Thus one would see contract research in areas where signalling costs (salary differentials between academia and industry) are low, where the top talent enters academia, and where academic research is much more advanced.

Difficulty of Replication

For university-industry interactions to be based on cutting edge developments occurring in academia, we need to explore why firms may not easily duplicate the academic laboratory environment. This duplication, for example, could take the form of hiring the researchers at the forefront of the field into internal laboratories. Previous discussions on cost sharing, cost reduction, and transaction costs offer part of the explanation. The institutional approach also notes that researchers may have different utility functions that nudge them toward either the realm of science or the realm of technology. Preferring the academic lifestyle, intellectual freedom and the security of tenure may keep certain researchers in academia even in the face of greater monetary rewards in industry.

Observers have also noted that the division of labor between industrial and universities laboratories is neither sharp nor innate (Nelson 1989). The sharp demarcation and implied linear relationship among basic research, applied research, and development is misleading. Many real-life R&D efforts are not easily categorized into the sharp classifications: fundamental research efforts spurred by industry problems, feedbacks between different stages in the research process, university laboratories conducting work closely aligned with industry practice, and industrial laboratories conducting Nobel-prize quality research at the frontiers of science. To the extent that the rigid institutions of "university" and "firm" cannot adequately divide the myriad of activities and interactions encompassed by the term "R&D" into two neat segments, one would expect relations between university and industry to result.

Behavioral Theory

The behavioral theory group of explanations for university-industry relationships examine issues within the organization. Since sponsoring research represents a behavior of the firm (and a possibly irrational one at that if research results are non-proprietary), robust theories of firm behavior should be applicable to this behavior.

Risk-reduction

Organizational theorists have stressed the various constituencies operating within the confines of the "firm" to explain various firm behaviors (Cyert and March 1963). From such an approach, one explanation of industry-sponsored research features risk reduction motives by R&D managers and general managers. The inherent riskiness of R&D may prompt general managers to diversify the risk by running parallel research efforts internally and externally at universities. Alternatively, one could posit a model in which risk averse R&D managers derive utility from successful projects, but are expected to work on prespecified research areas dictated by general managers. The R&D manager may then farm out risky undertakings with high probability of failure to university laboratories, while keeping shorter-term projects with more tangible outcomes for himself. Thus, in each case, university-industry connections result from risk aversion on the part of managers.

Habits

University relations may simply be a habit of the firm, an established routine that the firm finds difficult to shake. In accordance with Nelson and Winter's evolutionary theory (1982), many fledging companies may start as spin-offs from university laboratories or otherwise have strong initial ties to academia. These ties deepen or broaden over time as the firm's develops more experience with university laboratories. The firm initially establishes procedures to deal with university relations and research; later, it appoints personnel to handle those procedures. These personnel help the firm's interacting with academia to eventually become part of the firm's "learned behavior," an integral part of the company that serves as the path of first choice in problem-solving and decision-making. The inertia of these procedures and programs is then reinforced by a group of people whose jobs depend on the firm's establishing and maintaining external links. This group of people may represent an entrenched bureaucracy seeking to continue university research.

This school of thought leads to the proposition that firms active in technology transfer with academia have had a pattern of involvement with academia. Indeed, survey results (National Science Board 1982) have found that many contract research relationships grew out of faculty consulting relationships.

I.3.4 INFRASTRUCTURAL EXPLANATIONS

This small group of explanations sees firms utilizing university-industry relations as a means to improve infrastructure. As a result, firms only benefit from these relations in an indirect manner.

Recruiting tool

University research connections may enable a firm to enjoy direct links with graduate students with skills of interest for the purpose of identifying, helping, and eventually hiring them (National Science Board 1982, Blanchard 1990, Link and Rees 1991). These connections often take the form of graduate student fellowships, for which instructors nominate students and thus inform sponsors of who the top students are. In research agreements, the sponsor often has a multi-year relationship with the student on a technical project of interest to the firm. This relationship may include keeping appraised of progress through progress reports and presentations and meetings with company staff. The firm thus obtains extensive knowledge of the student's abilities and ability to interact with the firm's members. The student gets to know the firm's researchers and research interests on a first-hand basis. Regardless of whether these connections actually serve as a recruiting aid or not, the strong *perception* that they do serves as a motivation for corporate support of university research.

Philanthropy

Perhaps the null case regarding industry-sponsored research is that firms do so out of charitable motivations to support higher education. This may be seen as a way to improve the educational infrastructure involving the firm. Some observers have noted that firms may fund university research because of philanthropic considerations, or because a top executive is loyal to an alma mater. While this may explain some aspects of contract research, it is likely incomplete. Firms with a charitable intent can support universities, and university research, in other, easier methods. Giving an outright donation or unrestricted research grant avoids many of the costs associated with signing a research contract. Endowing a faculty chair or funding a fellowship may be more visible ways to support research. Further, some firms ardently strive to keep their sponsorship of academic work secret, or explicitly note that they do not do so for altruistic motives (Gjostein 1991). As a result, considering all these factors leads me to conclude that philanthropy is an unsatisfactory explanation for university-industry research relationships.

1.3.5 DEMAND-SIDE EXPLANATIONS

While discussion of demand-side explanations are outside the scope of this thesis, they will be briefly mentioned. Evidence for the importance of demand-side explanations for industry funded academic research comes from survey results (National Science Board 1982) and casual observation. Rather than turning down offers to conduct research, researchers in academia incessantly worry about writing funding proposals. Further, some universities maintain corporate outreach offices that serve to establish and maintain links between industry and academia. Sometimes, these offices can provide potential research sponsors with a 'catalog' of research projects.

The primary demand-side explanations for corporate research focus on universities as business-like entities. These explanations will be quickly summarized here. Institutions of higher education are concerned with diversification of revenues, particularly in the face of government budget difficulties, leading to efforts to seek support from the private sector. They are concerned about the effects of inflation on the expensive process of undertaking research. If inflation for R&D costs has outpaced the government's funding increases, then the university's demand for industry funds will grow. Universities seek to grow, to increase their prestige. As such, even with no inflation, they may simply be expanding their research programs, expansions requiring funds unavailable from government.

The other explanations focus on the role of the university in relation to the private sector. Academia serves industry, in part, by working on more applied, practical research. Thus, even if demand for total research funds remains constant, researchers may a greater share of industry funds as they substitute industry-related projects for more theoretical government-sponsored projects. In addition, seeking industry funds may enhance the quality of education. If more graduate students begin to join industry, universities may strive to improve the quality of their education by offering training on problems facing industry (Smith 1984).

I.4 Evidence from the Literature

This section provides an overview of the economics and policy-related literature on university-industry research relationships, particularly that based on surveys. Quantitative studies will be reviewed in Chapters II and III as appropriate, particularly the studies relating to appropriability (Jaffe 1989) and economic geography (Bania, et. al. 1991). The important literature based on cases or industry studies will not be covered here. Interested readers are referred to Fusfeld & Haklisch (1984) for an overview of academic relationships in several industries, to the National Science Board (1982) for electronics industry issues, and Tippie (1989) for biotechnology issues. Johnston and Edwards (1987) provide an overview of industry relationships at several prominent universities. Readers interested in particular efforts to spur regional industrial innovation can check Saxenian (1989) on Silicon Valley, Miller & Cote (1987) covering Minnesota and Pennsylvania, and the AASCU (1986) on efforts involving state universities.

Surveys

The bulk of existing empirical research into university-industry research relationships takes the form of company surveys. Generally focusing on company motivations, company characteristics, and forms of interaction, these surveys typically cover only a small set of the firms sponsoring research at universities. With considerable agreement, these surveys tell us that firms are primarily motivated to participate in university-industry research relations for two practical reasons: access to personnel and access to technology.

Peters and Fusfeld conducted one of the earliest, broadest, and most commonly-cited surveys (National Science Board 1982). Based on interviews, questionnaires, and on-site visits involving academia and business participants in over 300 research relationships (broadly defined), they probed the motivations behind such interactions on the part of industry and academia. From the responses of 56 large corporations in several industries, they found that the most commonly cited motivations for establishing these research connections were to obtain access to manpower (both students and faculty), cited by 75% of the firms, and to new science and technology, cited by 52% of the firms. Other commonly cited motivations, in descending order of frequency, include the general support of technical excellence, access to campus facilities, enhancement of company image, improved community relations, use of an economic resource, and specific problem-solving.

In surveying 39 universities, Peters and Fusfeld found motivations stemming from the benefits of a company as a research partner, in addition to the uncertain relationship with government support. They found that two-thirds of university-industry relations surveyed were initiated by universities, with the primary motivations being diversification of the funding base (cited by 41%), student exposure to actual research problems (36%), and better training for graduates entering industry (33%). Other frequently cited reasons included the fewer restrictions associated with industrial funding, immediate societal importance of work with industry, access to corporate R&D facilities, and access to government funds supporting joint research.

A few years later, Levin, Klevorick, Nelson and Winter (1987) conducted the "Yale survey" into appropriability conditions in over 100 manufacturing industries. From an initial universe of publicly-traded firms with extensive R&D involvement (1981 expenditures of over $35 million or 1% of sales), they obtained survey responses from 650 R&D executives on the importance and limitations of appropriability mechanisms in their business, spillover channels, time to duplicate innovations, and other key topics. Though the survey did include questions pertaining to appropriability of university research results, the survey included questions on the importance of university research to the line of business. Cohen and Levinthal (1989) used this and other data to examine the ordinal ranking of non-industry knowledge on industry R&D intensity. The sources of non-industry knowledge ranged from universities (not targeted to the needs of manufacturers) to government to equipment suppliers (very targeted to manufacturers' needs). They found that industries attaching greater importance to academic research had to conduct more R&D to learn from that research than industries attaching importance to more targeted research.

In a survey with emphasis similar to the Peters and Fusfeld one, Blanchard (1990) surveyed 120 small high-technology firms in eastern Massachusetts to determine their use and perceived value of university interaction. Among the 36% having ongoing relations with universities, the primary stated benefits of ongoing university relations were the "identification of students for future employment" and "maintenance of technical currency by the firm's R&D organization." Commonly cited reasons for not interacting with the many universities in Massachusetts included cost, lack of awareness of research opportunities, and perception that university research was too basic to be applicable.

A third survey (Link and Rees 1991) with similar findings involved 209 respondents of various sizes in five technology-based industries. Link and Rees found that the most common corporate incentives for firms of all sizes to participate in university interactions were related to product development and future employment. These motivations outweighed those due to tax-related, facilities-related, and problem-solving motivations. They also found that large firms, as measured by employee count, are more likely to be involved in university-based research programs. As for the type of interaction with industry, the large firms (over 100 employees) tended to use faculty consulting arrangements, while small firms relied more upon sponsoring graduate research assistants. Firms of all sizes used research contracts less frequently than either faculty consultants or graduate research assistants.

Using econometric analysis, Link and Rees found propensity to participate in academic research relationships is positively related to firm size, after controlling for industry concentration and the firm's performance of basic research. A key calculation of Link and Rees was the estimation of the benefits of these research relationships in terms of estimated rates of return for all R&D outlays. Using a total factor productivity growth framework, they ascertained that firms, both large and small, participating in university research enjoyed double the rate of return to R&D than did those that did not participate. Further, small firms had higher returns to R&D than large ones. Interesting as this finding is, the authors did not address the question of causality.

Most recently, Mansfield (1991) used survey data to examine the link between academic research and industrial innovation in seven industries. He surveyed 76 major publicly-traded firms with 1985 R&D expenditures of $1 million or 1% of sales. Responses indicated that 11% of new products and 9% of new processes could not have been developed "without substantial delay" of a year or more in the absence of recent academic research. Using crude estimates of the dollar value of these contributions, the time lag from academic discovery to commercial introduction, he computes a 23% rate of return to academic research. Mansfield concludes that there is considerable evidence that academic research contributes to industrial innovation.

Evaluation of Survey Results

While the survey approach has its merits, it has some shortcomings: the selection of the sample universe, willingness of firms to participate, and ability of willing firms to furnish accurate historical data. The overview of the database in Chapter II shows the potentially large extent of sample selection problems in the literature's surveys. In particular, it documents the large number of firms involved with sponsored research (on the order of 5000) in comparison with the small sample sizes in the surveys. In addition, Chapter II shows the prevalence of small firms involved with universities, suggesting that most surveys focusing on large firms could produce biased results.

The last issue bears elaboration. Early in my thesis, I considered contacting a few major pharmaceutical firms for details of their research agreements. However, preliminary inquiries led to the discovery that these firms did not keep central records on this activity. Further, it became apparent that for firms with many divisions or subsidiaries, or overseas firms, the decentralized records problem would be especially acute. Finally, industry trade associations were considered, but discussions with various university officials did not reveal any with the desired data.

Survey results described in this section suggest that industry's need to access human knowledge and technical information occurs on a wide scale. To the extent that government and foundation research sponsors do not need to recruit new hires and keep abreast of technical developments, one would expect the observed funding pattern differences between commercial and non-commercial sources.

Though the literature has furthered our understanding about these relationships, it has left many interesting and important questions unexplored. We have no systematic knowledge about what types of firms participate in academic research. It would be important to know more about how they may appropriate the results of work that they sponsor. In addition, our knowledge of the important of universities to the local economy has not been based on systematic analysis.

The next chapter describes the construction of a new data set on university-industry research relationships. Though it cannot address all the questions raised in this chapter, the data set serves as a foundation for the thesis and other work in this area.

Chapter II: Description and Overview of Database

II.1 Introduction
II.2 Methodology
II.3 Overview of Data Set

II.1 Introduction

This chapter describes the unique, new database on sponsored research that forms the basis for Chapters III and IV of the thesis. The database covers the sponsored research involvement of 5604 business entities at 65 U.S. universities, including up to 16 years of data as well as selected department level information.

Section II.2 describes sponsored research, a particular form of university-industry research relationships, which is the focus of the thesis. It then details the collection of sponsored research data, strengths and shortcomings of the methodology, and the construction of the database.

Section II.3 provides an overview of the data from four perspectives-- the university, the firm, the temporal, and the spatial. The data reveal that cross-sectional variations among universities in sponsored research funding are largely due to differences in the number of sponsors. Similarly, in examining within-university variation, industry sponsored research volume at universities has steadily increased over the last decade because of growth in the number of sponsors, rather than in the average funding amount per sponsor. Sponsored research interactoins to a large extent involve industries and academic fields of high technological opportunity, particularly in drugs and electronics. In addition, corporate research sponsorship patterns to be highly skewed. Most firms sponsor relatively small amounts at a single university in a monogamous relationship, while a few others invest significant amounts at campuses across the country.

II.2 Methodology

This section describes the methodology leading to the collection of data on industry-sponsored research at universities. It discusses the strengths and shortcomings of the approach, before documenting the database construction process.

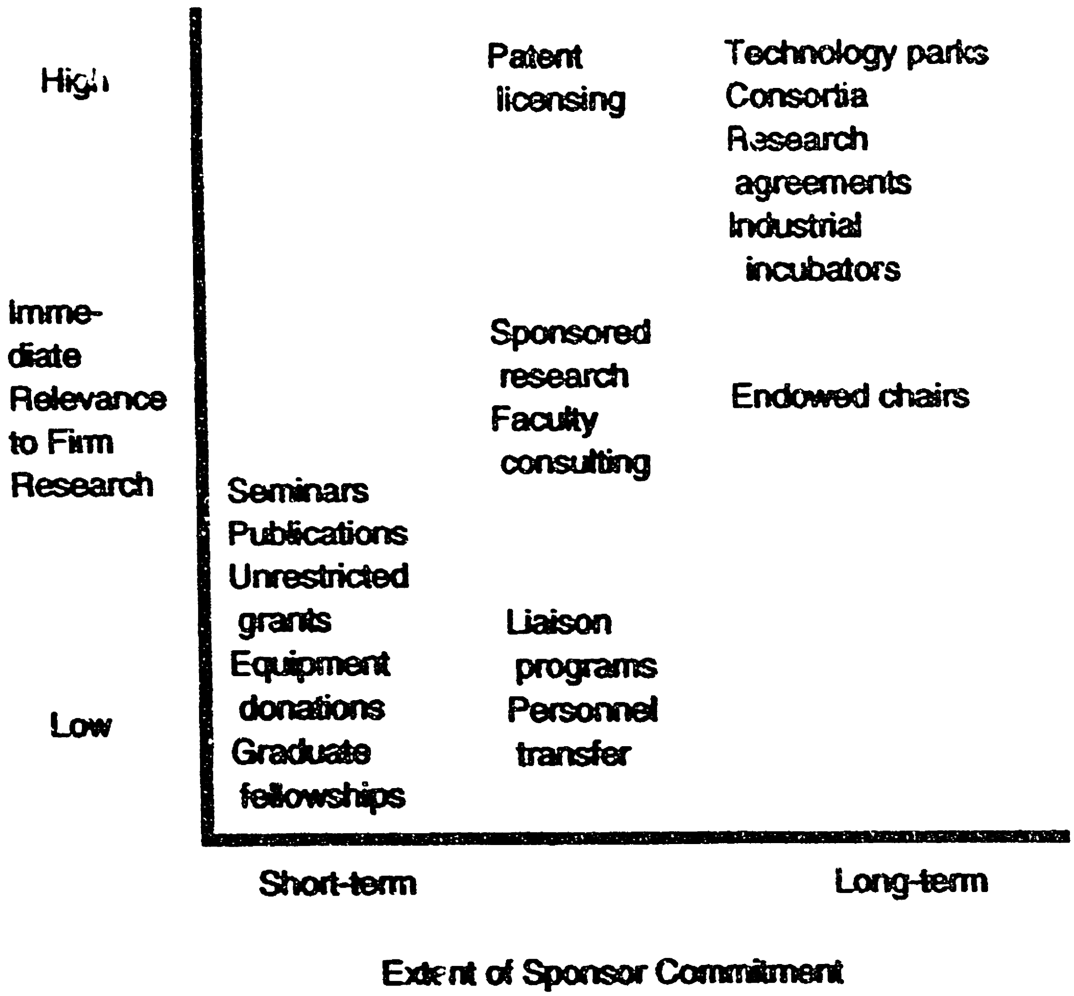
II.2.1 OVERVIEW OF SPONSORED RESEARCH

University and industry researchers interact in numerous ways, with different motivations, timeframes, resource commitments, and range of outcomes. An empirical study of university industry research relationships thus needs to define specifically what is meant by the term "university-industry research relationships." This section briefly illustrates the spectrum of research relationships, and then a particular form of those relationships, that of industry-sponsored research, or contract research.

Though there are many ways to characterize the many modes of interaction between academia and the private sector, I do so along the dimensions of industry's resource commitment in the relationship and the immediate relevance of the relationship to the firm's internal research efforts. Figure 1 provides a chart placing various forms of interaction along these two dimensions. The spectrum of possible interaction ranges from unrestricted research grants, with a very low commitment of time and low effect on the firm's efforts, to industrial parks, where firms establish a research team for several years with the goal of learning from university research.

Somewhere in the mid-range of the spectrum lies industry-sponsored contract research, also known as sponsored research. Though more details on what happens in sponsored research will be described in the following pages, I claim here that industry-sponsored research provides us with a foundation for understanding more involved interactions, especially academic research centers, research agreements and university-based consortia. These are simply variations on the basic sponsored research project, differing in the locale of the research and duration of the agreement. Second, universities have had several

Figure 1: Typology of University-Industry Research Relationships



decades of experience with sponsored research. University involvement with industry sponsored research has thus been of a longer duration, and apparently more widespread across universities, than many more-recently developed forms of cooperation. Finally, unlike some of the arrangements at the lower resource commitment end of the scale in Figure 1, contract research is primarily focused on the essential characteristics that we are interested in: a for-profit entity supporting science and engineering work to discover knowledge with potential commercial applications.

Even though sponsored research features many benefits as a focus for investigation, we should be aware that sponsored research represents an imperfect measure of a firm's interactions with academia. A better measure may include company payments for faculty consulting and graduate fellowships, though such information is not readily accessible. This focus on contract research to the exclusion of other interaction modes may lead to sampling concerns. Link and Rees (1991) have found some survey evidence that large firms are more likely to participate in academic research programs and employ faculty consultants Small firms tend to sponsor graduate students rather than sponsor research projects. Thus, excluding data on graduate student fellowships may understate the extent that small firms establish linkages with academia, while tending to overstate the involvement of larger firms in university-industry research relationships. With these caveats in mind, in the next section I describe the nature of sponsored research.

What Happens in Sponsored Research?

Having seen the place of contract research in the overall spectrum of university-industry research relationships, I now focus on the issues involved with contract research sponsored by industry, particularly some of the established contract norms guiding sponsored research. While different universities may have slightly different procedures and policies, the broad facts likely remain the same across institutions.

Industry's sponsorship of academic laboratories dates back to at least the 1860s and 1870s, when Bayer AG employed academic scientists in situations requiring specialized technical expertise (Meyer Thurow 1982, reported by

Stankiewecz 1986). Since that time, this sponsorship of research generally has involved a single industrial firm agreeing to underwrite the costs of a university research project with a specified scope of work, budget, and time frame. The sponsor provides input into the project design and typically monitors work through progress reports or laboratory visits. Work is conducted on university premises under the responsibility of a university principal investigator, who has final say on project selection and design; research under the technical direction of the sponsor is not acceptable. The uncertainties inherent in research means that the principal investigator works on a best-efforts basis, with no guarantee of success. In general, contracts do not set firm deadlines for obtaining particular results, impose penalties for failure to make progress, or provide for withholding payment if results prove unsatisfactory. Typical contract durations range from one to three years in duration. During that time, the university recovers both direct (wages, expenses, etc.) and indirect (overhead) research costs on an as-incurred basis, earning no profit.

The major issues surrounding industry-sponsored projects center around the outputs from the research, in which the objectives of industry and university are not in harmony. The next section describes the non-proprietary nature of academic work.

The Non-proprietary Nature of Industry-Sponsored Research

One might expect that areas of contract tension in the sponsored research process involve the output of the research projects, particularly publications and patents. The university's mission of serving the public through creating and openly disseminating knowledge can clash with the firm's objectives, focused on obtaining profits through proprietary knowledge. The tangible results of sponsored research work --papers, presentations, and patents -- are non-proprietary. Though sponsored research agreements differ significantly, in almost all situations university researchers enjoy freedom to present or publish results in a timely manner, subject to two conditions. The first case occurs when the sponsor provides the university with proprietary background information for the study. In this situation, sponsors often have the right to review proposed publications to ensure that no proprietary information is inadvertently disclosed. The second case occurs when patent rights may be at stake, for articles may be reviewed for patent possibilities or delayed for patent filing. Surveys have found that several universities grant industry sponsors prepublication review periods ranging from three to six months (NSB 1982). The sponsor has no right to request the suppression of other information or findings.

In regard to other intellectual property rights, faculty and students are generally required to make disclosures of a potentially patentable invention to a central body, usually some sort of patent office. This office determines which disclosures are promising enough to become patent applications, before proceeding to apply for patents. Titles to any patents from the research project almost always resides with the university (National Association of College & University Business Offices 1978, National Science Board 1982, L. Nelsen 1989), which may then license to the private sector. Among the licensing options available to the sponsor are non-exclusive licenses for internal research programs, exclusive licenses, and the waiver of all license rights in return for a portion of royalty income derived from licensing to third-parties.

Even if the sponsor should desire an exclusive license, it may end up being outbid by a rival, though it may be given slightly favorable terms in the bidding process (National Association of College & University Business Offices 1978, L. Nelsen 1991). In selecting from bidding firms, the university seeks the one most likely to bring the idea to market, based on perceptions of firms' abilities and commitment levels. See L. Nelsen (1989 and 1991) and Stankiewicz (1986) for more detailed discussions of the challenges inherent in this aspect of university-industry relationships.

From this section, we note an important difference between industry and university research: the fruits of university research are non-proprietary. Not only are the preliminary results disseminated in seminars and conferences open to the scientific community, but also the end products of the work become journal articles or theses that enter into the public record. Sponsor firms do not have the legal authority to compel university researchers to conceal any information or to modify any findings. Further, these firms do not automatically acquire license to any patents resulting from the research that they sponsor. These considerations indicate that the knowledge resulting from industry-sponsored contract research is potentially appropriable by competitor firms. The sponsor firms may enjoy an appropriability advantage by having first access to research results, however.

Having discussed what occurs in industry-sponsored university research, I now describe the construction of an original data set on sponsored research.

II.2.2 COLLECTION OF DATA

To explore the key issues surrounding sponsored research described earlier in Chapter I, the ideal data set would identify all firms involved in university research, as well as the intensity and breadth of their research support by university over time. The most comprehensive data on university-industry research interactions comes from the annual survey, "Survey of Scientific and Engineering Expenditures at Universities and Colleges" of the National Science Foundation (1990). I describe this survey because I refer to it several times and because it represents an important source of information on academic research.

The annual NSF survey covers 459 U.S. institutions of higher education. This sample includes all doctorate-granting institutions and a few other schools granting a graduate science/engineering degree or performing at least $50,000 of R&D. University participation in the survey is voluntary, with a 97.6% response rate. The survey requests information on R&D expenditures by source of funds, total and federal R&D expenditures by academic area, and equipment expenditures. As for industry funding, the survey requests a single figure from each university each year. This number represents the sum of all R&D grants and contracts from profitmaking organizations, thereby excluding corporate foundations. In contrast to figures on federally-supported research, the industry figure is not collected at the departmental level.

Three factors should be kept in mind when analyzing the NSF data. First, this data tends to understate the extent of university-industry technical cooperation. As described in Section II.2.1, university and industrial researchers interact in numerous manners, including faculty consulting, equipment donations, graduate student fellowships, patent licensing, and technology parks. Because the NSF data only cover industrial research contracts and grants, many important and pervasive forms of research interaction are excluded. Nevertheless, the NSF data, as described later in this chapter, generally do include more types of these interactions than the figures in the database. As a result, NSF figures tend to be higher than data set figures on sponsored research alone.

Second, a university's participation in the NSF survey is voluntary, meaning that in some years for some schools, the NSF had to estimate industry funding amounts. Universities completing the survey have latitude for interpretation in completing the survey, as the survey responses have traditionally not been subject to independent verification. The NSF data series have occasionally been revised as a result of the agency's data checking efforts.

Finally, the NSF data does not disaggregate industry funding in any manner. It provides no indication of the industries or firms funding academic research, nor any idea about which university departments receive that funding. No other known government or industry organization has such data available. In particular, obtaining detailed data on university interactions from individuals firms proved infeasible. For large firms in particular, records of these interactions tend to be decentralized and not readily retrievable.

The search for more detailed data then turned to university sources of research data, and in particular to university offices of sponsored research. These offices generally handle a university's administration of all sponsored research projects, regardless of funding source. As a result, a university's sponsored research office represents a central source of data on one facet of the university's research interactions. However, previous researchers (NSB 1982) found that universities in general did not have the means to furnish such data. This difficulty in data collection gradually changed, because starting around 1985, many sponsored research offices adopted computerized record-keeping systems. As a result, records on industry funding became more detailed and readily-accessible. A data request was made to obtain this information.

The Data Request

The basic universe of the data request was the set of all universities ranked in the top 100 R&D performing institutions in 1989, in terms of either total R&D or industry-supported R&D. Rankings were based on National Science Foundation survey data (1990). Because of the partial overlap between universities ranked in terms of total R&D and in terms of industrially-supported R&D, this produced a total of 128 possible universities. I followed the NSF convention of treating university systems with several campuses as different units, so that, for example, the University of California's Berkeley and Los Angeles units count as two universities. In addition, a few institutions have decentralized record-keeping, with separate schools (generally professional schools such as medicine) keeping their own historical sponsored research records. Such decentralized records may mean incomplete data from some sponsored research offices. Sponsored research administrators alleviated this concern by noting that the industry interaction by the non-included schools was minimal or involved drug studies (which are excluded from my database)[1]. The following data was requested:

1. List of for-profit companies sponsoring research relating to science and engineering at the university during 1975-90, excluding corporate and private foundations sponsoring research.
2. For each company for each year for each department, the total dollar amount of the sponsored research contracts signed and total expenditures, excluding unrestricted grants, funds for instruction, medical clinical studies, fellowships, endowed chairs, etc.

The first point of the data request targeted company-level data on scientific investigations motivated by industry's desire to further technical knowledge for business purposes. The data request thus excluded sponsored research in

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1 The difficulty of data collection for decentralized institutions affects the aforementioned NSF survey as well. The NSF collects and publishes data on affiliated research institutions separately from its annual survey of university R&D.

the humanities as well as foundation-supported research which may be motivated by charity motivations. I requested data extending back to 1975 because of limits to data availability after preliminary discussions with several universities. Also, the year 1975 roughly coincided with new Securities and Exchange Commission requirements for the reporting of R&D expenditures (Bound, Cummins, Griliches, Hall and Jaffe 1984).

The second point requested annual data to examine the temporal element of sponsored research. It also requested data disaggregated by department or school to permit more detailed analyses, such as that in Chapter IV. In addition, the second point recognized that data kept may be in the form of either annual expenditures or awards. Typically, sponsored program offices maintain records on awards, while accounting offices track expenditures resulting from the award in less accessible records. The two offices do not merge their data into consolidated statements. The data set thus consists mainly of awards data.

The request focused on data for contracts only. This focus sought to eliminate noisy items from the furnished data, particularly those items occasionally classified as contract research such as graduate fellowships. In particular, contracts for clinical drug studies are excluded. Described in Spilker (1989), drug studies represent work different from the others included in the sample. Often involving large efforts across several institutions, drug studies typically focus on the safety and efficacy of medicinal compounds before final regulatory approval for marketing. Although they do further understanding of important aspects of medicine, their primary goal is to obtain data on a potential drug's administration. Thus, these large-scale investigations focus on issues much closer to commercial application rather than on underlying principles of science or technology. I thus excluded clinical drug studies from my analysis because the large dollar amounts involved across multiple campuses raise data issues, and because the type of work differs from typical laboratory investigations.

Universities that shared data did so under the understanding that the data furnished would be held in confidence and that only aggregate, statistical results not linking a particular firm with a particular university would appear in any research results.

The data collection effort began in January 1991 and ended in August 1991, yielding data from 73 institutions. Descriptive statistics on the data received appear in Table 1, while details appear in Table 2 (a two-page table). Of the 73 universities sharing data, 65 had information entered into the data set[2]. For the 65 universities, the next portion of Table 1 indicates the number supplying information for each year. The average years of data coverage per university is 5.75 years. Only two universities provided data starting from 1975. Data for 1990 was not available for two universities at the time they furnished data, while three separate institutions did not furnish 1989 data. As a result, the table on data coverage by year appears to only show 63 universities in total, though it actually includes 65 institutions in total. Approximately 62% of these institutions supplied data on contracts awards, with the remainder supplying expenditures data. A total of 53 universities (81% of the total) provided information broken out by academic department. In contrast, only 24 universities (37%) furnished information that was cleaned or could be readily cleaned of information such as clinical drug trials.

Table 2 provides detailed information on the nature of the university-supplied data. It lists information about the complete fiscal years that the university furnished data, the years of data in the database, whether the data included departmental breakdowns, whether the data represented awards or expenditures, and whether the data was cleaned of drug studies. The second column shows the complete fiscal years of data supplied by the university, with fiscal year 1989-90 treated as 1990. A few universities furnished partial data for some years, which has been included in the data set. The third column in Table 2 describes the actual data years used in the database, which may not correspond to all the years of data furnished.

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2 The eight universities not in the data set furnished valuable data that was not in a format allowing comparison with data from the other 65.

Table 1: Summary of Characteristics of Data Set

Number of Universities Supplying Data	73
Number of Universities in Data Set	65
Average years of data coverage	5.75 years

Year	Number of Universities Covering Year
90	63 (2 universities did not have 1990 data)
89	62 (3 different universities did not have 1989 data)
88	62
87	41
86	30
85	24
84	17
83	16
82	15
81	13
80	11
79	5
78	5
77	5
76	3
75	2

Univs. with Awards Data	Univs. with Expenditures Data
40	25 (19 from SUNY)
(62%)	(38%)

Univs. with Departmental Data	Univs. without Departmental Data
53 (19 from SUNY)	12
(81%)	(19%)

Univ. Data Cleaned of Drug Trials	Univ. Data Not Cleaned of Drug Trials
24	41 (19 from SUNY)
(37%)	(63%)

Table 2: Universities Furnishing Data

Name	Data Furnished	Data Used	Depts.	Awards/ Expend.	Cleaned of Drug Studies
Brown	1986-90	1986-90	Y	Awards	N
Carnegie Mellon	sponsor list	None			
Clemson	1987-90	1987-90	N	Awards	N
Colorado Sch. of Mines	sponsor list	None			
Colorado State	1985-90	1985-90	Y	Awards	N
Georgia Inst. of Tech.	1986-90	1986-90	Y	Awards	Y
Harvard	1984-90	1984-90	N	Awards	Y
Indiana	1990	1990	Y	Expend.	N
Iowa State U. of S. & T.	1987-90	1987-90	N	Awards	N
Johns Hopkins	1990	1990	Y	Awards	Y
Louisiana St.	1990	1990	Y	Awards	Y
MIT	1980-90	1980-90	N	Awards	Y
New York University	1975-90	1975-90	Y	Awards	Y
Northwestern	1975-90	1975-90	N	Awards	Y
Oregon State	1983-90	1983-90	N	Awards	Y
Princeton	1987-90	1987-90	Y	Awards	Y
Purdue	1978-90	1987-90	Y	Awards	N
Rutgers	1987-90	1987-90	Y	Awards	Y
Stanford	1980-89	1980-89	Y	Expend.	Y
SUNY - Buffalo	1988-90	1988-90	Y	Expend.	N
SUNY - Stony Brook	1988-90	1988-90	Y	Expend.	N
SUNY- 17 other sites	1988-90	1988-90	Y	Expend.	N
Texas A&M	1986-90	1986-90	Y	Awards	Y
Texas Tech	1985-90	1985-1990	Y	Awards	N
Univ. of Arizona	1976-90	1980-1990	Y	Awards	N
UC Berkeley	1985-90	1985-1990	Y	Awards	N
UC Irvine	1985-90	1985-1990	Y	Awards	Y
UC Los Angeles	1987-90	1987-1990	Y	Awards	Y
UC San Diego	1986-90	1986-1990	Y	Awards	N
Univ. of Chicago	1987-90	1987-1990	Y	Awards	N
Univ. of Dayton	SIC data	None			

Table 2 (continued): Universities Furnishing Data

Name	Data Furnished	Data Used	Depts.	Awards/ Expend.	Cleaned of Drug Studies
Univ. of Delaware	1980-90	None	N	Awards	
Univ. of Florida	1985-90	1985-1990	N	Awards	Y
U. of Illinois -- Urbana	1988-90	1988-1990	N	Expend.	N
Univ. of Iowa	1976-90	1976-90	Y	Awards	Y
Univ. of Lowell	1981-90	1981-1990	N	Awards	N
U. of Maine -- Orono	1985-90	1985-90	Y	Awards	N
U of Maryland Balt.	1987-90	1987-90	Y	Awards	Y
U. of Mary.-Coll.e Park	1987-90	1987-90	Y	Awards	Y
U. of Mass. -Amherst	1980-90	1980-90	Y	Awards	Y
Univ. of Michigan	1981-90	1987-90	N	Expend.	N
Univ. of Minnesota	aggregate data	None			
U. of Misso.- Columbia	1980-90	1980-90	Y	Awards	N
U of Nebraska -Lincoln	1984-90	None	Y	Awards	
Univ. of Notre Dame	1976-89	1976-89	N	Awards	N
Univ. of Oklahoma	1981-90	1981-90	Y	Awards	N
Univ. of Pennsylvania	1976-90	1976-90	Y	Awards	N
Univ. of Pittsburgh	1986-90	1986-90	Y	Expend.	Y
U. of So. California	1982-90	1982-90	Y	Awards	N
U T Health Ctr-Houst.	1982-90	1982-90	Y	Awards	N
U T Health.Ctr San Ant	1987-90	1987-90	Y	Awards	Y
Univ. of Washington	partial data	None			
Utah State Univ.	1980-90	1980-90	Y	Awards	Y
Virginia Tech	sponsor list	None			
Washington State U.	1988-90	1988-90	Y	Awards	N
Wayne State Univ.	1985-90	1985-90	N	Expend.	Y
West Virginia Univ.	1986(7)-90	1986(7)-90	Y	Awards	Y

Note 1: There are only 57 entries in the table above because I aggregated 17 S.U.N.Y. campuses into a single entry for this table. The data for all S.U.N.Y. campuses was in the same form, so listing them separately would have been redundant.

Note 2: Universities with "None" in the "Data Used" column were not included in the database.

The differences between the data furnished and data used resulted from two factors. Several universities (such as the University of Michigan and Purdue) supplied data for some years that was not included in the database, data of much detail. Resource limitations prevented all the years of data supplied from being manually entered into computer form. Because the bulk of the analysis focused on data from 1987 onward, I chose to enter only data from 1987 onward into computer form for those institutions. Cursory analysis of the years not included found no evidence that the truncation resulted in any biases. In addition, as the table indicates, not all institutions provided data in a format usable in the analysis. These eight institutions are denoted in the "data used" column by a "none" designation.

According to National Science Foundation figures, these 73 universities accounted for approximately 40-45% of all industry research funding in academia in 1989 (1990). One university system (the State University of New York system) provided data for all 19 of its campuses, only two of which were in the top 100 institutions. As a result, the 73 institutions furnishing data include only 56 of the original 128 campuses from which data was requested. Of these 73 institutions, eight had data not quite suited for inclusion in the database. Thus, the 65 universities in the data set include 48 universities requested to provide data (56 less eight), in addition to the 17 State University of New York (S.U.N.Y.) campuses provided without being initially targeted. Schools not listed in the table represent those not in the top 100 (excluding the S.U.N.Y. institutions) or those unable to provide data[3].

The participating schools include a balance of public and private institutions representing a total of 31 states. They include strong science & engineering schools (MIT, Stanford, and Georgia Tech) as well as traditional liberal arts institutions (Brown, and the University of Notre Dame). The universities include those performing large amounts of sponsored work (University of

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3 The universities in North Carolina around the Research Triangle area are conspicuous by their absence despite several requests for data. These R&D intensive institutions include N.C. State University at Raleigh, Duke, and the University of North Carolina at Chapel Hill.

Michigan) and those performing more limited amounts (University of Lowell). Table 3 indicates the composition of universities furnishing data and universities included in the data set in terms of research volume. NSF information of R&D performance (both for industry funds and total funds) are used to rank institutions; the table presents the number of schools falling into each ranking category. The data set includes five of the top ten universities receiving industry research support, and 39 of the top 100. The data set covers universities throughout the range of industry research involvement and total research.

As many interesting hypotheses relate to the characteristics of the firms underwriting academic laboratories, it became apparent that information on the indsutry, size, age, location, diversity, and other characteristics of sponsors would be needed. As the sponsored research offices could only furnish the names of the companies, the characteristics of these companies were looked up and entered into a separate part of the data set. Matching the data on sponsored research with that on company characteristics is the foundation for many of analyses that follow.

II.2.3 STRENGTHS OF METHODOLOGY

Obtaining and utilizing sponsored research data from universities in this manner has strengths and drawbacks, which are highlighted here. In particular, there are six major advantages -- broad coverage, potentially greater accuracy, ready comparability, information over time, focus on research, and information at the departmental level.

In theory, the data set covers research contracted by all firms sponsoring research at certain schools over time, with very few exceptions. This coverage means freedom from sample selection bias problems involving firms (inherent in surveys) of identifying firms to survey, firms' reluctance to provide data, or decentralized firm record-keeping. This approach of obtaining data from universities brings out many privately-held, smaller, or defunct firms that previous surveys may have missed. In addition, the data set includes many new ventures, some started as recently as 1989. In particular, the database includes the research funding of all industries, not just high-technology or manufacturing. As a result, it provides a more comprehensive view of this academic-industrial interaction than previous studies focusing on technology-intensive industries (Blanchard 1990, Mansfield 1991, Link and Rees 1991). Its broad coverage includes agricultural, commodity, utility, and service firms, some of which, as we will see, have a large presence in academic laboratories.

In contrast to data collected from surveys, my sponsored research data comes from the same quantitative data that university officials use. Because university administrators have every incentive to ensure that data they use is accurate, the data provided is based on the most accurate data available. This approach avoids many pitfalls associated with interviews and case studies, such as vagaries of memory, personnel changes, etc. It also avoids many incentive problems with surveys, where little incentive exists to take time to interpret questions and provide accurate data.

Third, the data measures effort expended at university laboratories based on a readily-quantified, objective measure: contract research dollars. This measure facilitates analysis of sponsored research across industries, universities, and time on a uniform basis. In contrast, for example, using records on equipment donations raise questions involving equipment quality and valuation.

The dataset also has a temporal element. With data coverage extending back five years (1986) for 46% of the schools and ten years (1981) for 20% of the universities, the dataset allows preliminary investigations of temporal changes in these research relationships. This will permit examinations of determinants of the increase in industry support and other questions.

Another strength of the methodology is that the data-collection efforts focused on research for the sake of eventual market benefit. While the data set does not disentangle sponsored research contracts motivated by non-economic motivations, the literature suggests that these cooperative research interactions have an underlying economic motivation (NSB 1982, Blanchard 1990, Berman 1990, Gjostein 1991). This focus on sponsored research data thus eliminates potential sources of data noise in investigating technology-related motivations behind these interactions.

Finally, within the limits of the data, this data set includes some information disaggregated by university department. Possibly excepting line of business data, there are very few data sources that permit examination of a firm's efforts by different technical areas. Nevertheless, the methodology employed in data collection has some shortcomings, including the four described in the following paragraphs.

II.2.4 SHORTCOMINGS OF METHODOLOGY

Though sponsored research has many characteristics that make it a suitable vehicle to study university-industry research relationships, it does have shortcomings. As noted earlier in this chapter, a wide spectrum of possible interaction modes between the private and academic sector exists. If firm use of particular interaction modes depends upon firm characteristics such as size, as suggested by survey results of Link and Rees (1991), then an analysis of the relation between sponsored research involvement and firm characteristics may be biased.

Second, lack of data on sponsored research outputs precludes the direct examination of interesting questions. The availability of information on sponsored research outputs would facilitate evaluation of the effectiveness of these research interactions and many other important issues. Ideally, we would like to quantify the benefits from sponsored research. Information on more tangible research outputs such as patents and publications from sponsored projects is not readily available across universities. In addition, if sponsored research tends to fall within the realm of fundamental work, then the results may be many years in coming and not readily quantifiable. In contrast, for example, faculty consulting and patent licensing may entail more readily-identified benefits.

Another major data-related limitation of the data set is its incompleteness in terms of university coverage. Some universities chose not to participate for various reasons, causing an incomplete data set and injecting the possibility of sample selection bias. Reasons given by the non-participating universities, and possible bias effects, include the unavailability of data, the unavailability of resources to furnish the data, and confidentiality requirements. The first reason generally involved universities with low levels of research (according to aggregate NSF figures) that had not upgraded their record-keeping systems. For example, a few of these schools only kept readily-available records of industry support in the aggregate, with no firm-specific figures readily available. At the other end of the size spectrum, institutions with high levels of research claimed to be too busy to provide data. Finally, a few universities expressed concerns about releasing data due to agreements with some industry sponsors or fear that their own researchers would be harmed by other schools' poaching sponsors.

To the extent that non-participating universities have characteristics different from the participants, a sample selection bias may result. The extent or direction of this problem is difficult to ascertain, though an examination of Table 3 suggests a slight tendency of the data set to include research-intensive universities. A total of 24 institutions in the top 50 (in terms of industry funding) are in the data set, compared to only 16 in the second 50. This would suggest that my analyses are more applicable overall to universities with substantial industry interactions. Even with any sample selection concerns, the current data set represents the most detailed resource available for empirical studies of university-industry research relationships.

A second potential group of data set shortcomings involves the non-uniformity of university records, which involves several issues: availability of historical data, level of detail, and types of records kept. Each of these will be described in turn.

As noted earlier, universities differed greatly in data availability, due to differences in university record systems and available resources to retrieve information. An examination of Table 2 shows the data set to be an unbalanced panel with differences in terms of coverage over time, level of detail, and cleanliness.

Table 3: Composition of the Universities Furnishing Data

NSF Rank in Terms of Industrial Research Funding	No. of Universities Furnishing Data	No. of Univs. in Database
1-10	7	5
11-20	7	6
21-30	8	7
31-40	3	3
41-50	2	2
51-60	3	3
61-70	5	5
71-80	5	3
81-90	3	2
91-100	3	3
100+	27	26
Total	73	65

NSF Rank in Terms of Total R&D	No. of Universities Furnishing Data	No. of Univs. in Database
1-10	8	6
11-20	6	6
21-30	3	3
31-40	4	4
41-50	9	7
51-60	3	3
61-70	4	4
71-80	4	3
81-90	4	3
91-100	2	2
100+	26	23
Total	73	65

Number of States Represented = 31

Universities also provided information at varying levels of detail. In particular, the fourth column of Table 2 demonstrates that many universities were not able to furnish data with departmental disaggregation. This heterogeneity in level of detail means that some analyses requiring departmental data cannot include all the universities.

The third cause of data heterogeneity is that universities furnished different types of data because of differences in their internal record systems. The fifth column in Table 2 shows whether the database records for a university represent awards data (the contract amount awarded by the firm in a fiscal year), or expenditures data (the amount of the contract expended in a fiscal year). Some universities, such as MIT, furnished expenditures data in a format that allowed conversion to awards data. I did so wherever possible.[4] In addition, some institutions provided partial data that reflect only the first few months in fiscal year 1991.

Another manifestation of differences in sponsored research records is the ability to ensure "clean" data. As noted in the last column of Table 2, database entries for some universities may include items such as drug tests and fellowships, which I seek to exclude from my analyses.

In the next subsection, I describe the process of cleaning the data and the assumptions made in converting the furnished data into a database.

II.2.5 CONSTRUCTION OF DATABASE

The collection of data was followed by the construction of the database. The database consists of two portions. The first portion of the database covers sponsored research by firms at universities, using information provided by

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[4] Some institutions furnished records on all expenditures within a given year, regardless of when the contract was initially awarded. I converted this information to an awards format, which resulted in some data records extending beyond the timeframes of either the second or third column of Table 2. For example, there is one database entry of a contract awarded before 1970, but which had not been fully expended by the 1980s.

sponsored research offices. Because this data did not include the characteristics of firms sponsoring projects, the second portion of database includes information on the firms' characteristics. The second portion was developed using publicly-available information on companies, such as business directories. The following paragraphs describe each of these sections in turn.

Data on Sponsored Research

The sponsored research data was provided in various ways, including pages from annual reports documenting contract research, printouts from specially-tailored computer runs, diskettes containing downloaded data, and data made available on-site. This section documents some of the key steps in turning this agglomeration of data into a single codified database.

The first step in the process involved verifying that the universities furnished the data requested. I used several mechanisms to purge items such as clinical drug trials, fellowships, funding from foundations, and other similar items from the data. Many universities themselves were able to eliminate noisy data by computer database selection procedures. In other cases, I manually examined project titles or university-supplied classification codes to eliminate many items. Similarly, some university administrators reported that for their university, sponsored research projects carried different overhead rates than did clinical drug studies and other items. As a consequence, for these universities, I inspected indirect research costs to eliminate some unwanted data items. In addition, wherever possible, anomalous data entries were checked by contacting the universities or cross-referencing in other university records.

The data records were then manually entered into computer format. Five major pieces of information were entered -- the company name, the university funded, department funded (where available), dollar amount of sponsored research, and year. To the extent possible, the company and department data were entered just as they appeared in academic records. The entry for the dollar amount of sponsored research represents the total firm support at the university (or university department, if available) for a given year. Thus, in general, it does not represent an individual project. Though some universities did provide project level data, computer storage space considerations resulted in the more aggregate figure recorded. A very few negative figures from academic records were still entered. Discussions with university officials indicated that these negative "funding amounts" represented adjustments to earlier transactions

Issues of Data Uniformity and Company Identification

After entry of university data into computer form, the major challenge of the database construction project arose -- the process of making data across universities uniform and identifying the firms. University records exhibit wide variety in how things are named and the amount of detail supplied. The firm identification process proved challenging and time-consuming because of four features: heterogeneity in university nomenclature systems, name changes, company subsidiaries or divisions, and non-U.S. entities. The impact of these potential problems have been mitigated by a conservative approach in making firm identifications; only those "sure" identifications were included in the analysis. Each will be discussed in turn.

Universities furnished company names in several different formats, recording the same name in different ways. What one university calls "Dupont", another calls "Dupont & Co", while a third calls the firm "E.I. DuPont de Nemours." Many company identities were resolved through careful manual checking, but others remained unidentified or not uniquely identified, and left as such in the database. The major differences in nomenclature stemmed from abbreviations, word ordering, suffixes, punctuation, and treatment of firms named after people. With a few exceptions, abbreviated names were spelled out, so that "GE" became "General Electric." The "buried keyword" problem described in Hall et. al. (1988) also existed in my raw data; the key company name component was sometimes placed after the name of a division or foreign affiliate. I adopted the convention of ordering with the parent firm's name first followed by the division or foreign affiliate name. Thus, "Electronics Division of GE" became "GE Electronics."

Name suffixes differed across university records. For example, ascertaining that "IBM Inc." and "IBM CORP" represented the same firm proved facile.

However, determining whether the relatively unknown "ABC Co." differed from "ABC Corp." (to use an imaginary example) proved challenging, particularly in cases when business directories record actual firms with both names. I adopted a uniform system of abbreviations, so that "Inc" represented "Incorporated", "Inc.", "Incorp.", etc. Next, entries clearly representing the same, usual large, firm were codified into a standard name. Finally, ambiguous cases were left alone. As for punctuation, for purposes of uniformity, I eliminated all periods and commas from company names, eliminating separate entries for "Ford Motor Co" and "Ford Motor Co." in the data set. Even within the same university, over time, company names are non-uniform. Finally, I adopted the convention that firms named after individuals would be listed by the person's last name.

Subsequently, ambiguous entities from university records were clarified by manual checking in business directories. Similarly, information on the identified firms (such as size) were obtained from business directories manually. The name-matching process involved conservativism with a high standard for matching. If there was doubt as to whether "ABC" was actually "ABC Corporation" or "ABC Inc", the database entry "ABC" was left unidentified. Eventually, the codification process produced a total of 5604 business entities, not all of which were identified.

Data on Company Characteristics

The previous paragraphs described the process of transforming raw data into computer form. The university data supplied only one piece of information about the sponsor firms, their names. Because many interesting questions involve the characteristics of the firms involved, information on the sponsor companies was needed. In this section, I describe the process of constructing a data file on research sponsor characteristics.

Codifying the data on sponsored research received from universities produced a list of 5604 company names. For this list of names, business directories such as the "Corporate Technology Directory" and "Ward's Business Directory" provided information on a firm's size, diversity, age, location, and other characteristics. Each piece of data will be described in Section II.2.6.

Pinpointing the identity of a firm given a company name was done in a careful manner, as many small firms in different parts of the country shared the same name. In several cases, telephone calls to companies clarified questions about exact company name, but in others, ambiguity remained. To reduce contamination of subsequent analyses, I did not assume that the "ABC" sponsoring research at a Texas university was "ABC Corporation" located in Texas, and not "ABC Inc" located in Massachusetts. As a result, names shared by several distinct firms were left unidentified, but still included in the database. These records are used in analysis not dependent upon company characteristics (such as the university's sponsor count), but excluded from cases where those characteristics are the basis of analysis (such as sponsor size).

In addition, some universities (such as Wayne State and the University of Oklahoma) combined information on many small sponsors into an aggregate "Industry" or "Miscellaneous Industry" category. These entries were kept in the data set to allow the fullest possible coverage of a university's industry support. However, care should be taken in interpreting average sponsor amounts for these universities. Firms undergoing name changes tended to have multiple entries, one for before the change, and one for after.

The entire process identified 2530 business entities and left 3074 business entities not fully or uniquely identified[5]. In nominal dollar amounts, these identified firms are responsible for almost 80% of the research funding in the dataset. The unidentified entities may represent small, local firms not listed in major business directories, tending to make the estimates of geographic effects in Chapter IV very conservative. Though the identification process could not provide full coverage, it still has produced the largest known record of firm involvement in sponsored research across universities. The next section describes the computer files constituting this record.

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5 By "identified" I mean having reliable information on employee count, location, and SIC code.

II.2.6 DESCRIPTION OF DATA FILES

The result of the database construction process is a SAS Version 6.06 database on sponsored research consisting of two parts. The first portion includes 22744 records of 5 variables, each based on university-provided information. The five variables, their type, their length, and their location on the computer records are summarized in Table 4.

Table 4: Summary of University Data File Variables

Name	Type	Length	Location	Brief Description
CO	character	40	25	industrial sponsor name
UNIV	character	25	0	university sponsored
DEPT	character	25	65	university department
YEAR	numeric	8	90	year of funding
RESDOL	numeric	8	98	nominal dollar amount of funding involved.

The following paragraphs further explain the five variables.

CO – This is the name of the industrial sponsor or ultimate parent company of an industrial sponsor. CO represents the means by which sponsors are identified in the data set, in addition to one of the means by which the data set can be matched to other data sets. The nomenclature conventions behind CO are described elsewhere in this section. Though the vast majority of the entities are firms, some of these are industrial consortia, joint ventures, or not-for-profit organizations with the characteristics of firms (such as some research institutes).

UNIV – The university at which CO sponsored research. Campuses within the same university system in the database (such as the University of California's Berkeley and Los Angeles campuses) are recorded separately.

DEPT – The university department or research center where the research was conducted. DEPT is the department name provided by the university, prior to any mapping into NSF technical fields. It is not available for all institutions.

Even for some institutions providing departmental detail, some research projects did not include department information.

YEAR – The year of sponsored research involvement. As universities operate on a fiscal year, YEAR represents the "year ending" fiscal year of either awards or expenditures. Thus, schools that providing data for fiscal year 1989-90 had the data treated as YEAR=90. For institutions providing awards data, YEAR records the fiscal year in which the award was granted. For those providing expenditures data, YEAR records the fiscal year of expenditure.

RESDOL – This is the main variable in the data set. It generally measures the nominal dollar amount of sponsored research spending by CO at UNIV (in DEPT, where available) in YEAR. Depending on how the university maintained records, RESDOL could thus measure the firm's sponsored research at the entire university during a year, the firm's sponsored research at a department during a year, or the firm's sponsored research at some project-related level during a year. Thus, in using RESDOL, one may need to sum the variable by company, university, or department as appropriate, depending upon the analysis. RESDOL measures awards amount for some institutions, and expenditure amount at others. Some negative values thus result, reflecting adjustments to expenditures from prior years.

The second part of the data set is derived from business directories about the characteristics of the industrial firms sponsoring research. Sources of data included the "Corporate Technology Directory", "Ward's Business Directory", Dun & Bradstreet's "Million Dollar Directory", "Standard & Poor Register", and "America's Corporate Families." This portion of the database consists of 5604 records of 9 variables each, as briefly described in Table 5.

Table 5: Summary of Company Data File Variables

Name	Type	Length	Location	Brief Description
CO	character	40	0	industrial sponsor name
PARENT	character	40	40	ultimate parent company of CO
EMP	numeric	8	104	number of employees
SALES	numeric	8	96	sales ($ million)
SIC	numeric	8	88	four digit SIC code
DIVERSITY	numeric	8	112	number of four digit SIC codes
ZIP	numeric	8	120	five digit zip of CO
FOUND	numeric	8	128	year that the firm was founded
CODE	numeric	8	136	code for special organizations.

The paragraphs that follow provide more detail on the company information portion of the database. Each variable is documented in turn.

CO -- This is the name of industrial sponsor or ultimate parent company of an industrial sponsor. Though the vast majority of the entities are firms, some of these are industrial consortia, joint ventures, or not-for-profit organizations with the characteristics of firms (such as some research institutes).

PARENT -- ultimate parent company of the firm in CO. The default involves setting PARENT equal to CO. Parent companies were identified by manually looking them up in the "Corporate Technology Directory" and "America's Corporate Families", except in cases of company divisions with the parent's name included (such as Amoco Chemicals). The information in these directories on corporate ownership is very recent, because resource limitations prevented the temporal changes in company ownership to be explored. The lack of information on parent company changes may produce distortions for companies that changed ownership frequently.

EMP -- Size measured by number of employees, generally for 1990. It was obtained from business directories such as "Ward's Business Directory" and the "Corporate Technology Directory." In the case of small firms, listings frequently provide only a range, such as 50-100 employees. In these cases, the midpoint was used.

SALES -- Firm size measured by millions of dollars of sales, generally for 1990. This figure is also obtained from business directories. For listings on small firms providing only a range, the midpoint value was used.

SIC -- The four digit SIC code of the firm's primary line of business. The assignment of a four digit SIC code to a firm represents an approximate process, at best. As neither the firms themselves nor government agencies provide a uniform primary code for each firm, the assignment depends upon individual judgment. Common sources of business information (such as Compustat, Standard & Poor's, Dun & Bradstreet) often provide very different SIC codes for the same firm, even firms not generally known as conglomerates. My assignment of technology-intensive firms to a single SIC code was based on information from the "Corporate Technology Directory." This directory lists all the firm's products and services, assigning each to a SIC code. Unfortunately, sales by individual product is not available. I defined the main SIC code as the one to which the Directory assigned the most products or services. For firms not listed in this directory, I used the primary SIC provided in "Ward's Business Directory" or "Standard & Poor's Register."

DIVERSITY -- Diversity of a firm's product line, measured by the number of four digit SIC code industries in which the firm operates. For technology-intensive firms, I manually counted the number of SIC codes listed for the firm (and its subsidiaries and divisions) in the "Corporate Technology Directory." For firms not in that directory, I counted the number of SIC codes provided in the "Standard & Poor's Register." A comparison of firms listed in both directories revealed that the "Register" tended to provide fewer SIC codes per firm, meaning that my DIVERSITY variable for non-technology intensive firms may be downward biased.

ZIP -- Five digit zip code of the firm's headquarters. This measure of a firm's location proves crucial in Chapter III. In an ideal world this piece of information would be furnished by university sponsored research offices, because the problem of large firms with many branches and facilities would be alleviated. Inquiries with sponsored research office proved unsuccessful, causing this information to be obtained from business directories. For subsidiaries and divisions of larger firms, the zip code represents, where known, the zip code of the subsidiary or division headquarters. This variable is generally absent for non-U.S. firms, although if they have U.S. affiliates, these affiliates will have zip codes and thus recorded.

FOUND -- Year that the firm was founded. This piece of data was obtained from business directories such as the "Corporate Technology Directory" and "Ward's Business Directory." In a few cases, the FOUND variable may represent when the firm changed ownership, such as being bought out or merged.

CODE -- Code denoting special organizations, particularly those with characteristics which may lead to their exclusion from certain analyses. There are six possible values:

1 -- company is a foreign parent company (153),
2 -- company is a foreign subsidiary (157),
3 -- company was or is involved in major merger or reorganization (44),
4 -- entity is not a for-profit corporation(100)
5 -- entity is a joint venture, joint sponsor, etc. (21),
0 -- none of the above.

Data on non-U.S. firms may not be directly comparable to data on U.S. firms due to exchange rate fluctuations affecting sales data, less available data on product line diversity, and difficulty of establishing a zip code for geographic analyses. Companies involved in reorganizations or mergers pose severe comparability problems in temporal analyses. A few database entries involve industry consortia or not-for-profit organizations (particularly research institutions) that have characteristics similar to firms. Also, some non-profit organizations reported receiving non-trivial funding from industry sources, and were retained in the data set. In some analyses, excluding the research involvement of these entities would be misleading, so these entities were retained in the data set. Finally, some projects are funded by joint sponsors or joint ventures, and thus cannot be allocated entirely to one firm. Rather than arbitrarily splitting the funding to the constituent firms, I have kept the data as received to permit future study of this phenomenon. In addition, there are only 21 sponsors with these characteristics.

In summary, the database was constructed from original source material received from university sponsored research offices. It covers the research sponsorship of 5604 business entities at 65 universities in science and engineering fields for up to sixteen years. Data for some universities is disaggregated by academic field. Firms are identified by name, permitting analyses of sponsor characteristics by matching the database on sponsored research with a database on firm characteristics. The next section shows what these data records and variables reveal about the universities and firms involved in sponsored research involvement.

II.3 Overview of Data Set

This section provides an overview of the data set on industrial sponsored research. This overview lays the foundation for understanding subsequent analyses and results. The emphasis will be on the key variable in the database, the amount of industry sponsored research at universities. The data will be analyzed from two perspectives, that of the university and that of industry. In addition, this section will explore the temporal and the geographic elements of industry sponsored research funding.

II.3.1 FUNDING AT UNIVERSITIES

This section examines the universities and university departments receiving sponsored research funding. A summary of sponsored research in 1989 using universities as the observational unit is shown in Table 6. The choice of the year 1989 for analysis was essentially arbitrary; it represented a year in which almost all the universities supplied data. The total amount of sponsored research at the 65 universities was $294 million, with a mean of $4.5 million and a median of $2.3 million. In the aggregate, the figures in the data set were 24% lower than the NSF figures for the same institutions, while the average university had a difference of 21%. A distribution table (also in Table 6) informs us that only a few universities (13.8% of the sample) receive at least $10 million annually, while many (over 30%) receive less than $1 million.

I analyze the number of sponsors per university in the bottom portion of Table 6. The mean number of business entities sponsoring research at one of the 65 universities is 54, with a maximum of 313. A wide range of university interaction with companies is apparent, with over 27% of the universities having no more than 10 sponsors, while 4% of them have at least 200. These figures may be understated for some universities with multi-sponsor consortia programs, or with research accounting categories such as "Miscellaneous Industrial Sponsors." The figures suggest that the large differences in university research funding may be due to the differences in university research sponsors. The simple correlation coefficient between a university's funding amount and its number of industrial sponsors is 77%.

Table 6: Industry Research at Universities

SUMMARY STATISTICS ON RESEARCH VOLUME (1989)	
Total sponsored research at 65 universities	$294.2 million
Mean Per University	$4.5 million
Median	$2.3 million
Maximum	$26.4 million
Minimum	$200,000
Total industry-funded research at 65 univs.	$389.4 million (NSF Figures)

DISTRIBUTION OF FUNDING

Range	Number	% of Univs.	% of Funding Accounted For
$20 million and up	1	1.5%	9.0%
$15-19.9 million	3	4.6%	16.7%
$10-14.9 million	5	7.7%	21.4%
$5-9.9 million	12	18.5%	29.7%
$1-4.9 million	24	36.9%	21.0%
less than $1 million	20	30.8%	1.6%

SUMMARY STATISTICS ON NUMBER OF SPONSORS

Basic Statistics on Number of Sponsors at 65 Universities

Mean	54
Median	37
Maximum	313
Minimum	1

DISTRIBUTION OF A UNIVERSITY'S NUMBER OF SPONSORS

Sponsors	Number of Universities	% of Universities
201+	3	4.6%
101-200	7	10.8%
51-100	11	16.9%
41-50	7	10.8%
31-40	8	12.3%
21-30	3	4.6%
11-20	8	12.3%
1-10	18	27.7%

Correlation between funding amount and number of sponsors=77%

Table 7 ranks the top 35 (out of 65) universities in the database in terms of their industrial research sponsorship. These figures are for 1989, unless otherwise noted[6]. For comparison purposes, NSF figures on industry funding in 1989 appear in the third column, with the percentage difference of database figures from NSF figures in the fourth column. In both sets of data, we see that MIT had the highest dollar volume of industry support for universities in my data set, followed by the University of Michigan. Subsequent rankings diverge, sometimes dramatically. Nevertheless, the data show a wide range of industry involvement with universities, with research sponsorship ranging from $26 million to a few thousand dollars (for a few universities not shown in Table 7).

The NSF and database figures diverge for several reasons. NSF figures tend to be larger, because they include unrestricted industry grants and gifts for research, clinical drug studies, work with "leased-laboratory" characteristics, and equipment purchased with research funds. As previously described, these categories of industry support are excluded from this database. For 11 universities out of 50 for which comparisons were possible due to NSF data availability, NSF figures were smaller than database figures. Accounting-based timing differences may be at work. The NSF figures measure expenditures, while 62% of the universities in the data set have awards data, which may get expended over a multi-year period. In years with substantial award activity, the awards total will tend to be higher than the expenditure total.

Table 8 provides a ranking of the top 35 universities in the database in terms of the number of industrial sponsors in 1989, where a sponsor is a business entity such as a parent company, division, or subsidiary. The University of Michigan had funding from the most firms (313), followed by Purdue and Texas A&M. The figures for some institutions may include firms sponsoring drug studies, and hence could be overstated to the extent that those firms do not sponsor basic research.

The figures in Tables 7 and 8 show significant variation in extent of industry interaction with institutions of higher education. They do not indicate whether

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[6] A few institutions provided data only for 1990.

Table 7: Universities in Database Ranked by Industry Sponsored Research Funding (Top 35)

Database Figures for 1989 Unless Noted
NSF Figures for 1989

Rank	University	Database $	NSF $	% Difference
1	MIT	26,418,000	39,650,000	-33%
2	Univ. of Michigan	17,917,000	22,023,000	-19%
3	Texas A&M	15,735,000	21,204,000	-26%
4	Stanford	15,427,000	13,764,000	12%
5	Geogia Tech	14,261,000	21,346,000	-33%
6	U. of Illinois Urbana	12,948,000	15,785,000	-18%
7	U. of Arizona	12,055,000	9,729,000	24%
8	U. of Florida	11,960,000	10,579,000	13%
9	USC	10,847,000	14,716,000	-26%
10	UC San Diego	9,429,000	6,824,000	38%
11	U. of Pittsburgh	9,260,000	9,406,000	-2%
12	UCLA	8,515,000	7,548,000	13%
13	Purdue	8,351,000	11,451,000	-27%
14	U. of Pennsylvania	7,988,000	9,582,000	-17%
15	Johns Hopkins	7,294,000	11,013,000	-34%
16	Iowa St. U. of Sci. & Tech.	6,955,000	4,408,000	58%
17	Harvard	6,314,000	10,461,000	-40%
18	Wayne State	6,107,000	3,850,000	59%
19	U. of Missouri Columbia	5,827,000	6,434,000	-9%
20	UC Berkeley	5,797,000	8,480,000	-32%
21	U. of Iowa	5,599,000	10,301,000	-46%
22	Northwestern	4,989,000	5,289,000	-6%
23	Louisiana State	4,502,000	2,120,000	112%
24	Brown	4,247,000	4,291,000	-1%
25	Clemson	3,828,000	3,849,000	-1%
26	UC Irvine	3,654,000	4,582,000	-20%
27	U. of Massachusetts	3,059,000	11,480,000	-73%
28	Princeton	2,927,000	5,640,000	-48%
29	U. of Lowell	2,817,000	2,849,000	-1%
30	U. Texas Hlth Sci Ctr Hou.	2,744,000	3,266,000	-16%
31	Rutgers	2,674,000	6,087,000	-56%
32	Indiana Univ.	2,609,000	2,591,000	1%
33	U. of Oklahoma	2,310,000	1,991,000	16%
34	Colorado State	2,249,000	2,432,000	-8%
35	U. of Maryland Baltimore	2,158,000	11,183,000	-81%

Table 8: Universities in Database Ranked by Number of Industry Sponsors (Top 35)

Database Figures for 1989 Unless Noted

Rank	University	Database $	# of Sponsors	Notes
1	Univ. of Michigan	17,917,000	313	
2	Purdue	8,351,000	253	
3	Texas A&M	15,735,000	237	
4	U. of Florida	11,960,000	192	
5	Geogia Tech	14,261,000	164	
6	U. of Arizona	12,055,000	152	
7	Iowa St. Univ. of Sci. & Tech.	6,955,000	145	
8	U. of Pittsburgh	9,260,000	134	
9	MIT	26,418,000	130	
10	U. of Illinois Urbana	12,948,000	115	
11	U. of Lowell	2,817,000	96	
12	UCLA	8,515,000	90	
13	U. of Iowa	5,599,000	90	
14	U. of Pennsylvania	7,988,000	82	
15	Indiana Univ.	2,609,000	82	1990 data
16	U. of Missouri Columbia	5,827,000	79	
17	Stanford	15,427,000	73	
18	Clemson	3,828,000	61	
19	USC	10,847,000	57	
20	Northwestern	4,989,000	56	
21	UC Berkeley	5,797,000	54	
22	U. of Maryland College Park	1,880,000	50	
23	Louisiana State	4,502,000	49	1990 data
24	SUNY Stony Brook	2,077,000	48	
25	U. of Massachusetts	3,059,000	47	
26	UC San Diego	9,429,000	46	
27	Rutgers	2,674,000	43	
28	Harvard	6,314,000	42	
29	West Virginia Univ.	1,324,000	40	
30	U. of Oklahoma	2,310,000	38	
31	U. of Maryland Baltimore	2,158,000	38	
32	Oregon State	1,982,000	38	
33	Colorado State	2,249,000	37	
34	UC Irvine	3,654,000	36	
35	Brown	4,247,000	35	

this variation is "expected" given the extensive heterogeneity in university sizes, for example. Figure 2 presents the cumulative distributions of three quantities with respect to number of universities for 53 institutions. The sample size has been reduced from 65 to 53 because of the necessity to have NSF data for all universities in the sample. Each (x,y) point shows the percentage y of each quantity accounted for by the top x universities. For example, it shows that the top ten recipients of sponsored research funds account for approximately 50% of all funds at the 53 universities. In contrast, the top ten recipients of research funds from other non-industry sources (federal government, state government, institutional, and miscellaneous) accounted for just over 40% of these non-industry funds. Government and similar funding is less concentrated than industrial funding, which is what we would expect if political considerations of equity affect federal and state government allocations of research funds. Thus, industry funding appears to be more concentrated at a few institutions than would be "expected" in comparison with other funding patterns. Figure 2 also plots the distribution of sponsor count. Though we have seen that the number of sponsors exhibits substantial variation, this variation tracks that of funding very closely, and is what might be expected.

The next table, Table 9, lists the 35 universities with the highest sponsored research funding per industrial sponsor. Johns Hopkins and Wayne State[7] top the list. The data suggests that some institutions with high average amounts, such as Johns Hopkins and the University of Texas Health Science Center at Houston, maintain very extensive relationships with a select group of firms. It also shows universities with other types of relationships with industry. These universities (such as the University of Michigan or the Iowa State University of Science and Technology) seem to have a large number of sponsors, but relatively low average funding amounts. I interpret this to mean that these universities seek a broad involvement with industry, perhaps through multi-member research consortia in which members share research project costs.

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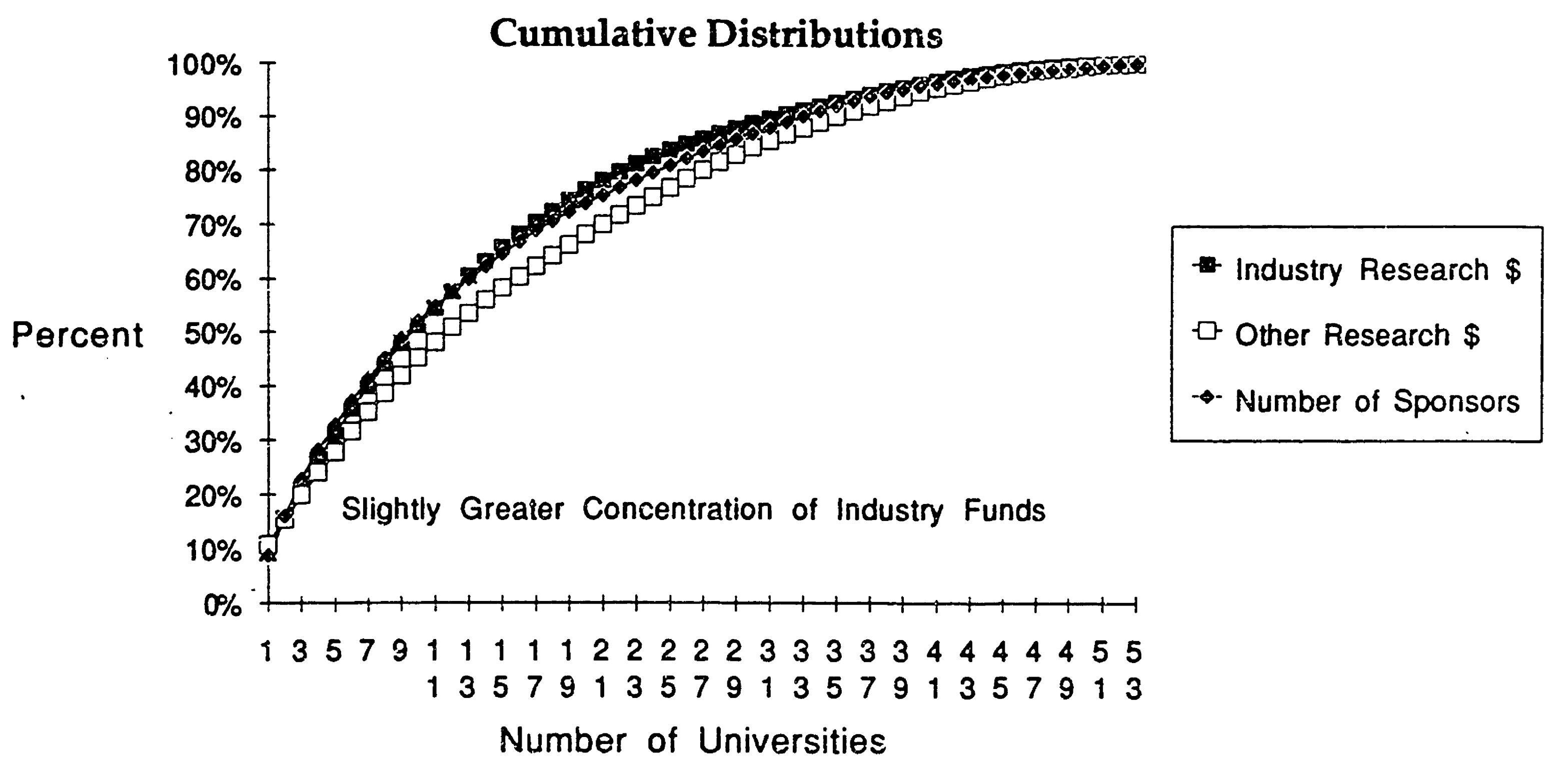
[7] In Table 9, Wayne State has a lower industry total than in previous tables because much of its funding was attributed to an industrial research category with an unknown number of sponsors.

FIGURE 2



Cumulative Distributions
Percent
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Slightly Greater Concentration of Industry Funds
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53
Number of Universities
Industry Research $
Other Research $
Number of Sponsors

Table 9: Universities in Database Ranked by Average Funding By Industrial Sponsor (Top 35)

Database Figures for 1989 Unless Noted

Rank	University	$/Sponsor	Database $	No. of Sponsors	Notes
1	Johns Hopkins	521,000	7,294,000	14	
2	Wayne State	505,000	2,021,000	4	*
3	SUNY CtrA	364,000	364,000	1	
4	U. Texas Hlth Sci Ctr Hou	343,000	2,744,000	8	
5	Stanford	211,000	15,427,000	73	
6	UC San Diego	205,000	9,429,000	46	
7	MIT	203,000	26,418,000	130	
8	Utah State	195,000	1,952,000	10	
9	USC	190,000	10,847,000	57	
10	Harvard	150,000	6,314,000	42	
11	Princeton	146,000	2,927,000	20	
12	Brown	121,000	4,247,000	35	
13	U. of Illinois Urbana	113,000	12,948,000	115	
14	UC Berkeley	107,000	5,797,000	54	
15	SUNY Broo	106,000	1,171,000	11	
16	U. of Maine Orono	103,000	1,754,000	17	
17	UC Irvine	102,000	3,654,000	36	
18	U. of Pennsylvania	97,000	7,988,000	82	
19	U. of Notre Dame	95,000	1,613,000	17	
20	UCLA	95,000	8,515,000	90	
21	Louisiana State	92,000	4,502,000	49	1990 data
22	Northwestern	89,000	4,989,000	56	
23	Geogia Tech	87,000	14,261,000	164	
24	U. of Arizona	79,000	12,055,000	152	
25	SUNY Albany	78,000	700,000	9	
26	U. Tex. Hlth Sci Ctr San /	77,000	2,154,000	28	
27	U. of Missouri Columbia	74,000	5,827,000	79	
28	SUNY College New Paltz	74,000	74,000	1	
29	U. of Pittsburgh	69,000	9,260,000	134	
30	Texas A&M	66,000	15,735,000	237	
31	U. of Chicago	65,000	848,000	13	
32	U. of Massachusetts	65,000	3,059,000	47	
33	Clemson	63,000	3,828,000	61	
34	U. of Florida	62,000	11,960,000	192	
35	U. of Iowa	62,000	5,599,000	90	

* Wayne State records did not indicate some sponsor names.

Alternatively, these academic institutions may simply accept smaller research contracts.

Funding at University Departments

Using the university as the focus of analysis, Tables 7 through 9 have demonstrated the considerable variety in how universities interact with the private sector. Because the data set includes some information by university department, we can probe more deeply using the university department as the unit of analysis. Such an examination is interesting because casual observation and the economics literature suggest that academic fields vary in terms of their impact on industry. Economists have long realized that industry interacted with numerous academic departments in both the sciences and engineering (NSB 1982). But evidence about the effect of this funding on a departmental level has come much more recently. Of five major technical areas (drugs, chemicals, electronics, mechanical arts, and others), Jaffe (1989) found that the effect of academic research upon industrial patenting was strongest in the drug-related academic areas (biology and medicine). As described in Chapter I, Mansfield (1991) surveyed 76 major firms in seven industries on the importance of academic research. Responses indicated that the percentage of new products and processes developed with "very substantial aid" from recent academic research was highest in the drug and information processing industries. Finally, responding to a recent survey in the United Kingdom (McKinsey 1991), 80 large companies rated biological and chemical technology as the most important sources of innovation over the last decade. From these results, we might expect extensive industry supported research related to the drug and information processing industries, namely in the fields of medicine, biology, electrical engineering, and computer science. However, to the best of my knowledge, the literature has not examined data on industry research support by academic field.

To explore the relationship between industry funding and academic field, I first map the various department names provided by universities into a few uniform, broader academic departments or fields. Individual academic departments are unsuitable for analysis because of differences in how universities organize their faculty and name their departments. Also, if many research projects draw on insights from not one but several related departments, a more appropriate unit of study is thus based upon the common ground of these departments. I thus take the 594 distinct department names supplied by the universities and map them into one of the sixteen standard and five miscellaneous NSF departments. Interdepartmental research centers are tricky to map, with many of them left unmapped as a result. The NSF guidelines on mapping disciplines, or university departments, into NSF technical fields are provided in NSF publications (1990).

Thus, following NSF guidelines that form the basis for its surveys, I grouped all academic departments with names similar to aerospace, astronautics, and aerospace engineering into the NSF technical field aeronautical and astronautical. Not all department names or research centers furnished by sponsored research offices could be readily mapped into the NSF framework, and these were treated as "unmappable" in the analysis. Further, many universities did not provide departmental information.

Using the NSF mapping guidelines, I calculated industrial research support by department in 1989 for all universities in the sample, and present the results in Table 10, ranked according to total industry amount. The second and third columns, respectively, display the amount and percentage of total industry funding accounted for by each field. As expected, departments of medical science and electrical engineering received the most industry sponsored research support, at $37.1 million (27.1% of total) and $18.1 million (13.2% of total) in 1989 respectively[8]. These two technical fields are related to technology-intensive industries such as pharmaceuticals, biotechnology, information processing, and computers. Fields in which the research can be characterized as more "basic" or further removed from commercialization, such as astronomy, physics, and mathematical sciences, received much less industry

8 The top ranking of Medical Science in Table 10 cannot be attributed solely to the inclusion of some clinical drug studies in the data. I performed a similar analysis using the 17 universities with departmental data cleaned of drug studies. The rankings of the top seven departments remained unchanged, with Medical Science still receiving approximately twice the funding as electrical engineering.

Table 10: Industry and Federal Funding of University Departments

Sample for Industry Analysis: Universities in Database with Data for 1989.
Sample for Federal Analysis: All Universities in NSF Sample.
Figures in $ million.

Technical Field	Industry Amount	% of Total Mapped	Federal Amount	% of Federal Total
not mappable	$146.9			
Medical Science	$37.1	27.1%	$2505	29.1%
Electrical Eng.	$18.1	13.2%	$388	4.5%
Other Eng.	$15.3	11.1%	$471	5.5%
Biological Sci.	$13.5	9.8%	$1720	20.0%
Mechanical Eng.	$8.1	5.9%	$210	2.4%
Chemistry	$7.4	5.4%	$424	4.9%
Civil Eng.	$7.1	5.2%	$104	0.0%
Computer Sci.	$6.4	4.7%	$318	3.7%
Agricultural Sci.	$5.1	3.7%	$346	4.0%
Chemical Eng.	$3.3	2.4%	$92	0.0%
Oceanography	$3.3	2.4%	$266	3.1%
Other Life Sci.	$2.7	2.0%	$202	2.3%
Earth Sci.	$2.3	1.7%	$186	2.2%
Astronomy	$1.9	1.4%	$88	0.0%
Physics	$1.7	1.2%	$598	6.9%
Aero/astro. Eng.	$1.3	0.9%	$113	1.3%
Other Science	$0.8	0.6%	$139	1.6%
Atmospheric Sci.	$0.8	0.6%	$125	1.5%
Mathematic Sci.	$0.7	0.5%	$156	1.8%
Other Environmental Sci.	$0.4	0.3%	$68	0.0%
Other Physical Sci.	$0.2	0.2%	$86	0.0%
Total	$284 ($137.1 mapped)	100%	$8605	100%

funding. Federal government funding of all academic research, presented in the fourth column, also emphasizes medical science and biological science to a large extent. However, in contrast to industry, the government places more priority in the basic sciences of physics (funding of $598 million) and chemistry ($424 million) than in the more applied electrical engineering ($388 million) and mechanical engineering ($210 million) fields.

Information on total industrial sponsorship of technical fields, of the sort shown in Table 10, furthers our understanding about the allocation of corporate resources. However, from the point of view of decision-makers the important quantity may be the average funding per department. Table 11 displays industry funding per department within each technical field. This table has several notable differences from Table 10. In particular, even though oceanography was not among the leaders in total industry sponsored research, because there were only two oceanography departments in the sample, oceanography had the highest average industrial funding per department, at $1.65 million. The average medical science department performed $1.2 million of sponsored research for industry, the second highest total, followed by astronomy at $950,000. Differences in the number of departments in the sample may have two causes, differences in the number of departments in existence and differences in the propensity of departments to conduct industry sponsored research. Though the data set cannot distinguish between the two reasons, Table 11 suggests that decision-makers should account for differences in the number of departments interacting with industry.

In summary, fields related to medicine and electrical engineering receive the most industry sponsored research support in my sample. This is consistent with other findings in the literature regarding the link between academic research and industrial innovation, as previously described. The data is consistent with the notion that sponsored research may be a means of technology transfer between the two sectors. In the next section, I examine university-industry interactions using the firm as the unit of analysis.

Table 11: Average Industry Funding Per University Department

Sample : Universities in Database with Data for 1989.

Technical Field	Industry Funding $ million	Number of Departments	Funding/ Per Dept. $
not provided or not mappable	$146.9		
Medical Science	$37.1	31	$1,200,000
Electrical Eng.	$18.1	22	$823,000
Other Eng.	$15.3	27	$567,000
Biological Sci.	$13.5	33	$409,000
Mechanical Eng.	$8.1	16	$506,000
Chemistry	$7.4	30	$247,000
Civil Eng.	$7.1	24	$296,000
Computer Sci.	$6.4	19	$337,000
Agricultural Sci.	$5.1	15	$340,000
Chemical Eng.	$3.3	20	$165,000
Oceanography	$3.3	2	$1,650,000
Other Life Sci.	$2.7	12	$225,000
Earth Sci.	$2.3	19	$121,000
Astronomy	$1.9	2	$950,000
Physics	$1.7	19	$89,000
Aero/astro. Eng.	$1.3	11	$118,000
Other Science	$0.8	8	$100,000
Atmospheric Sci.	$0.8	6	$133,000
Mathematic Sci.	$0.7	11	$64,000
Other Environmental Sci.	$0.4	2	$200,000
Other Physical Sci.	$0.2	3	$67,000
Total	$284 ($137.1 mapped)	360	

II.3.2 FUNDING BY FIRMS

Table 12 presents an overview of university-industry research relationships using the firm as the unit of analysis. To alleviate biases from transitory timing factors, I use the average of three years nominal funding (spanning 1988-90) as the basis of discussion[9]. As noted before in Table 2, of the 65 universities in the database, 61 provided at least three years of annual data. Table 12 shows that 3853 companies, their subsidiaries, or their divisions sponsored academic research at some point during 1988-90 at those 61 universities. The top portion displays data for business entities, which include divisions and subsidiaries, while the bottom portion maps those divisions and subsidiaries back to the ultimate parents. Both sets of data are presented to check the robustness of the general outlines of firm sponsorship to changes in the unit of analysis.

The average total annual amount per parent company was a little over $70,000, which means that the average firm and its affiliates spent $70,000 annually distributed over the 61 academic institutions combined. However, the much lower median funding figure ($8,300) suggests a skewed distribution, with a few firms heavily funding campus laboratories together with many firms funding for small sums of money. The top portion of Figure 3 shows the distribution of annual funding average over three years by the parent firms. It illustrates that approximately 80% of the 3236 ultimate parent companies sponsored an average annual total of less than $50,000! Indeed, analyzing the most-active research sponsors reveals an even more concentrated picture of research funding, as shown by the distribution table below:

Distribution of Average Annual Company Funding

Funding Range	Percent of Firms	Percent of Funding
$1-$99,999	88.7%	19.0%
$100,000-$499,999	8.6%	25.2%
$500,000-$999,999	1.3%	13.8%
$1 million and up	1.1%	42.1%

9 I use nominal, rather than real, figures because some university data include expenditures, which reflect nominal expenditures of multi-year awards.

Table 12: Overview of University Research Funding

Average annual nominal funding during 1988-90	$250.0 million
Total Universities in Database	65
Total Business Entities in Database	5604

Business Entity = parent company, company division, subsidiary, etc.

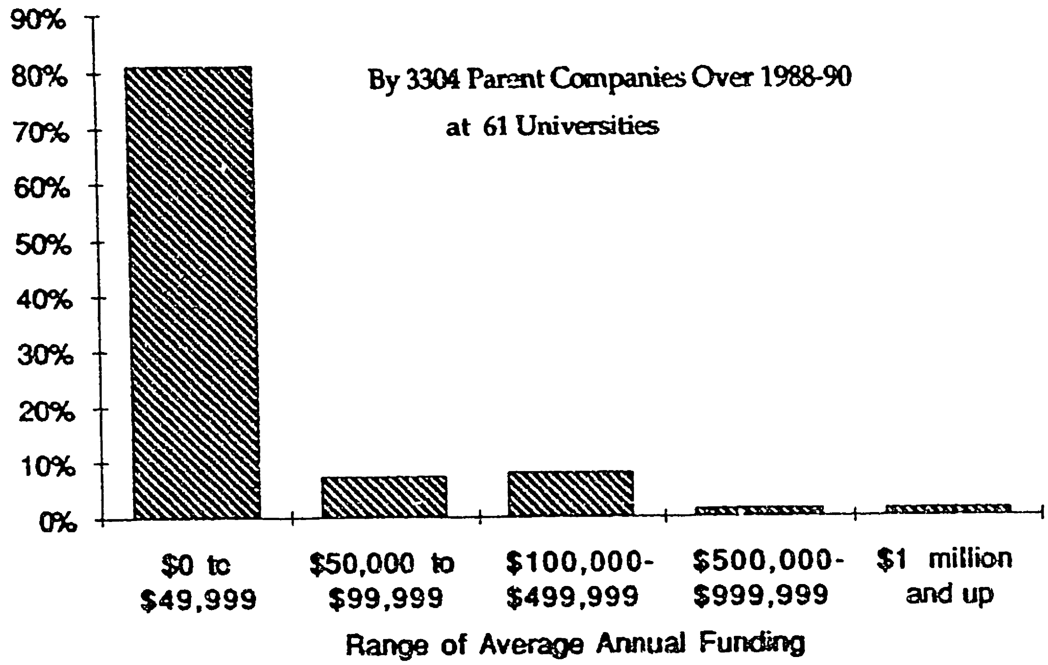
Research Sponsorship by Business Entities at 61 Universities	
Business entities sponsoring research in 1988-90	3853
Mean annual total funding per business entity	$65,000
Median	$9,000
Maximum average annual funding per firm	$15.0 million
Mean number of universities funded (out of 61)	1.6
Maximum number of universities funded	38

Research Sponsorship by Parent Companies at 61 Universities	
Parent cos. sponsoring research during 1988-90	3236
Mean annual funding per parent firm in 1988-90	$70,300
Median funding	$8,300
Maximum funding	$15.1 million
Mean number of universities funded (out of 61)	1.8
Maximum number of universities funded	41

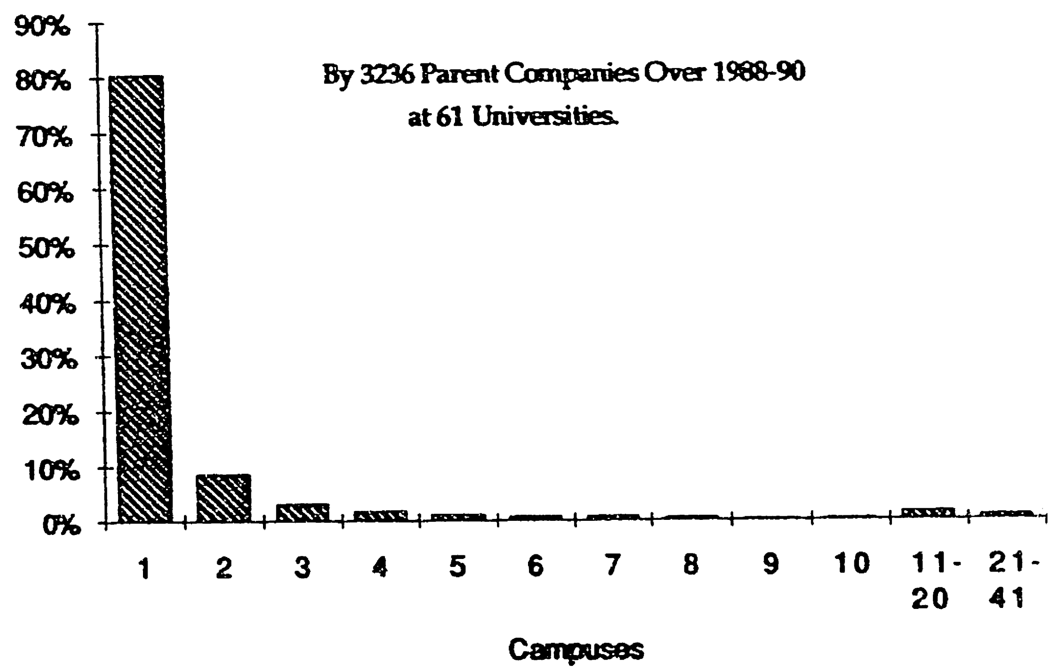
All dollar figures are in nominal dollars.

Figure 3

Distribution of Average Annual Funding



Distribution of Number of Universities Sponsored



The large sponsors (of over $1 million) account for a disproportionately large share of the research volume, with only 1.1% of all firms responsible for 42.1% of all support.

Table 12 also provides data on the mean and maximum number of universities funded. In examining the number of universities at which a firm supports research, we see that the average business entity sponsors research at 1.6 universities out of a possible 61. The bottom portion of Figure 3 graphs the distribution of the number of universities at which these ultimate parent companies sponsored research from 1988-90, confirming the essentially monogamous nature of these relationships. Approximately 80% of the corporations sponsored research at just a single campus in the sample, while an additional 8% sponsored at just two campuses.

The finding of largely limited company presence across universities is all the more striking if we recall that separate campuses in the same university system have been treated as different universities. However, the high maximum (38) suggests that a few firms have a broad presence across the nation's campuses. Mapping company subsidiaries and divisions back to the parent company level (shown in the bottom part of the table) leaves the basic big picture of university-industry research relationships unchanged: a few firms sponsoring large amounts at several universities, combined with many firms funding relatively small amounts at a single institution. The correlation between the number of campuses sponsored and total research outlays is 68%, suggesting that most of the firms sponsoring for small amounts do so at one university.

The first portion of Table 13 (a two page table) shows a ranking of ultimate parent companies in terms of their total research funding during 1988-90 and in terms of total campuses at which it supported research. We see that, by a large margin, IBM sponsored the most academic research during 1988-90, followed by the industry consortium Semiconductor Research Corporation and the telecommunications giant AT&T. The list of top sponsors features considerable variety, including firms in several industries (most related to electronics or medicine) and countries.

Table 13: Rankings of Sponsor Firms

Organizations Sponsoring the Most Research at the 61 Universities with Data for 1988-90 (annual average over 1988-90)

Organization	Nominal Amount	Campuses	$/Campus
IBM Corp.	$15.1 million	38	$400,000
Semiconductor Res.Corp.	$7.1 million	18	$400,000
AT&T	$6.0 million	21	$280,000
Electric Power Res. Inst.	$5.0 million	21	$280,000
General Motors	$4.9 million	29	$170,000
Hoffman LaRoche	$4.4 million	22	$200,000
Hoechst AG	$4.1 million	25	$160,000
Dupont	$2.9 million	41	$70,000
Gas Research Inst.	$2.6 million	13	$210,000
Upjohn Co.	$2.6 million	28	$100,000
Eli Lilly	$2.6 million	32	$80,000
Digital Equipment	$2.6 million	19	$140,000
Ciba Geigy	$2.6 million	24	$110,000
General Electric	$2.5 million	31	$80,000
Pfizer	$2.5 million	28	$90,000
Merck	$2.3 million	29	$80,000
American Cyanamid	$2.2 million	28	$80,000
Boeing	$2.0 million	19	$110,000
Amoco	$2.0 million	15	$130,000
Dow Chemical	$1.9 million	33	$60,000

Organizations Sponsoring Research at the Most Campuses During 1988-90

Organization	No. of Campuses	$/ Campus
Dupont	41	$70,000
IBM	38	$400,000
Dow Chemical	33	$60,000
Eli Lilly & Co.	32	$80,000
General Electric	31	$80,000
General Motors	29	$170,000
Martin Marietta	29	$60,000
Merck & Co.	29	$80,000
Procter & Gamble	29	$50,000
American Cyanamid	28	$80,000
Johnson & Johnson	28	$60,000

continued on next page

Table 13 (continued): Rankings of Sponsor firms

Organizations Sponsoring Rese: rch at the Most Campuses During 1988-90
(continued from previous page)

Organization	No. of Campuses	$/ Campus
Pfizer	28	$90,000
Upjohn	28	$100,000
Universal Energy Systems	26	$20,000
Hoechst AG	25	$160,000
Ciba Geigy	24	$110,000
Exxon	24	$40,000
Lockheed	24	$70,000
Abbott Lab.	22	$40,000
Bristol Myers	22	$50,000

Organizations Sponsoring Highest Average Amou ’er Campus

Organization	No. of Campuses	$/ Campus
Texas Eastern Gas	1	$1,500,000
Takeda Chemical	1	$1,100,000
Tokyo Electric	1	$1,100,000
Planetary Design Corp	1	$850,000
National Medical	1	$830,000
Whittaker Electronics	1	$790,000
Oasis Systems Int	1	$770,000
Transportation Res. Inst.	1	$760,000
Geltech	1	$750,000
Angelini Pharmaceuticals	1	$660,000
Sematech (consortium)	1	$560,000
Valid Logic	1	$530,000
UAW/Form Motor	2	$450,000
Merit Computer	1	$450,000
Decatur/FRP	1	$430,000
Protatek	1	$430,000
Rail Co	1	$420,000
IBM	38	$400,000
Semiconductor Res. Corp.	18	$400,000
Marko Materials	1	$400,000

The second portion of Table 13 ranks firms (ultimate parent companies) in terms of the number of campuses at which they sponsor research. Dupont and its subsidiaries sponsored investigators at 41 separate campuses at sometime from 1988-90. Comparing the top list and the bottom list reveals some notable differences in which firms are listed, suggesting different firm strategies in utilizing academic research. For example, for the campuses in the data set, Dupont sponsors investigations at many campuses for modest amounts, while IBM sponsors at a large number of campuses for large amounts. In contrast, some firms sponsor extensive amounts of academic research (such as AT&T), but do so at a very few universities. However, the incompleteness of the database cautions against interpreting these differences too seriously, for firms may sponsor research at the many universities not in the database.

Finally, the third portion of Table 13 (on the second page of the table) displays figures on the 20 organizations with the highest funding total per campus. The list is striking because of the differences with the first two portions of Table 13. Whereas the first two lists featured large multinational firms, much smaller entities predominate in this list. Almost all of these entities sponsored research at just one campus in my sample.

Size and Sponsored Research Outlays

Of the 5604 business entities in the database, a total of 2123 sponsoring research were identified through business directories. As a result, for those entities, we can analyze the characteristics of firms sponsoring academic research, not just their funding amounts or distribution. Of the characteristics of the firm, the relationship between size and R&D performance has been the focus of an extensive literature (summarized in Cohen & Levin 1989). Recent empirical studies find a positive, nonlinear relationship between firm size and R&D expenditures (Bound, Cummins, Griliches, Hall, and Jaffe 1984). If similar size-related factors affect both R&D and academic research outlays, then we would expect a general positive relationship between firm size and academic research expenditures.

Relationships between firm size and academic research cooperation, however, have been based less on empirical testing, than on casual observation. The consensus in the early 1980s was that most sponsors were Fortune 500-type companies with extensive R&D budgets. For example, after their field study covering several major universities, Peters & Fusfeld (NSB 1982) reported that "very rarely did we discover an instance of a smaller company providing funds for university research." Indeed, of the 287 cases of corporate funded research that they documented, "only one had been funded by a company with sales of less than $10 million." Other scholars and observers have also focused on large firms in examining academic-industrial relationships, particularly publicly-traded firms (Mansfield 1991) or those corporate giants involved in multi-million dollar agreements, such as Harvard-Monsanto or MIT-Exxon (Johnston & Edwards 1987). By the 1990s, observers obtained survey evidence on the occurrence of small firms sponsoring academic research (Link and Rees 1991), as well as acknowledgment by small firms about the importance of academic research collaboration (Industrial Research Institute 1991). However, the relationship between size and research sponsorship remained unexamined. The next section describes what the data set reveals.

Of the firms sponsoring research at some time during 1988-90, information on firm size, in terms of numbers of employees, was obtained for 1341[10]. A size distribution of these firms appears in Table 14. Over a fifth (23%) of the research sponsors can be characterized as very small firms, with fewer than 100 employees. Over half of the sponsoring firms (57.7%) have fewer than 1000 employees. As much of the literature (NSB 1982, Mansfield 1991) on these research relationships has focused on very large corporations, an examination of my data set suggests that this emphasis on large corporations may be overlooking a significant number of smaller firms interacting with academia, albeit for disproportionately small absolute amounts. Though many small firms are active in academic research, a better measure of their importance may be the absolute dollar volume of research that they sponsor. The

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[10] This total of 1341 firms is smaller than the 2123 total identified business entities in the entire database because it only includes those firms sponsoring research from 1988-90.

Table 14: Size Analysis of Research Sponsors

Distribution of 1341 firms sponsoring research during 1988-90 at 65 universities.

Size range (employees)	Number of Firms	% of Firm Number	Cumulative Number
1-99	308	23.0%	23.0%
100-199	121	9.0%	32.0%
200-299	93	6.9%	38.9%
300-399	64	4.8%	43.7%
400-499	48	3.6%	47.3%
500-999	140	10.4%	57.7%
1000-9999	359	26.8%	84.5%
10,000-49,999	151	11.3%	95.7%
50,000-99,999	33	2.5%	98.2%
100,000-199,999	17	1.3%	99.5%
200,000+	7	0.5%	100%

Size range (employees)	% of Research Funding	Cumulative Research Funding %
1-99	7.6%	7.6%
100-199	2.5%	10.1%
200-299	2.3%	12.5%
300-399	1.7%	14.2%
400-499	1.1%	15.3%
500-999	6.2%	21.5%
1000-9999	20.4%	40.9%
10,000-49,999	21.4%	62.3%
50,000-99,999	8.7%	70.9%
100,000-199,999	9.6%	81.4%
200,000+	18.6%	100%

bottom portion of Table 14 displays a distribution of research funding volume by firm size. The 1341 firms sponsoring research in 1988-90 spent $491 million in nominal terms at universities in my database. Of this $491 million, firms with fewer than 100 employees accounted for only 7.6% of the total funds, though they represent 23% of all sponsors. Conversely, the seven firms (0.5% of the total number) with over 200,000 employees were responsible for a disproportionately large 18.6% of the funding.

Though the untransformed data has a few outliers, a plot of the logarithms of size and research sponsorship (Figure 4) suggests a weak positive relationship between size and research sponsorship, particularly for larger firms. The correlation between employees and university research is 0.59, while that between the log of employees and log of university research is 0.32. To examine nonlinearities, I computed the correlation between the log of research funds and the the square of the log of employees. This correlation of 0.35 suggests a significant nonlinearity in the relationship. Chapter III examines the relationship between size and research sponsorship via regression analysis in greater detail, and controls for more factors affecting research sponsorship.

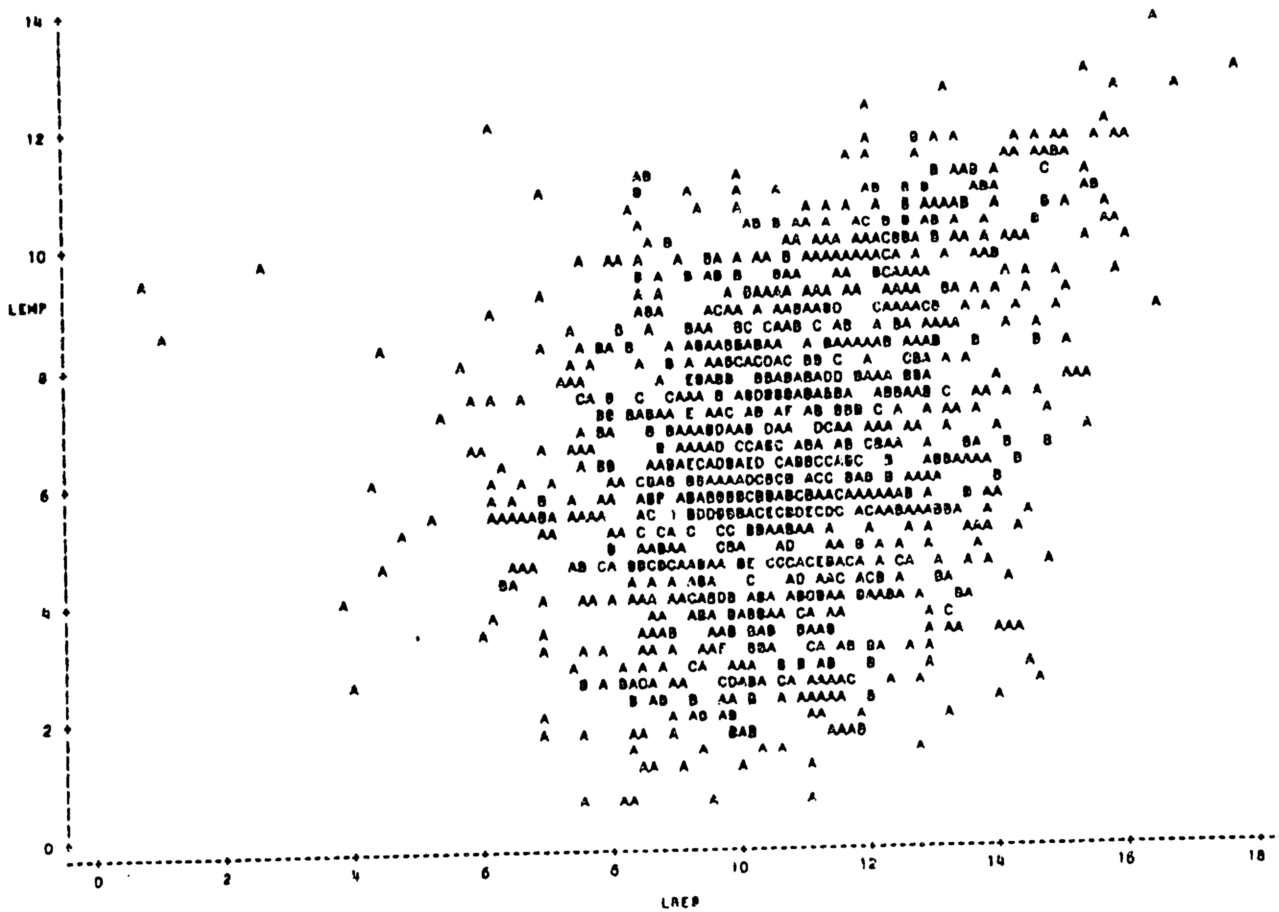
Therefore, the extensive presence of small firms in industry-academic interactions suggests that the literature's traditional emphasis on large corporations has overlooked an important phenomenon. Though these small firms account for small research volumes compared to the large companies, a complete story of technological innovation would describe how these small entities obtain technical knowledge, in part through academic interactions.

Extending our overview from the firm level to the industry level, Figure 5 presents a graph of 3 digit SIC code industry-level involvement in campus research. The graph plots data for the 2123 entities with SIC codes identified sponsoring research during 1988-90 at 61 universities. Drug firms (SIC 283 which includes pharmaceutical and biotechnology firms) sponsored the most academic research in terms of total nominal funding 1988-90 with close to $120 million. Computer (SIC 357) and electronics (SIC 367) firms were the next most active sponsors.

FIGURE 4

The SAS System　　12:26 Monday, April 27, 1992　1

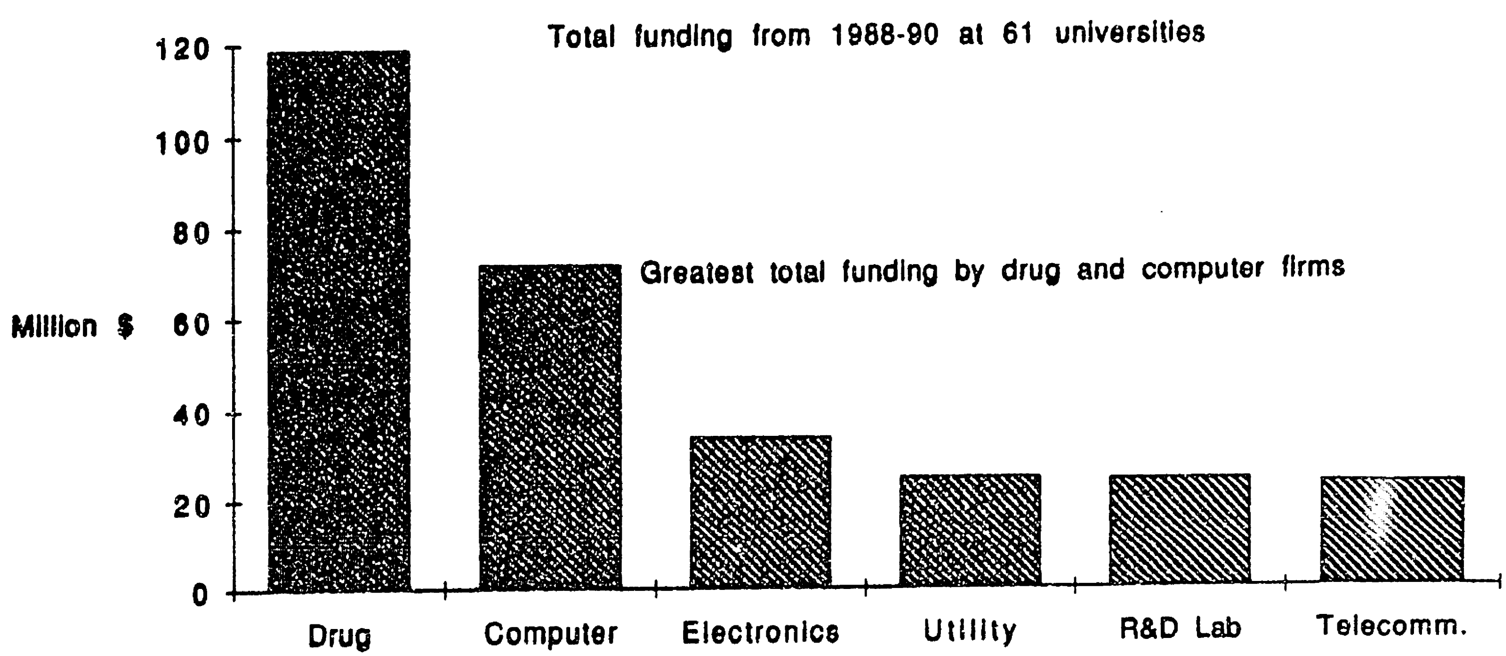
Plot of LEMP*LRES.　Legend: A = 1 obs, B = 2 obs, etc.



NOTE: 1897 obs had missing values.

FIGURE 5

Industries Funding the Most University Research



The next graph, Figure 6, displays the top 3 digit SIC industries in terms of the number of business entities in that industry sponsoring academic research. More firms in the drug industry sponsored academic technical work than in any other industry, followed by the related medical equipment industry. However, note the large number of non-manufacturing sponsors, particularly firms such as engineering/architecture firms, R&D laboratories, and computer service firms.

From Figures 5 and 6, it appears that drug-related firms make the most extensive use of university-industry research relationships, both in terms of dollar amounts and in terms of number of firms involved. However, this finding is subject to the limitations of the data set, such as incomplete coverage and firm identification, and may be due to the large number of drug firms in a fragmented industry that features pharmaceuticals, biotechnology firms, and generic drug producers. The figures presented may also overstate drug firm involvement in sponsored research because the data may include some clinical trials funded by drug firms[11]. The heavy research involvement by drug and electronics-related firms is consistent with the picture presented in the previous literature (Jaffe 1989, Mansfield 1991). The finding that many service related (engineering/architecture, R&D, and computer service) firms also interact with campus laboratories suggests, however, that the literature's focus on large, technology-intensive manufacturers may have missed an important part of these research relationships.

Universities in the medical science field perform the most sponsored research for industry, while drug-related firms sponsor the most academic research. It would be natural to assume that the drug-related firms sponsor faculty in the medical sciences, but the literature has not established this link. The data in Table 15 (a two page table) links a sponsor's industry with the academic field that it sponsored projects. The sample set is all identified firms at the 53 universities in the data set with departmental information for 1989[12]. The

[11] However, departmental analysis using data cleaned of drug studies produced results similar to analysis using the entire sample. This finding suggests that the impact of drug studies in the data is minimal.

[12] For five universities with no 1989 data, the year 1990 was used.

FIGURE 6

Industries (3 digit SIC) with Most Academic Research Sponsors

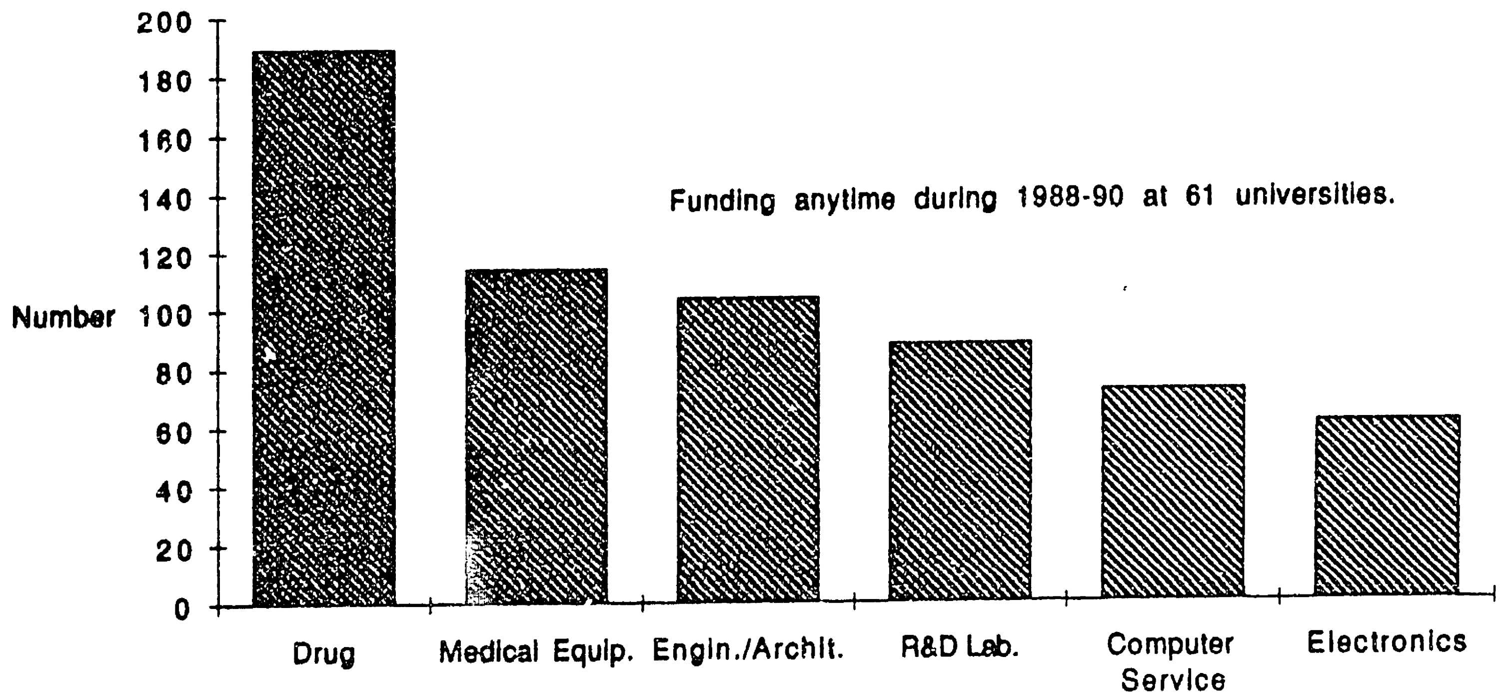


Table 15: Top Industries Funding Academic Fields

All identified firms at the 53 universities with departmental data for 1989.

Agri. Sci. $3,451,897	Percent
Chemicals, Drugs	45%
Food Products	15%
Utilities	14%

Comp. Sci. $5,954,440	Percent
Mach., Computer	30%
Communications	27%
Software	13%

Atmos. Sci. $676,175	Percent
Service	52%
Utilities	26%
Automot., Aircraft	14%

Earth Sci. $1,733,275	Percent
Utilities	52%
Other Manuf.	10%
Petroleum, Gas	8%

Astronomy $1,911,246	Percent
Elect. Instruments	48%
Automot., Aircraft	21%
Mach., Computer	12%

Elect. Eng. $17,934,021	Percent
Electronics	38%
Communications	18%
Utilities	12%

Aero/Astro Eng. $3,451,897	Percent
Automot., Aircraft	18%
Communications	9%
Other Manuf.	4%

Math. Sci. $608,836	Percent
Utilities	43%
Automot., Aircraft	28%
Mach., Computer	12%

Bio. Sci. $7,292,568	Percent
Chemicals, Drugs	55%
Services	15%
Utilities	11%

Mech. Eng. $7,485,274	Percent
Automot., Aircraft	23%
Mach., Computer	21%
Utilities	15%

continued on the next page

Table 15: Top Industries Funding Academic Fields (continued from previous page)

All identified firms at 53 universities with departmental data for 1989.

Chem. Eng. $3,720,008	Percent
Services	44%
Chemicals, Drugs	13%
Utilities	12%

Med. Sci. $31,804,935	Percent
Chemicals, Drugs	68%
Services	8%
Elect. Instruments	6%

Chemistry $6,289,408	Percent
Chemicals, Drugs	54%
Elect. Instruments	11%
Utilities	7%

Physics $1,241,512	Percent
Mach., Computer	32%
Services	23%
Utilities	15%

Civil Eng. $4,008,779	Percent
Services	23%
Automot., Aircraft	15%
Chemicals, Drugs	14%

Key

Automot., Aircraft	SIC 37	Mach., Computer	SIC 35
Chemicals, Drugs	SIC 28	Petroleum, Gas	SIC 13
Communications	SIC 48	Services	SIC 87
Electronics	SIC 36	Software	SIC 73
Elect. Instruments	SIC 38	Utilities	SIC 49
Food Products	SIC 20	Other Manufact.	SIC 39

sample here includes universities with departmental data. An industry is defined at the broad 2 digit SIC level, while once again the academic field is based on NSF definitions. For each academic field, Table 15 shows the total industrial funding recorded, followed by the percentage funding accounted for by the top three industries. The figures on academic field totals in Table 15 tend to be lower than those in Table 10, because Table 15 includes only firms assigned to an SIC code.

Most of the funding patterns in Table 15 are expected, such as the large funding by chemical and drug firms in chemistry, electronics firms in electrical engineering, and computer firms in computer science. However, it is unexpected, for example, that service firms (which include R&D laboratories and engineering firms) sponsor the most work in chemical engineering, while utilities appear to have great interest in agricultural science, atmospheric science, biological science, and physics. Overall, however, the funding patterns shown suggest that most academic fields receive sponsored research funding from directly-related industries. Appendix A (four pages) presents the complete mapping of funding by 2 digit SIC code industries to the NSF technical areas. In the next section, I turn to an examination of changes over time in contract research.

II.3.3 FUNDING OVER TIME

From Figure 1 in Chapter I, we know that university-industry research relationships have steadily increased in both nominal and real terms over the last several years, but do not know how or why this increase has occurred. We do not know to what extent this increase has been uniform across academic fields, or if it has been concentrated in a few. We also do not know whether the increase results from additional firms funding academic research, which has different implications than an increase due to the same firms funding greater amounts. In this section, I examine research funding over time.

Changes over time in university research sponsorship have not been examined previously. The closest analytical examination of the sort was described in the comprehensive National Science Board study (NSB 1982). That study reported that, from 1970 through the early 1980s, the greatest increase in the number of firms reporting "voluntary aid to education" -- not necessarily the same as research support -- resulted from firms in the food and chemical industries. There is thus some basis for expecting the data to show funding increases over time in chemistry and food-related areas such as agricultural science.

Because a proper comparison involves the same universities over time, this temporal analysis uses a sample of eight universities[13] with department-level data extending from 1989 back to 1980. The departments used are the broad NSF technical fields described earlier in this chapter. The sample only includes a few universities, generally ones with significant industrial interaction. Changes in nominal industry support of academic fields at these universities from 1980 to 1989 are shown in Table 16. Assuming that departmental definitions stayed relatively constant (I know of no evidence either way), we see that the eight universities enjoyed a 155% increase in real funding from

[13]These eight universities in the database are New York University, Stanford, University of Massachusetts, University of Pennsylvania, University of Arizona, University of Iowa, University of Missouri, and Utah State. Their ranks in terms of 1989 industry funding are 12, 17, 24, 26, 27, 45, 76, and 155, suggesting that the sample includes those with substantial industry funding.

Table 16: Changes in Funding by University Department

Industry Figures Based on 8 Database Universities with Departmental Data for Both 1980 and 1989

Federal Figures Based on NSF Sample Universe

Department	Industry $000 1980	Industry $000 1989	% Increase	Federal $000,000 1980	Federal $000,000 1989	% Increase
Other Life Sci.	0	222	NA	92	202	120%
Atmospheric Sci	2	207	10250%	67	125	87%
Biological Sci.	230	3242	1310%	1030	1720	67%
Chemistry	400	3157	689%	245	424	73%
Medical Science	1731	12592	627%	1416	2505	77%
Electrical Eng.	1017	6462	535%	184	389	111%
Chemical Eng.	96	600	525%	68	93	37%
Astronomy	429	1911	345%	59	88	49%
Mechanical Eng.	441	1897	330%	147	210	43%
Other Eng.	997	3587	260%	333	471	41%
not mappable	3136	10712	242%			
Civil Eng.	1017	2905	186%	88	104	18%
Physics	121	310	156%	322	598	86%
Computer Sci.	765	1617	111%	114	318	179%
Aero/astro Eng.	296	386	30%	46	113	146%
Earth Sci.	1180	1180	0%	188	186	-1%
Mathematical Sc	522	400	-23%	79	156	97%
Agricultural Sci.	1043	787	-25%	679	346	-49%
Other Sci.	466	0	-100%	146	139	-5%
Overall Nominal	13889	52174	276%	5303	8187	54%
Overall Real (1980 $)	11149	28318	154%	5303	5555	5%

1980 to 1989[14]. Several departments witnessed dramatic increases in industry interest. The largest percentage increase in identified fields occurred in atmospheric sciences, though with low funding amounts in absolute terms. More significant dollar total increases occurred in biological sciences (1310% nominal increase), chemistry (689%), medical science (627%), electrical engineering (535%), and chemical engineering (525%). In absolute nominal dollars, the medical science departments at the nine universities received the greatest increase over the last decade, a gain of over $10 million.

For comparison purposes, the right-hand portion of Table 16 includes figures on changes in Federal academic research support during the same period at all universities. Nominal spending increased by 54% overall, but real research support increased by a mere 5%. In addition to much less dramatic percentage increases, federal funding changes over time exhibit different priorities from those of industry support. In terms of percentage support, the fields of computer science and aeronautics/astronautics received the greatest relative increase, even larger than their percentage increase in corporate funds. However, federal and industrial funding sources both allocated the greatest absolute increase in resources toward the medical science field.

Table 16 illustrated significant increases at the department level for the eight universities during the last decade. The increases in sponsored research volume could be due to increases in average volume by department, or they could be due to increases in the number of departments at the eight universities receiving industry funding. Table 17 analyzes the extent to which these increases resulted from more departments interacting with industry, rather than from greater average amounts per department. The first four columns of Table 17 are reproduced from Table 16. The middle two columns of Table 17 present figures on the number of academic fields at the eight universities performing sponsored research for industry; the overall increase in department count of 33% (from 57 to 76) is small in comparison with the funding increase. The next two columns display the average per department in those years. The rightmost two columns list the percentage increase in

14 Real dollars calculated using the GNP deflator.

Table 17: Changes in Industry Average Funding by Department

Figures Based on 8 Database Universities with Departmental Data for Both 1980 and 1989

Technical Field	Industry $000 1980	Industry $000 1989	% Increase	No. of Depts. '80	No. of Depts. '89	$000/Dept. 1980	$000/Dept. 1989	% Increase Nom.	% Increase Real
Other Life Sci	0	222	NA	0	2	0	111	NA	NA
Atmos. Sci.	2	207	10250%	1	2	2	104	5075%	3411%
Biological Sci	230	3242	1310%	4	6	58	540	840%	538%
Chemistry	400	3157	689%	4	7	100	451	351%	206%
Medical Sci.	1731	12592	627%	5	7	346	1799	420%	253%
Electrical Eng	1017	6462	535%	5	5	203	1292	535%	331%
Chemical Eng.	96	600	525%	2	6	48	100	108%	41%
Astronomy	429	1911	345%	1	1	429	1911	345%	202%
Mechan. Eng.	441	1897	330%	1	4	441	474	8%	-27%
Other Eng.	997	3587	260%	4	5	249	717	188%	95%
not mappable	3136	10712	242%	6	8	523	1339	156%	74%
Civil Eng.	1017	2905	186%	5	4	203	726	257%	142%
Physics	121	310	156%	2	3	61	103	71%	16%
Computer Sci.	765	1617	111%	3	4	255	404	59%	8%
Aero/ast Eng.	296	386	30%	2	3	148	129	-13%	-41%
Earth Sci.	1180	1180	0%	3	3	393	393	0%	-32%
Mathemat. Sci	522	400	-23%	3	3	174	133	-23%	-48%
Agricult. Sci.	1043	787	-25%	3	3	348	262	-25%	-49%
Other Sci.	466	0	-100%	3	0	155	0	-100%	-100%
Total Nominal	13889	52174	276%	57	76				
Total Real (1980 $)	13889	35400	155%						

department averages in nominal and real terms. A comparison of the average increases per department with the average increases per technical field highlights a few large differences. In particular, though chemical engineering as a field enjoyed a 525% increase from 1980 to 1989, the number of departments accepting industry funds tripled during that time. This meant that the average chemical engineering department only saw a 108% increase in industry sponsorship. In general, the increase in industry sponsored research appears due to increases in average funding amount per department. However, for the fields of chemical engineering and mechanical engineering, the increase has also resulted from more departments receiving industrial research funds.

Changes in Sponsors Over Time

To examine the cause for increases in industry sponsored research, I examine the number of firms sponsoring research over time, in addition to the average funding amounts over time. My sample here includes the 11 universities that provided data for 1980 as well as 1989[15]. This analysis uses a larger sample than that of Table 16, which featured eight universities, because we are no longer restricted to universities providing departmental-level data. The sample tends to be weighted toward those with substantial industry involvement. Information on several measures of firm-level involvement appear in Table 18. The second column shows the number of sponsors at the 11 universities, which increased by 154%. This just about matched the 156% increase in real industry funding over the same time period, from $22 million to $57 million in 1980 dollars. The fourth column displays the average real funding amount at all the 11 universities by firms over time. This average increased by just 1% after adjusting for inflation over the decade! This figure is surprising because it implies that the growth in private sector research funding did not result from larger average support levels. However, the growth in the number of sponsors (154%) has kept pace with the real increase in industry funding (156%). This suggests that most of the increase in

[15] These eleven universities include the eight institutions listed in footnote number 13 with the addition of MIT, the University of Notre Dame, and Northwestern. Their industry funding ranks are 1, 69, and 57 respectively.

Table 18: Industrial Sponsorship Over Time

Sample of 11 Database Universities
Providing Data for 1980 Through 1989

Year	Spon-sors	Industry Funding 1980 $	Mean 1980 $	Maximum 1980 $	Firms Over $1 Million 1980 $
1980	209	22,154,000	106,000	3,600,000	2
1981	270	21,130,200	78,260	2,457,000	2
1982	266	24,619,896	92,556	1,542,600	4
1983	287	25,098,150	87,450	2,557,500	2
1984	309	31,935,150	103,350	2,703,000	6
1985	325	35,832,225	110,253	5,551,200	5
1986	374	34,312,256	91,744	4,286,400	6
1987	454	38,723,022	85,293	3,863,700	4
1988	475	41,583,400	87,544	5,295,000	4
1989	530	56,775,720	107,124	5,085,000	7
% change '80 to '89	154%	156%	1%	41%	250%

Top Sponsors	
EPRI	1980-82
IBM	1983-89

industry-sponsored research has occurred because of universities having additional sponsors, rather than receiving larger contracts from the same firms.

The fifth column of Table 18 suggests that the importance of the largest sponsors (in terms of sponsored research funding) has grown since 1980, relative to the average sponsor. The real dollar amount of research accounted for by the largest sponsor increased by 41% between 1980 and 1989, compared to the 1% increase by the average firm. From 1980 through 1983, the top sponsor at the 11 universities was the Electric Power Research Institute (EPRI); starting in 1983, IBM became the leading sponsor.

The last column in Table 18 shows that the number of industrial sponsors funding over $1 million in 1980 dollars slowly increased from two in 1980 to seven in 1989. Thus, it appears that another component of the increase in sponsored research over the last decade involves larger contract amounts by a very few firms.

As we have seen, the second column of Table 18 records 209 industrial sponsors at the 11 universities in 1980. It would be interesting to see whether these firms comprised the 530 sponsors in 1989. A comparison of the 209 sponsors in 1980 with the 530 sponsors in 1989 found the following:

Classification	Number
Firms sponsoring in 1980 but not 1989	137
Firms sponsoring in 1989 but not 1980	458
Firms sponsoring both 1980 and 1989	72

The figures above, while not able to account for parent companies shifting the "source" of sponsored research, are suggestive. Almost two-thirds (137 out of 209) of the firms sponsoring in 1980 did not do so in 1989, at least at the 11 universities in the sample. Further, 86% (458 of 530) of the sponsors in 1989 were not sponsors in 1980, suggesting that the "portfolio" of a university's research sponsors changed dramatically over time. In the last decade, for the

11 universities in the sample, the ratio of new sponsors to the ratio of "discontinued" research sponsors was greater than 3 to 1.

Given that the growth in university-industry research relationships has been fueled by additional sponsors, then it is natural to investigate the characteristics of these "new" sponsors. As a large body of literature (Saxenian 1989, Miller & Cote 1987, Brett, Gibson, & Smilor 1988, Allen & Levine 1986) has noted the importance of universities to new business ventures, we might expect many of the additional research sponsors to be newly-established ventures, particularly in fields of high technological opportunity.

We can obtain some idea of the extent of new business interaction with academic laboratories by examining the variable FOUND, date of company founding. For corporate sponsors at all 61 universities in the database, Table 19 shows that at least 391 business entities (approximately 15% of the "identified" firms) were formed or founded after 1980 (this excludes entities such as the deregulated telephone companies). Most of these new sponsors were R&D laboratories (36 firms) as well as medical instrument, biotechnology, and software firms (Table 18). In nominal terms, these new companies sponsored $64 million in research at universities in the data set. Thus, it appears that young firms have a significant presence on campus laboratories, and that these firms tend to be service-oriented or medical-related enterprises.

In summary, if sponsored research is any guide, university-industry research relationships have changed substantially over the last decade. Consistent with NSF aggregate data, the database confirms that industry funds increased relative to federal funds, both overall and in many technical fields. Researchers in the medical sciences enjoyed the greatest dollar gain in industry sponsored research support and government support. However, in other fields, federal research showed priorities different from industrial research support. In my sample, the bulk of the increased industrial sponsored research volume came from increases in the number of sponsors, not from greater average sponsorship amounts. Indeed, after accounting for inflation, average firm outlays for contract research remained flat over the decade. This lack of growth in average firm real funding at the sampled universities is all the more

Table 19: Sponsorship by New Business Entities

Top Twelve Industries of the 391 Research Sponsors at All Universities Founded After 1980:

SIC Code	Industry	Number	Total Nominal Funding
SIC 8731	R&D Service	36	$7.5 million
SIC 3841	Medical Instrum.	27	$3.2 million
SIC 2836	Biotechnology	26	$5.5 million
SIC 7372	Software	23	$4.7 million
SIC 8711	Engineering Serv.	20	$1.3 million
SIC 2834	Pharmaceutical	17	$2.9 million
SIC 3674	Semiconductor	12	$2.3 million
SIC 3826	Laboratory Instr.	10	$420,000
SIC 3571	Computers	9	$2.8 million
SIC 8999	Misc. Services	9	$440,000
SIC 2835	Biotechnology	8	$2.3 million
SIC 2879	Agric. Chemicals	7	$200,00

striking given evidence that the firms sponsoring research in 1980 tended not to be the ones doing so in 1989. Finally, it appears that newly-established firms are actively involved with university-industry interactions, particularly firms in service and medical-related areas.

II.3.4 FUNDING ACROSS DISTANCE

While universities are generally perceived as providing benefits to a region's economy, particularly in technology-based industries (Johnson 1984, Fusfeld & Haklisch 1984, Dorfman 1984, Saxenian 1989), the exact mechanisms of technology transfer between the academic and private sectors remain poorly understood. The implicit assumption underlying regional economic development efforts featuring universities is that research results accrue to local firms to a greater extent than to distant ones. Though researchers have found evidence of this localization of R&D spillovers, we lack an understanding of why it occurs.

As described in Chapter I, Jaffe (1989) found evidence at the state-level of geographically-mediated knowledge spillovers from university research. He hypothesized that industry-funding of academic laboratories comprises a mechanism for this knowledge transmission by promoting closer interaction between researchers in the two sectors. However, he found no support for the hypothesis in the data.

More recently, Jaffe, Trajtenberg, and Henderson (1992) use corporate and university patent data as a means to track the geographic spread of knowledge spillovers. Comparing the location of a patent's assignee with that of organizations subsequently citing that patent, they find evidence that R&D spillovers are subject to geographic localization. However, the mechanisms underlying the observed localization effect, as before, could not be examined with the patent data used.

The sponsored research data set may find evidence on the mode of transmission by examining the geographic relationship between a university and its corporate sponsors. Sponsored research features more interaction between industry R&D personnel and faculty professors than technology transfer mechanisms such as patents. If R&D spillovers are localized, perhaps through the face-to-face researcher communications, we would expect to see universities sponsored by local firms, all else equal. If, on the other hand, R&D spillovers are global and rapid in the manner implied by earlier economic analysis (Arrow 1962), then a university would conduct sponsored work for firms near and far, with no clear patterns.

The availability of company and university zip code information[16] allows a rough measure of their proximity. The (traditional) five-digit U.S. zip code system divides the successively smaller zones. The first digit indicates which area of the country an entity resides; the second digit indicates the region of interest within the area defined by the first digit. Similarly, each succeeding digit defines a smaller and smaller area of land within the boundaries prescribed by the previous digits. Thus, entities closer together will have more of their leftmost, initial digits matching[17], so that we can reasonably expect zip code 02139 to be very close 02138 (a four digit match), but fairly distant from 94139 (a zero digit match).

In Table 20, I present information on the extent of university interaction with local firms. I define companies and universities as "local" if they share the same first two digits of the zip code, indicating in general that they are in the same portion of a state. As previously noted, the database does not have location data for all sponsors. The table's top portion covers a university's sponsored research volume from local firms. From the summary statistics, the average funding from local firms is shown to be $370,000. Nevertheless, the much lower median ($130,000) suggests that many universities did not receive funding from identified local firms. Indeed, the table of the distribution of the local funding amounts reveals that 20% of the universities in my sample did not receive a single dollar of research funding identified as coming from local firms!

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16 University zip code data are not in the database.

17 This statement may not hold in localities located near discontinuities in the zip code mapping system.

Table 20: Sponsored Research Amount from Local Firms

Funding from Local Firms at the 63 Universities with Three Years Data

SUMMARY STATISTICS

Average Annual Amount from 1988-90

Mean	$370,000
Median	$130,000
Maximum	$3.3 million
Minimum	$0

DISTRIBUTION

Range	Number	Percent
$2 million+	1	1.6%
$1 million-$1.9 million	6	9.5%
$500,000-$999,999	8	12.7%
$1 - $499,999	35	55.6%
$0	13	20.6%

UNIVERSITIES WITH HIGHEST AVERAGE LOCAL RESEARCH VOLUME

University	Average Annual Local Amount (1988-90)
University of Michigan	$3.30 million
UCLA	$1.97 million
Stanford	$1.83 million
Northwestern	$1.40 million
Wayne State	$1.37 million
Georgia Tech	$1.13 million
University of Pennsylvania	$1.10 million
University of Florida	$0.97 million
Univ. of Cal. Berkeley	$0.97 million
Univ. of Pittsburgh	$0.83 million

At the other extreme, several universities received substantial funds from local firms. The universities receiving the most sponsored research support in 1988-90 from local companies are ranked in the bottom portion of Table 20. The University of Michigan had the highest average nominal sponsored research volume from local firms. However, Michigan could simply be receiving "local" research funding not because of any particular characteristics, but simply because it sits in a region where a large amount of R&D funding originates, even though this funding may be randomly distributed. This view may be supported by the extensive local funding received by Wayne State, also in Michigan, and by the appearance of several Pennsylvanian and Californian universities on the list. Nevertheless, the figures presented suggest that universities differ in the extent of their interactions with local firms. In Chapter IV, I use econometric analysis to examine more closely the determinants of these regional sponsored research differences.

Certain universities may receive large amounts of local research funding because they receive more funding in general, perhaps because they have more researchers. Thus, even if research sponsorship were randomly distributed, these institutions would receive more local dollars, because they receive more total dollars. This suggests that a relative measure of local research sponsorship can distinguish between true geographic effects and size effects. To normalize for size, I compute a university's local funding as a percentage of its total identified industry funding. These computations appear in Table 21. It is interesting to note that the average university received only 15% of its industrial funding from local firms. The distribution of relative influence from local firms is highly skewed, with 20.6% of universities receiving no local support and only 6.3% receiving more than half of their funding locally. This indicates that, to a large extent, universities depend upon distant firms to underwrite their laboratories.

The bottom portion of Table 21 exhibits the universities that differ from the norm; these are institutions with the highest local funding percentage. Most of the universities that appear on this ranking did not appear on the ranking in Table 20, which was based on absolute dollar amounts. This difference has

Table 21: Sponsored Research Percentage from Local Firms

Percentage of Funding from Local Firms
for 63 Universities with Three Years Data

SUMMARY STATISTICS

Percentage of Funding from 1988-90 from Local Firms

N=63 Universities

Mean	15%
Median	6.7%
Maximum	100%
Minimum	0%
Mean Weighted by Universities' Funding Levels	12%

DISTRIBUTION

Range	Number	Percent of Total
51-100%	4	6.3%
41-50%	2	3.2%
31-40%	2	3.2%
21-30%	8	12.7%
11-20%	10	15.9%
1-10%	24	38.1%
0%	13	20.6%

UNIVERSITIES WITH THE HIGHEST PERCENTAGE LOCAL SPONSORSHIP

University	Local %	Average Annual Local Amount
SUNY Oswego	100%	$10,000
SUNY Fredonia	100%	$4,000
Wayne State	95%	$1.4 million
SUNY Brockport	53%	$22,000
Louisiana St.	46%	$600,000
Univ. of Maine Orono	42%	$370,000
Northwestern	34%	$1.4 million
Rutgers	34%	$760,000
UCLA	28%	$2.0 million
UC Irvine	27%	$400,000

several interpretations, one of which is that university size promotes more global spillovers. Because the top universities in the percentage rankings tend to have smaller research volume, we can hypothesize that small universities are responsible for localized knowledge transmission, after controlling for size. Smaller universities are funded locally, while large ones are funded globally, leaving aside questions of how they became small or large to begin with.

In Table 22, I replicate the analysis of Table 21 using a more detailed unit of analysis, the university department (once again mapped into NSF technical fields). Local is once again defined to be a two-digit zip code area. University departments receive about the same average proportion of funding from local firms (14%) as universities as a whole do (15% from Table 21). However, almost half (49.6%) of the 230 departments in the sample receive no sponsored research from firms headquartered locally. A few departments (9.6% of the sample) conduct more than half of their sponsored research with local firms. A list of the ten departments with the greatest local percentage of contract research during 1988-90 appears at the bottom of Table 22.

Departments performing a high percentage of their industry sponsored research for local firms tend to have small industry-sponsored research volumes. The average local funding amount for these ten departments is only $94,000 annually. Conspicuous by their absence in the list above are heavily-funded departments such as electrical engineering, suggesting that firms interested in electrical engineering are located across the country and also sponsor investigators across the country. In contrast, firms interested in earth science seem to be located in southern California and New York, and sponsor locally.

A basic picture emerges from the discussion on differences in total and percentage local support of universities. Large universities conduct more contract research for local firms, but also tend to perform extensive sponsored research for non-local business. I conjecture that distant firms are more aware of research opportunities at the largest, most prestigious universities. In contrast, examining the relative importance of local funding compared to all industrial funding, suggests that most contract funds comes from distant firms,

Table 22: Departmental Sponsored Research Percentage from Local Firms

SUMMARY STATISTICS ON PERCENTAGE OF LOCAL FUNDING (1988-90)

N=230 University Departments

Mean	14%
Median	.0011%
Maximum	100%
Minimum	0%
Mean Weighted by University Department Funding Levels	12%

DISTRIBUTION

Range	Number	Percent of Total
51-100%	22	9.6%
41-50%	5	2.2%
31-40%	10	4.3%
21-30%	16	7.0%
11-20%	24	10.4%
1-10%	39	17.0%
0%	114	49.6%

DEPARTMENTS WITH HIGHEST PERCENTAGE LOCAL SPONSORSHIP

University	Department	Local %	Average Annual Local Amount
Louisiana St.	Biological Sci.	100%	$16,000
U. of Mass.	Medical Sci.	100%	$15,000
USC	Chemistry	100%	$6,000
UCLA	Earth Sci.	96%	$240,000
USC	Earth Sci.	94%	$130,000
U. of Pittsburgh	Chemical Eng.	91%	$200,000
SUNY at Buffalo	Earth Sci.	91%	$10,000
U. of Pittsburgh	Physics	90%	$220,000
Stanford U.	Medical Sci.	83%	$44,000
Louisiana St.	Mechan. Eng.	78%	$61,000

tending to produce global knowledge dissemination. However, universities with a smaller research volume tend to be more local in their research interactions in percentage terms, suggesting that knowledge spillovers from their laboratories are local. At the academic departmental level, most departments have, in percentage terms, rather limited interaction with local firms. Chapter IV explores these questions in more detail.

II.4 Summary

In this chapter, I have introduced a new, unique database on industry-sponsored research at 65 U.S. universities. The database covers the sponsored research activity of over 5600 business entities for up to 16 years (from 1975 to 1990). I have described the process of database construction, before using the data set to reveal salient characteristics about research relationships.

Universities vary considerably in their industrial interactions in terms of volume, number of sponsor firms, and, possibly, types of relationships. Some universities enjoy extensive support from a few firms, while others interact with numerous companies for much smaller average funding levels. Industry sponsorship also varies by academic field, with medical science and electrical engineering receiving the most industry funding. In addition, industrial sponsorship of faculty investigators displays areas of emphasis and growth different from federal government sponsorship. This difference indicates that the two types of funding have different motivations and dynamics.

The distribution of company sponsorship can be characterized as a few firms sponsoring large amounts of research, together with the vast majority of firms sponsoring very small levels. For universities in the database, over the three year period 1988-90, even though IBM funded an annual average of $15 million in academic work, over 85% of the other sponsors funded less than $100,000 each annually. Similarly, though a few firms sponsor research at up to 41 college campuses in the dataset, over 80% of them interact with only one.

One reason for the relatively limited research involvement is that the firms themselves are small. Almost one-third (32%) of the identified sponsor firms have fewer than 200 employees; they account for 10% of research funding. On the other hand, just seven giants (0.7% of firms) of over 200,000 employees apiece sponsor 18.6% of all academic research work in the sample. Firms in the drug, computer, and electronics industries contract for the greatest volume of research, but the most sponsors come from the drug, medical equipment, and service (architectural, engineering, and R&D) industries.

Funding of academic research has undergone notable changes over the last decade. For a small sample of universities, industry's support has more than doubled, even after adjusting for inflation; in comparison, overall federal government support has remained almost constant. Corporate interest in almost all fields of knowledge has increased, with particular gains apparent in medical science and electrical engineering in absolute terms, and atmospheric science and biological science in relative terms. This increase in industrial contract amount appears to have resulted more from more firms cooperating with faculty, rather than from increases in average contract amounts. Newly-established firms represented an important part of these additional research sponsors, particularly companies providing R&D services, medical instruments, and biotechnology products.

Cooperation between academic and industrial researchers through contract research may have important geographic effects. Universities differ dramatically in the amount of interaction with local firms, although this may primarily represent size and location effects at work. The universities and university departments receiving a considerable portion of their industry funding locally are generally smaller institutions. These very broad generalizations suggest that large universities attract sponsored research funds from local and distant firms, promoting the global diffusion of knowledge spillovers, while small institutions interact with regional firms, tending to mediate diffusion of spillovers.

In the remainder of the thesis, I analyze why firms sponsor nonproprietary research, and what role geographic proximity plays in this sponsorship.

	Appendix A: Industry Funding to Technical Field					
SIC	Atmos. Sci.	Astronomy	Aero./Astr Eng.	Agricult. Sci.	Biological Sci.	Chemical Eng.
2-9				163605		
12				21131		
13				48394		
14						
15						
16				150000		
20				505395	336082	
21						
22						35000
23						
24						
26			30040	92122	43594	2458
27						
28	57398	50000	33461	1556276	4006813	486913
29				5375	104640	95775
30						
32		5000		1300		
33			13313	5000		35000
34						
35		230548	30121			339845
36		36200			43785	286924
37	92000	399943	620776		10000	46325
38		917994	5000	150	288877	28246
39			130000	40550	101604	266104
40						
44						
46						
48		10000	311999			
49	173543			475554	835271	450939
50				304609		
51-53				77534	144775	
58,59				6100		
60-67					1000	15000
73		91070			130815	
79						
80						
81					165000	
87	352234	170491	54018	48802	1065950	1631479
89					14362	
Total	675175	1911246	1228728	3501897	7292568	3720008

SIC	Chemistry	Civil Eng.	Comp. Sci.	Earth Sci.	Electrical Eng.	Mathemat. Sci.
2-9						
12						
13	140157			145000	10000	
14		15000				
15		5000				
16		11489				
20	4114			17000		
21	6050					
22						
23						
24		90480		200	41000	
26						
27						
28	3370957	568376	10269	95811	160000	20000
29	394080	43455	65578	63000		
30		3800				
32	65000	27000		5250		
33		32095				
34		30700			67852	
35	426443	217982	1813986	55000	1702392	70514
36	41084	33814	285886	14200	6835148	39435
37	125956	620126	587572	79827	1040922	172888
38	692728	475979	337503	4917	1187418	
39	116965	16416	265000	170277	155000	15011
40		35437				
44						
46		7524				
48	15000	199337	1607694		3159263	
49	457379	376499	11228	906612	2211436	259737
50	25048					
51-53	12250			33300		
58,59						
60-67		19108				
73	17500	190189	748140		93913	23393
79		52817				
80						
81	35000					
87	312759	936156	221614	142881	1043783	5000
89	30938				225894	2858
Total	6289408	4008779	5954470	1733275	17934021	608836

SIC	Mechan. Eng.	Medical Sci.	Physics	Non-classified	Other Eng.	Other Envir. Sci.
2-9		44000			7567	
12						
13					10000	
14						
15						
16					1905	
20		582593			68445	
21						
22						
23	16000					
24						
26	40000	226580		7449	1850	
27				3274	40000	
28	362509	21473867	50000	439224	357109	
29	112270		27354		17499	156500
30	171328				500	
32		1275		1670	151714	
33	109554				821090	
34	539852	83574	14328		166893	
35	1606288	72919	401118	5243297	4187220	133100
36	750914	1778941	90982	228445	1232048	
37	1745731	99014	91585	302803	1415219	
38	203892	2042613	46017	1249943	456764	
39	149814	438196	23079	117745	850509	
40					96000	
44	5996					
46						
48	30000		25000		325068	
49	1087533	621087	183434	644311	1269639	44119
50	633	178000				
51-53		245870		200		
58,59		1000				
60-67		29140		21275		
73	235297	386610		87078	96500	
79						
80		446154				
81		645029				
87	174819	2408462	288615	1621621	1051535	15000
89	142844			4789	81118	
Total	7485274	31804924	1241512	9973124	12708192	348719

SIC	Other Life Sci.	Other Phys. Sci.	Other Sci.	Totals
2-9				215172
12				21131
13				353551
14			1500000	1515000
15				5000
16				163394
20	12692		46087	1572408
21			112000	118050
22				35000
23				16000
24				131680
26				444093
27				43274
28		49980	175257	33324220
29		3500	8242	1097268
30				175628
32			7	258216
33			9473	1025525
34	16500			919699
35			49632	16580405
36				11697806
37	147517	108171	20000	7726375
38	63532			8001573
39				2856270
40	42575			174012
44				5996
46				7524
48	30619			5713980
49	322234		66509	10397064
50			90	508380
51-53				513929
58,59				7100
60-67		17000		102523
73	25264			2125769
79				52817
80				446154
81				845029
87	169137			11714356
89	22886			525689
Total	852956	178651	1987297	121437060

Chapter III: Appropriating the Returns from Private Investment in Public Knowledge

III.1 Introduction
III.2 Sponsoring Non-proprietary Research
III.3 Characteristics Driving Sponsored Research
III.4 Appropriability of University Research in the Literature
III.5 Description of Variables
III.6 Econometric Analysis
III.7 Summary and Evaluation of Results

III.1 Introduction

University-industry research relationships represent a broad and growing form of research interaction. These research relationships raise two key questions. First, why does a firm finance research resulting in non-proprietary technical knowledge? Second, given that the firm can mitigate appropriability problems and thus fund public knowledge, why does it sponsor the research at universities? This chapter of the thesis investigates appropriability issues in university-industry research relationships using the new data set on sponsored research described in Chapter II.

Structure of Chapter

In this chapter, I examine empirically why profit-seeking firms may sponsor research at universities that results in knowledge with characteristics of a public good. Using the two questions posed above as a basic framework for discussion, in Sections III.2 and III.3, I outline a conceptual structure to analyze university-industry research relationships. Since the literature on these relationships is not well-developed, I use the conceptual structure to summarize how economic theory helps explain these research interactions and to develop eleven hypotheses on these interactions. In Section III.2, I describe economic explanations for how firms may overcome the appropriability problem and thus finance non-proprietary research. In Section III.3, I present a description of the distinguishing aspects of university research that may motivate university-industry research relationships, once appropriability concerns are mitigated. Finally, in Section III.4, I review the empirical literature on university-industry research relationships, and conclude that these hypotheses basically remain unexplored.

In Section III.5, I describe the construction of variables used for hypothesis testing, which is described in Section III.6 I find evidence that firms sponsor university research because they mitigate appropriability problems through advantages conferred by size, diversity, and technical absorptive capability. This technical capability interacts positively with firm size in determining academic research sponsorship, suggesting that university research complements internal R&D for large firms. I also find evidence that many small firms sponsor university research for different reasons. I conjecture that these small firms treat academic research more as a substitute for internal R&D, in part to access university expertise to share fixed research costs. In addition, firms in industries with greater technological opportunity sponsor more academic research. However, firms in industries with reduced government funding of relevant academic fields tend to fund more, suggesting that government and industrial academic funding are substitutes.

III.2 Sponsoring Non-proprietary Research

Using the theoretical literature as a guide, I discuss in this section why firms may choose to sponsor non-proprietary research despite appropriability concerns. By non-proprietary research, I refer to technical research efforts where the results will be disseminated freely and rapidly, thereby acquiring the nature of a public good. Economists have long examined the difficulty of appropriating new technical knowledge and the potential disincentives from spillovers to privately fund R&D (Arrow 1962, Levin & Reiss 1984, Spence 1984). In the case of non-proprietary research, particularly at universities, these questions become especially acute, as many of the traditional modes of securing private proprietary control over research results (particularly patents, copyrights, and secrecy) are not relevant for the sponsor.

In Chapter I, I examined broad explanations for sponsored research. In this section, I focus on economic appropriability issues and hypotheses relating to sponsored research. I suggest that a firm may overcome these problems because of advantages relative to rivals in converting the research results into economic benefit. These advantages result from market structure and firm characteristics, such as size, diversity, and technical expertise. In the following paragraphs, I describe each of these sources of appropriability advantage in turn, while also developing hypotheses linking these advantages to a firm's university research funding amount. By not positing explicitly the decision process underlying this funding, I do not probe the question of whether these hypotheses describe a firm's absolute amount of campus funding, or the amount relative to internal R&D expenditures. In keeping with literature practice and in consideration of data availability, I describe absolute funding amounts in the discussion that follows.

The underlying null hypothesis for the discussion that follows is that sponsorship of university research does not depend upon firm characteristics:

> Hypothesis 0: Sponsorship of university research is unrelated to firm characteristics.

Among the characteristics thought to affect appropriability of sponsoring research, I first discuss the effects of market structure and size.

Market Structure and Size

Ever since Schumpeter, economists have investigated the influence of size and market concentration upon the firm's ability to appropriate the returns of R&D. The literature has sometimes aggregated the "size advantages" due to market power, a measure of relative size, with those due to absolute size. Though the two sets of advantages are related, I will discuss them separately, first examining appropriability advantages conferred by size relative to the market. Other important factors in the Schumpeterian tradition thought to affect R&D investment, such as capital market advantages, are not discussed here. This paper focuses on appropriability advantages.

With barriers to entry, a pure monopoly solves the appropriability problem of university scientific endeavors because it has no rivals to free-ride on research results. Protected against disturbances caused by rival firms (Schumpeter 1962, p. 88-90, p. 103), the monopolist has a stable platform from which to exploit the fruits of its R&D investment, even if the results enter into the public domain. Its ability to exploit the returns to R&D are likely greater if the R&D is directed toward more-targeted investigations closer to commercialization. Truly basic research undertakings may produce results applicable in industries other than the monopolist's.

Firms in oligopolistic industries may enjoy similar advantages due to fewer rivals and fewer sources of market uncertainty compared to industries characterized by competition. In particular, since investments in basic research may require many years before any payback occurs, a firm is more likely to fund basic research if the firm expects still to exist when the scientific experiments bear fruit (Rosenberg 1990). Thus, compared to transient firms, firms with significant market presence may have a higher likelihood of appropriating the future benefits from current research investments. This idea leads to the first two hypotheses:

> Hypothesis 1: Firms in more concentrated industries sponsor more university research.

> Hypothesis 2: Firms with greater market share sponsor more university research.

After Schumpeter, economists have advanced reasons for firm size to be a determinant of innovative success. Two further dimensions of size, absolute size and diversity, are discussed in the following paragraphs.

The large firm may have greater opportunity to develop serendipitous discoveries through greater internal resources (Kamien & Schwartz 1982). In addition, in an age of increasing technical specialization, only a large firm will be able to field the requisite number of specialists for complex R&D endeavors (Galbraith 1967) and be able to exploit complementarities between R&D and other business functions. These functions, such as marketing and planning, may be better developed within larger firms. Finally, a large firm may be able to appropriate greater economic benefit from R&D by being able to spread fixed R&D costs over a greater number of units sold, thereby boosting returns to the R&D investment (Cohen & Levin 1989).

I thus propose that size confers appropriability advantages in exploiting the economic value from public knowledge via economies of scale and via complementarities with other functions:

> Hypothesis 3: Larger firms have a greater demand for university research.

To the extent that university research can be characterized as basic research, a firm may also have advantages in appropriating publicly disseminated university research results due to its product line diversity. Compared to applied research or development, research that is more basic tends to be directed toward discovering fundamental scientific truths, rather than the solution of a specified technical problem. It also tends to have a broader range of areas in which the findings may ultimately become applicable.

This greater variance of outcome areas means that more diversified firms have a greater likelihood of finding basic research results useful, in whatever areas they may appear (Nelson 1959). Given that markets for information are imperfect, firms can best appropriate the gains from technical knowledge through internal development. Thus, diversified firms will be able to benefit from a greater proportion of basic research outcomes than will narrow ones. If entering into new product lines is costly, firms that already possess expertise in a broad array of areas will be the ones most able to benefit from basic research. These benefits are based on product lines of the firm, rather than functions of the firm, such as those underlying Hypothesis 3. These considerations lead to Hypothesis 4:

Hypothesis 4: More diversified firms fund more university research.

Firm Expertise

In the following paragraphs, I describe the role of a firm's expertise as a driver of appropriability. This expertise include technical capability as well as marketing capability. Well-developed skills in these areas may allow the firm to capture the economic benefits of new knowledge more effectively than competitors can.

One key ability of the firm consists of its ability to identify, understand, and learn from external scientific and engineering developments, what Cohen and Levinthal (1989) call its absorptive capability. A firm acquires this capability through previous R&D investments, which represent payments toward the substantial long-run costs of learning. It thus sponsors R&D for two reasons: to obtain knowledge that can be turned into new products or processes, and to maintain its technical absorptive capacity.

This concept of absorptive capability as a prerequisite for learning can be extended to the case of private funding of public knowledge. If firms do not automatically understand all the implications of new external developments, then technical knowledge, even though it may be widely disseminated, is not a free good. Rather, this public knowledge is absorbed only by certain firms with the capability to understand, absorb, and utilize it. Thus, a firm may sponsor nonproprietary research because it can absorb the implications of results better than competitors can. This leads to Hypothesis 5:

Hypothesis 5: Firms with greater technical absorptive capability sponsor more academic research.

In addition to having greater scientific and technological expertise, a firm may possess assets complementary to the "core technological know-how in innovation" (Teece 1986) more developed than those of rivals. These assets include the functions needed to turn laboratory invention into market innovation, particularly those of production, distribution, marketing and support. Having greater complementary assets in the presence of market imperfections can enable a firm to mitigate appropriability concerns. The firm can bring potentially marketable fruits of university to market more efficiently and quickly than competitors can. If quality and market timing advantages are important in technology-based competition, then the firm with more developed complementary assets can expect to reap more of the economic potential of university work. Considerations about appropriability advantages due to complementary assets lead to the sixth hypothesis:

Hypothesis 6: Firms with greater complementary assets sponsor more university research.

Further, if first-mover advantages are important, then the special relationship between a research sponsor and academic investigators may influence the sponsor's ability to benefit from its financial outlay. Sponsors likely learn about discoveries earlier than do non-sponsors, perhaps through progress reports. Thus, appropriability problems may be overcome through first-mover advantages in obtaining research results.

Summary

This section has introduced the null hypothesis that firm sponsorship of academic work is essentially a random process. Economic theory suggests, however, that this funding may depend upon firm characteristics. The section has discussed how firms may mitigate the appropriability issues from funding public knowledge through market power, size, diversity, technical absorptive capability, and complementary assets. The underlying theory is that public knowledge, though widely disseminated, may not be freely and equally appropriable. Rather, market and firm characteristics mean that some firms may be able to more fully exploit the economic potential of new knowledge in the public domain than others.

The next sub-section presents explanations for firm investment in university basic research once certain firms have alleviated appropriability problems. I posit that university research has important differences from industrial R&D, differences which motivate firms to establish research connections with academia.

III.3 Characteristics Driving Sponsored Research at Universities

In this section, I investigate how corporate research interaction with academic campuses can be partly attributed to the special characteristics of the university system. For firms with mitigated appropriability concerns, differences between academic research and industrial R&D can motivate corporate interactions with campus investigators. The differences between the two sectors include the nature of research performed, the expertise of personnel, and the communication networks involved. In addition, advantages of cooperating with academic investigators also include reduced research costs, mitigated agency problems, and less product-market competition. In the following paragraphs, I describe these characteristics and develop five hypotheses about the determinants of private funding of university research.

Differences in Type of Research

Industry involvement in university research may occur because firms seek to benefit from scientific investigations that is more "basic." Basic research can be characterized as being innovative, fundamental to subsequent work, broad in its impact, and further from commercial application (Henderson, Jaffe, & Trajtenberg 1990a). If this work is likely to generate innovative discoveries with far-reaching consequences, then cutting-edge scientific developments are likely to occur where basic research is emphasized.

Academic laboratories provide a setting well-suited to the performance of basic work, as investigators enjoy relative freedom from corporate concerns about return on investment and about practicality of work. This freedom tends to encourage basic work that is fundamental, risky, and novel (Dasgupta & David 1990). Thus, the greater basicness of academic work (Henderson, Jaffe, and Trajtenberg 1990a) means a greater likelihood that the cutting edge of science will reside in academia.

Having the locus of technology residing at universities provides firms with incentives to finance research at academia. The firms keep abreast of new developments via a "window" on new technology, which serves either as insurance against the catastrophe of technological obsolescence or as an option on a technology with commercial potential. Given that the institution of academic science differs from that of industrial technology, that this difference may lead to breakthrough scientific advances in academia, that industrial firms seek to benefit from these advances, and that some firms have solved the spillover problem, the following hypothesis is suggested:

> Hypothesis 7: Firms in industries with rapidly changing underlying university science bases will fund more university work.

Whereas Hypothesis 7 is based on differences between academia and industry in *what* gets explored, university research may also be unique because of *who* performs the work. Considerations of the distinct skills of university professors provide a second rationale behind university-industry research interactions.

Differences in Expertise

Professors may have more theoretical expertise than do industry R&D personnel, resulting from their self-selection into an academic career, from education, and from experience. Greater expertise in general principles may better enable them to investigate the implications of a technical discovery. As a result, firms that have alleviated appropriability concerns may sponsor university research to obtain technical guidance from professors; areas of guidance include how to exploit technological opportunities and where to conduct further applied work (Rosenberg 1990). Furthermore, the firm may seek the judgment of an impartial university investigator in evaluating the potential of new discoveries.

Thus, in this story, advances in technical knowledge occur in industry. Firms seek theoretical expertise to understand and more fully develop the new knowledge. As a result, firms enter into university-industry research relationships to obtain the guidance of professors in exploiting the technology's potential. I thus obtain Hypothesis 8:

> Hypothesis 8: Firms in industries with greater technological opportunity have a greater demand for university research.

In addition, the differences between academic and corporate researcher skills can also be exploited by firms in other ways. Combining theoretically-trained university researchers with technologically experienced industry developers in a joint undertaking can enable a firm to enjoy research synergies, which may increase the probability of project success (Cusumano & Sinha 1990).

Differences in Communications Networks

A third aspect distinguishing university research is the academic community's scientific communications network. Scientific progress depends upon free and open communications to exchange ideas and evaluate findings on a worldwide basis. This communication network has no exact industry counterpart because of secrecy concerns. Nevertheless, firms seeking to learn from external developments may benefit from developments in the academic scientific community. If the majority of the learning about these developments takes place through face-to-face discussions rather than through publications, then firms may seek what Rosenberg (1990) calls a "ticket of admission to an information network."

A firm then sponsors university research as a ticket into the academic scientific research community. Extending the arguments of Nelson (1990), I conjecture that firms supporting campus research have access to the sponsored researcher as well as his colleagues. The firm learns about scientific endeavors around the world, benefits from conferences that the sponsored researcher attends, and may find it easier to establish relations with other researchers. These communications enhance the firm's likelihood of learning about scientific experiments of interest and of maintaining its own technical currency.

Firms whose technological base has a larger underlying scientific community may need the research community access more. These firms may find greater difficulty identifying and keeping informed about interesting work related to their industry in a larger field. On the other hand, access may be more vital in small emerging fields prone to rapid change. These considerations about the importance of communications in scientific advance lead to Hypothesis 9:

> Hypothesis 9: Firms sponsor more university research if their underlying technology involves access to a larger university research community.

Once a firm has a certain level of absorptive capability and access to the academic research community, it needs frequent interaction with that community to benefit. Geographic proximity between corporate and academic researchers may increase the frequency of that interaction. If learning from university research occurs mostly through face-to-face interactions, then spillovers from academic research, rather than being widely available to all firms, may be mediated by geography (Jaffe 1989, Jaffe, Trajtenberg, and Henderson 1992). Thus, firms located near universities may have may reduced spillover problems.

Accessing Labor Market for Scientists and Engineers

Extensive interactions with academic investigators through sponsored research may also enable a private corporation to appropriate embodied knowledge. Through sponsoring research, the firm may gain an advantage over rivals in eventually hiring trained graduating students by establishing a relationship and by obtaining knowledge of their abilities. In turn, those working on the sponsored project gain expertise in an area of industry interest, as well as an intimate knowledge about one particular firm. The firm then can appropriate the embodied knowledge resulting from the sponsored research project by hiring the graduating researchers. From these considerations, I propose Hypothesis 10:

> Hypothesis 10: A firm's demand for academic research is positively related to its expected future needs for technical personnel.

Alternative to Industry Cooperative Research

Firms may participate in university-industry research relationships for many of the same reasons that they participate in industry cooperative research endeavors (sometimes known as joint research ventures). The following paragraphs briefly discuss the similarities and differences between sponsoring research via an industry cooperative endeavor and via a university research contract.

University research sponsors from the private sector can enjoy greater R&D incentives through the ex-ante sharing of research costs (Grossman & Shapiro 1986, Katz 1986) with other university research sponsors. This cost-sharing takes the form of other sponsors partially funding the costs of new buildings and equipment. The firm then accesses that equipment through a university research contract, thereby saving expenditures associated with owning infrequently-used equipment.

Further, the sponsor firm may enjoy additional cost savings due to generally lower research labor costs in universities than in industry. Thus, having solved the appropriability problem, the firm may share research equipment expenditures and reduce factor costs by contracting some R&D to academia. From the previous discussion, it can be hypothesized that industry will be more likely to sponsor university research where the possibilities to share research costs are greater:

Hypothesis 11: -- Firms will fund more university research if they have greater potential for sharing research costs.

A further similarity between sponsored research at universities and at a cooperative research endeavor is the potential to coordinate industry efforts. The "winner-takes-all" nature and uncertainty inherent in firms' R&D efforts may induce socially excessive industry-wide R&D levels (Dasgupta & Stiglitz 1980). To reduce research duplication, firms in the industry may seek a credible mechanism to coordinate scientific undertakings of general interest. In theory, university research sponsorship on a broad industry level represents a mechanism to coordinate basic research efforts and to disseminate findings. If firms in an industry agree ex-ante on inputs and areas of focus, they can thereby internalize the spillover externality.

Product market and agency problems can reduce corporate incentives to participate in cooperative research endeavors; these problems which are alleviated with a university as a research "partner." A firm cooperating in the R&D market with other firms may face those same firms as rivals in the product market. Thus, universities represent an ideal research partner, for they are non-competitors in the product market (Katz 1986, Cusumano & Sinha 1990).

In addition, industry support of university laboratories may help resolve agency problems. The problem of encouraging agent effort in the face of imperfect observability (Tirole 1988) may become particularly severe in cooperative research agreements, providing a firm's researchers with the incentive to shirk and free-ride on the partner's efforts. These agency problems may make a university research "partner" attractive for a firm. Once they have financial resources for a project, university investigators have incentives to expend effort, provided by the winner-take-all nature of academic science races, the demands of the tenure system, and the need to establish reputation for future funding (Dasgupta & David 1991).

Intangible benefits

Finally, a firm funding university research obtains intangible benefits not possible through funding internal R&D efforts. These intangible benefits include enhanced public image from supporting higher education as well as higher managerial morale from assisting an alma mater. Further, the firm's researchers may enjoy intellectual stimulation, possible prestige, and job variety from interactions with academia. In these cases, university research sponsorship acquires characteristics similar to corporate philanthropy. However, the firm can secure philanthropic benefits more readily through other mechanisms, such as fellowships or cash gifts. Thus, as before, I claim that philanthropic motivations for sponsored research work are secondary.

Summary

In Section III.3, I proposed that firms with advantages in appropriating gains from public knowledge may fund university research because of differences between scientific undertakings in academia and industry. These differences include *what* gets explored, *who* does the exploring, and *how* findings are disseminated. Corporate funding of the research is then motivated by the desire to access discoveries at the forefront of knowledge, to utilize the theoretical expertise of professors to exploit technological opportunity, and to learn directly from the academic community. Further, firms may be able to share equipment costs, reduce agency problems, alleviate market competition concerns, and enjoy goodwill-related benefits through funding university research. In Section III.4, I review the empirical literature on these explanations.

III.4 Appropriability of University Research in the Literature

Having discussed the appropriability-related issues and hypotheses raised by university-industry research relationships in Sections III.2 and III.3, in this section I review what previous studies have contributed to our understanding. This review expands upon the literature review of Section I.4 by concentrating on quantitative studies dealing with appropriability issues. The first subsection summarizes what we know about overcoming appropriability problems from funding university research. The second subsection discusses the literature examining corporate motivations to establish university research relationships. The key finding of this literature review is that many issues raised by these relationships remain unexplored.

Overcoming Spillover Disincentives

Despite a large literature examining spillovers, appropriability, and R&D incentives (Spence 1984, Levin et al. 1987, Jaffe 1988) as well as basic research (Griliches 1986, Mansfield 1980), the determinants of firm investment in university basic research producing openly disseminated results have remained almost unexamined. Economists have found evidence that greater spillovers may actually encourage private R&D investment by creating a positive externality reducing one's R&D costs (Levin & Reiss 1984, Jaffe 1988). However, we know very little about whether results from studies focusing on internal firm R&D are also applicable to privately-funded university research, in which the traditional modes of R&D appropriation (such as secrecy) do not come into play. Nevertheless, economists examining university-industry interactions have found scattered evidence consistent with some of the hypotheses raised in Section III.

Economists have found evidence of tangible industry benefits from university research (Berman 1989, Jaffe 1989, Mansfield 1991). However, they have not examined the relation between the expectation of obtaining academic research benefits and the commitment of resources for academic scientific endeavors. We have some indications that size may confer appropriability advantages in university research relationships (Link & Rees 1991), but the role of market concentration, technological opportunity, firm diversity, and other economic factors remains unexplored.

As described in Chapter I, Link & Rees (1991) have found that large firms, as measured by employee count, were more likely to be involved in university-based contract research programs than in faculty consulting arrangements or support of graduate assistants. This positive relation between firm size and contract research involvement is consistent with size advantages in appropriating findings from campus laboratories, although the authors did not describe the relationship in such terms.

Arora and Gambardella (1990) sought to explain the number of collaborative linkages that a firm enters into with other firms and universities as a function of its ability to evaluate technical information and to utilize the information. For a sample of 26 large pharmaceutical and chemical firms active in biotechnology, their results indicated that the number of firm-firm agreements is negatively related to the ability to evaluate information, but positively related to the ability to use the information. However, in extending their analysis to firm linkages with universities, they obtained less conclusive results, finding only that large firms establish more academic linkages.

Economists have found evidence that firms may enjoy appropriability advantages resulting from geographic proximity to universities. Jaffe (1989) discovered a significant and strong effect of total university research upon corporate patenting at the state level, even after controlling for industry R&D. However, his analysis did not show that university-industry research relationships facilitated spillovers, as the proportion of university-funding from industry proved "completely insignificant" in explaining corporate patent count.

In summary, the question of how firms overcome spillover disincentives from university research has not been systematically explored in the literature.

<u>University Research's Distinct Features</u>

In contrast to the literature on appropriating university research results, the literature on the special nature of academic research as a motivation for industry funding is much better developed. While scholars of technological change have found interesting results through case studies (see Fusfeld and Haklisch [1984] for a good overview), we focus on the literature covering the more universal aspects of university-industry research relationships, a literature heavily dependent upon surveys.

In three surveys of technology-oriented companies (National Science Board 1982, Blanchard 1990, Link & Rees 1991), the two most commonly cited motivations for establishing university research relationships were access to faculty and students, and the desire to keep current of technical developments. In particular, the survey finding that access to personnel was related to future employment considerations (Blanchard 1990, Link & Rees 1991) suggests that firms solve the appropriability problem by indirect means. Firms may be more concerned with eventually appropriating the knowledge embodied in personnel than with that contained in publications. The surveys' finding of industry's desire to keep abreast of science & technology supports the view that academic laboratories are at the leading edge of scientific research in many fields, that university-industry research relations represent a technology-transfer mechanism between the sectors, and that this transfer requires active company involvement.

Economists have also found evidence that academic research plays an important role in industrial patenting (Jaffe 1989) and in the development of new products and processes (Mansfield 1991), but have not fully explored the role of industry-sponsorship of academic laboratories in this technology transfer process. Berman (1989) has found evidence through aggregate R&D expenditure data that this sponsorship may be driven by industry's desire to access that technical knowledge more rapidly. However, the interactions between industry and academia remain unexplored at the firm level.

Summary

In summary, the economics literature has examined several sets of issues relating to university research. However, it has not systematically investigated how firms may appropriate the gains from sponsoring university research or how differences in research locales may motivate industry funding. Even basic questions, such as what industries sponsor university research, remain unanswered.

Overall, compared to our knowledge about internally-performed industry R&D, our knowledge of industry research expenditures at universities remains in a nascent state. The next section features a description of the data set and methodology I will use to further our knowledge of university-industry research relationships in a systematic manner.

III.5 Description of Variables

In Sections III.2 and III.3, I describe eleven hypothesis relating the amount of a firm's sponsored research expenditures and factors relating to its ability to appropriate results. In this section, I introduce dependent and independent variables for hypothesis testing using the database described in Chapter II.

The dependent variable, UNIVRES, represents a firm's demand for university research, as measured by its expenditures for sponsored research at universities in our database. From economic theory, I developed eleven hypotheses about factors influencing this demand; these hypotheses are examined by constructing suggested variables and seeing how well they explain a firm's level of university research funding. In the following paragraphs, I describe and evaluate each of these measures.

Concentration and Market Share (Hypotheses 1 and 2) -- An industry's concentration (CONC) is measured by its four-firm concentration ratio based on 1987 information presented in "Ward's Business Directory." A firm's market share (MARKSH) is the ratio of its sales to 3 digit SIC industry total sales. These highly-related 3 digit SIC were combined: oil-related (SIC 131, 291, and 299) and chemicals (SIC 281 and 282). Conversely, the 3 digit 283 SIC group was disaggregated to the 4 digit level: the biotechnology-related (SIC 2835, 2836) and pharmaceuticals (SIC 2833, 2834). Further, since using country-wide data will understate market power in industries with regional monopoly characteristics, concentration and market share for electric and gas utilities were set to one.

These variables suffer from the shortcomings of using highly-aggregated measures of market power. In particular, their construction has involved assigning the entire sales of s firm into a single SIC area. The concentration and market share measures thus constructed will be upwardly biased for large, diversified firms. Another aggregation problem stems from using a very broad 3 digit SIC group measure as the relevant "market" for the firm, obscuring the presence of many submarkets in which the firm may have market power. This aggregation effect works in a downward direction, tending to understate concentration and market share. Overall, the use of CONC and MARKSH, being based on aggregated data on firms and markets, is problematic. Results involving these variables should be treated with caution.

Size (Hypothesis 3) -- A firm's size was measured by the number of its employees. The commonly-used annual sales figures may most closely capture supposed size advantages to conducting R&D due to the ability to spread fixed costs over greater quantities. However, firms with high costs will tend to have high sales, even though the value-added by the firm may be low. In examining size as the ability to bear the risk of uncertain research ventures or because of having the requisite number of technical experts, a better variable will thus be a firm's number of employees. As a result, though the database includes sales figures, the analysis uses the more reliable employee figures[1]. This measure of firm size is relatively reliable.

Diversity (Hypothesis 4) -- I measure diversity by the number of 4 digit SIC industries in which the firm operates, as listed in "The Corporate Technology Directory" (1989 and 1990) and "Standard & Poor's Index" for 1990. These SIC listings are quite subjective, determined by the publishers

[1] Preliminary regressions suggested that results are similar regardless of the choice of sales or employees to measure size.

of the reference books. They vary depending upon the reference employed, and different references have different maximum numbers of SIC listings provided. In my database, the firms in technology-related areas had their information taken from "The Corporate Technology Directory" which provides an exhaustive breakdown of a firm's products. However, those in more traditional industries were looked up in "Standard & Poor's Index", which tended to be more concise in SIC listings. Thus, my diversity measure may be positively correlated with technology-intensity of the firm.

This approach also assumes that the 4 digit SIC classifications have approximately the same meaning across industries. In reality, it is likely that technology-intensive industries have many more sub-areas per SIC classification than do other industries. As a result, a diversified electronics firm, for example, may have only one or two SIC codes. My approach also disregards the relative amount of firm sales in each of the areas.

Finally, use of this diversity measure together with the market share measure previously described may not be logically consistent in some cases. The market share measure assumes all the firm's sales fall within a 3 digit SIC class, while diversity allows the firm to be in many classes. In the absence of readily available data on sales by market for such a large collection of firms, I again note that the market share measure may be upwardly biased.

In summary, use of the diversity measure is fraught with perils, but provides a readily-available measure for a large number of firms.

Technical Absorptive Capability (Hypothesis 5) -- I proxy for a firm's technical absorptive capacity by its R&D stock, (R&D STOCK) which is based on current and depreciated past R&D outlays. Following Hall et al. (1988), I calculate R&D stock based on a depreciation rate of 15% and initial growth rate of 8%. This widely-used measure, available for publicly-listed firms, captures the notion that a firm's capabilities depend upon current and past R&D efforts, and that these capabilities become obsolete over time.

However, R&D STOCK assumes that R&D efforts add to the firm's knowledge stock in a homogenous way, ignoring differences in types of R&D, industry differences in technological opportunity, industry differences in knowledge obsolescence, and alternate ways of learning, such as licensing or joint ventures. Nevertheless, the measure is widely-accepted, readily available, and relatively reliable.

Complementary Assets (Hypothesis 6) -- The ideal measure of a firm's access to complementary assets would include its ability to develop, distribute, produce, market, and support products. However, data availability forces a proxy in the form of a firm's stock of selling expertise. This proxy assumes that a company gradually builds its excellence in marketing and support over time, and that this excellence gradually erodes due to market and technological changes. Assuming that a firm develops this expertise through current and past expenditures, I calculate the firm's selling expertise stock in a manner analogous to that used by Hall (1988) to calculate R&D stock. Initial growth was set at 19%, based on 1975-79 data, while depreciation was assumed to be 15% annually, following Hall's assumption. The caveats applicable to the R&D STOCK variable apply here. In addition, the link between selling expenses and the notion of complementary assets is much weaker. These expenses, though readily available for publicly-traded firms, may depend upon market characteristics of the industry, size of firm, and other factors. Conceptually, this measure is on less than solid foundations.

University Research Pace (Hypothesis 7) -- I have hypothesized that rapidly-growing university research areas attract industry interest and funding. Our measure of the pace of research area technological change in universities (PACE) is the growth in total university research funds by area. Based on NSF data on scientific areas (NSB 1987 table 4-19) mapped into industry groups, PACE expresses the ratio of university research funds in 1986 to funds in 1981. Using PACE presents endogeneity problems, as the direction of causation could well run from industry research spurring subsequent research. This causation could result if corporate managers can identify promising technological areas more rapidly than other research sponsors do. PACE suffers from potentially severe aggregation problems, and should thus be treated as a broad indicator. The mapping employed is presented below:

Univ. Research Area	Industry Group	SIC	PACE
Astronomy	Research	87	1.43
Chemistry	Chemicals, drugs	28, 873	1.62
Physics	Research	87	1.74
Earth science	Utilities	491	1.59
Mathematical sciences	Electronics-related	36, 37	1.41
Computer sciences	Computers, software	357, 372, 376, 737	2.37
Agricultural sciences	Foods	20	1.45
Biological sciences	Drugs	283, 873	1.55
Medical sciences	Drugs, med. equipment	283, 384	1.61
Aeronaut. & astron. eng.	Aerospace	372	1.90
Chemical eng.	Chemicals, drugs	28 except for 283 291, 87	1.51
Civil eng.	Engineer. & archit., util.	491, 871	1.58
Electrical eng.	Computers, aerospace, & commun., utilities	357, 366, 367, 37 38, 3948, 48, 49	2.06
Mechanical eng.	Machinery	35, 367, 37	1.50

Values for industries with more than one field applicable were calculated by averaging all relevant technical areas. Industries not listed above had PACE set to economy-wide average of 1.57.

<u>Need for University Expertise to Exploit Technological Opportunity</u> (Hypothesis 8) -- I use two groups of technological opportunity measures, one based on industry data and one based on firm data to see whether high technological opportunity drives corporate funding of campus research.

At the industry level, the pace of an industry's knowledge advance (TECHOPP) is measured by the ratio of the number of US patents related to that industry in 1986 over the total in 1975. From Department of Commerce and Patent Office data (NSB 1987, table 6-10), I calculate the change from 1975 to 1986 in patents applicable over several industry groups, shown in the following table.

Group	SIC	TECHOPP
Food and kindred products	20, 21	.58
Textile & apparel	22, 23	.82
Chemicals except drugs	28 except 283	.66
Drugs	283	1.17
Petroleum refining and extraction	13, 29	.98
Rubber products	30	.83
Stone, clay, & glass products	32	.80
Primary metals	33	.68
Fabricated metal products	34	.78
Machinery except computers	35 except 357	.70
Computers	357	1.21
Electrical equipment except commun.	36 except 366	.83
Communications	366	1.01
Transportation except aircraft	37 except 372	.63
Aircraft	372	.76
Professional & scientific instruments	38	.96
Telecommunications	48	1.01

Industries not listed above had TECHOPP set to the overall unweighted average of 0.82. Use of aggregate patent statistics in this manner assumes that differences over time in patent regulations or propensities to patent are not significant. The assignment of patents to SIC groups raises problems in choice of assignment as well as the potentially broad application of certain key patents. Further, mere patent counts do not accurately capture the vast heterogeneity in the quality of the inventions embodied in the patents. Overall, this measure of technical opportunity should be viewed with caution.

At the firm level, if technological opportunity means radical innovation more so than incremental changes, one would expect the field to be dominated by new entrants into the market, as established firms tend to adapt inadequately to technological developments. Thus, in industries of high technological opportunity, the firms should be very young. I will use a firm's age (AGE) to proxy for its technological opportunity (with a negative relation). This measure raises several concerns, stemming from determinants of a firm's age and from the capacity for established firms to move into areas of high potential. In particular, the firm's age may be correlated with its size and diversity , potentially causing specification problems. Also, firms in mature industries may enter into emerging industries as a diversification measure, casting doubt on the assumed negative relation between technological opportunity and firm age.

Research community access (Hypothesis 9) -- Our measure of the size of the scientific research community (RESCOM) is the number of scientists and engineers employed by educational institutions in 1986(NSB 1987, table 3-5). These figures and the mapping to industry groups are shown in the following table.

Area	SIC groups	RESCOM
Physical scientists	28, 873	68700
Mathematical scientists	36, 37	52800
Computer specialists	357, 372, 376, 737	32500
Environmental scientists	281	16500
Life scientists	283, 873	136600
Aero/astr eng	372	3600
Chemical eng	28 except 283, 291, 873	5400
Civil eng	491, 871	8800
Electrical/electronics eng	357, 36, 37, 38, 398, 48, 49	24600
Mechanical eng	35, 367, 37	17000

Industries not listed abcve had log (RESCOM) set to 0. Using this measure assumes that the relevant scientific community is housed in academia, more than in government research laboratories or other locales. The RESCOM variable also suffers from a high degree of aggregation in both the scientific areas and SIC groups involved. Further, the mapping from area to SIC code is imprecise.

Recruiting Needs (Hypothesis 10) -- I would like to measure each firm's hiring needs for technically-trained personnel, for which data are not available. Instead, I use two proxies. In the panel data analysis at the firm level, I use EMPGROW, the annual change in the log of total number of firm employees, both technical and non-technical. This measure theoretically captures the firm's recruiting needs, but retroactively. Though the total employee figure does not distinguish between technical and non-technical personnel, this shortcoming may be alleviated if the firm's technical and non-technical personnel levels are jointly determined.

To focus more on technically-trained personnel, in cross-sectional analysis, I use PERSGRO, the ratio of an industry's science and engineering employees in 1986 to that in 1976(NSB 1987 Table 3-5). PERSGRO assumes that all firms within an industry hire from the same technical area. While realizing the impact of turnover rates and future growth, I will assume that firms form expectations about future personnel needs based on past growth. The following table presents the correspondence between the NSF technical areas and SIC industry codes needed to construct PERSGR. Use of this variable together with a technological opportunity variable may raise issues of multi-collinearity. Once again, the mapping process suffers from extreme aggregation and the possibility of multiple mappings.

Area	Industry group	PERSGR
Physical scientists	28, 873	1.69
Mathematical scientists	36, 37	2.94
Computer specialists	357, 372, 376, 737	3.98
Environmental scientists	281	2.15
Life scientists	283, 873	1.60
Aero/astr eng	372	1.94
Chemical eng	28 except 283, 291, 873	1.647
Civil eng	491, 871	2.30
Electrical/electronics eng	357, 36, 37, 38, 398, 48, 49	2.09
Mechanical eng	35, 367, 37	1.73

Values for industries with more than one field applicable were calculated by averaging all relevant technical areas. Industries not listed above had PERSGRO set to economy-wide average of 1.97.

Cost-sharing potential (Hypothesis 11) -- I seek to measure the potential for a firm to share research costs (particularly for equipment) via university research. The variable EQSTOCK is the total purchase price of national academic research equipment stock for ten areas (NSB 1987 Table 4-29). These areas were mapped into SIC industry groups at the 2 or 3 digit level, as shown below. Measurement concerns arise because these data do not account for depreciation or other determinants of cost sharing potential, such as the "average" cost of a R&D project by area, equipment intensiveness of research projects by area, age of equipment stock, etc.

Technical area	Industry SIC	EQSTOCK
Chemical eng	28 except 283, 291, 873	27
Civil eng	491, 871	22
Electrical eng	357, 366, 367, 37, 38, 398, 48, 49	83
Mechanical eng	35, 37, 367	67
Agricultural sci	20	43
Biological sci	283, 873	471
Computer sci	357, 372, 376, 737, 873	60
Environmental sci	281	120
Chemistry	28, 873	255
Physics/astronomy	87	227

Values for industries with more than one field applicable were calculated by summing all relevant technical areas. For example, SIC 491 has EQSTOCK=22(from civil engineering)+83(from electrical engineering)=105. Industries not listed above had EQSTOCK set to 1. This measure is highly problematic due to differences in equipment vintages, quality, and importance. Also, it neglects the differential between industry and academic equipment. In addition, the caveats about aggregation in the mapping process also apply.

Industry Dummies

Industry dummy variables were constructed for 11 broad industry groups. The following chart maps a firm's SIC code to the industry group.

Chemical	SIC 281, 282
Drug	SIC 2833, 2834
Biotechnology	SIC 2835, 2836
Machinery	SIC 35 except 357
Computer	SIC 357
Electronics	SIC 36
Aerospace	SIC 372
Instruments	SIC 38
Utilities	SIC 491, 493
Telecommunications	SIC 481
R&D Laboratories	SIC 873

In summary, the explanatory variables were constructed from publicly available sources to measure determinants of firm university research funding relating to appropriability and university research characteristics. They are summarized in Table 1.

Table 1: Summary of Variables

Hypo.	Variable	Quantity Measured	How Measured
1	CONC	market concentration	4 firm concentration ratio
2	MARKSH	market share	3 digit SIC market share
3	EMP	firm size	employees
4	DIVERSITY	firm diversity	number of 4 digit SIC codes
5	RNDSTK	technical capability	stock of R&D expenditures
6	SELXSTK.	complementary assets	stock of selling expenditures
7	PACE	univ. science growth	change in univ. res. area expenditures
8	TECHOPP	industry technol. opportunity	change in industry patent counts
8	AGE	firm technol. opportunity	firm's age
9	RESCOM	size of acad. res. community	university scientists and engineers
10	PERSGRO	firm's recruitment needs	growth in industry technical personnel
11	EMPGROW	firm's recruitment needs	growth in firm personnel
11	EQSTOCK	cost-sharing potential	univ. research area equipment stock

Because the data set includes firms of all sizes and forms of ownership, information needed to construct all independent variables was not available for all firms. For example, R&D expenditures and selling expenses were not available for the approximately 2000 privately-held companies and company divisions. Further, information needed to construct some variables is not readily available over time. As a consequence, I limit the number of variables or the number of firms included in analyses on a case-by-case basis. In the following section, I describe the estimations in more detail.

III.6 Econometric Analysis

In Chapter II, I described the data set to be used in econometric hypothesis testing. In Sections III.2 and III.3, I developed eleven hypotheses on sponsored research. In Section III.5, I described construction of the variables. In particular, data availability concerns suggested the need for two sets of econometric analysis, one cross-sectional and the other longitudinal. This section describes these regression analyses, starting with the cross-sectional. Two sets of cross-sectional regressions are run, one with publicly-traded firms, the second including privately-held firms as well. In addition, a third set of regressions utilizes panel data analysis on the publicly-traded firms.

III.6.1 Cross-sectional Analysis with Public Firms

From the theory-based discussion in Sections III.2 and III.3, I believe that a firm's demand for university research depends upon its ability to appropriate non-proprietary research results and upon the nature of university research related to its industry. Thus, a firm's research sponsorship, measured in dollars, is expected to be a function of characteristics such as size, diversity, market structure, and technological opportunity. In addition, the firm's outlays for academic research depends upon its need to keep abreast of academic developments, to recruit technical personnel, to share fixed costs, and to access researchers.

I assume that the basic demand equation includes firm and industry-related variables, and can be expressed in the following manner as Equation (1):

$$(1)\,UNIVRES_i=\beta_1 MARKSH_i+\beta_2 CONC+\beta_3 EMP_i+\beta_4 DIVERSITY_i+\beta_5 RNDSTK_i+\beta_6 SELXTK_i$$
$$+\beta_7 PACE_j+\beta_8 TECHOPP_j+\beta_9 AGE_i+\beta_{10} PERSGRO_j+\beta_{11} EQSTOCK_j+\beta_{12} RESCOM+\beta_j+u_i$$

Variables are expressed in natural logarithmic form. Firm-specific variables are subscripted by i, while industry-level quantities are subscripted by j. The supply of university research is assumed to be perfectly elastic, which is consistent with the casual observation that academicians spend much effort seeking research funds. The dependent demand variable $UNIVRES_i$ is the log of the total research dollars that firm i funded at 61 universities from 1988 to 1990, expressed in current dollars. The regressors have been previously described. Industry-specific intercepts are represented by β_j, while the random error term u_i reflects unobserved factors affecting a firm's sponsorship of academic research. It is assumed to have mean zero and be independently and identically normally distributed. By saying a "firm", I refer to a publicly traded ultimate parent company, meaning that research sponsorship by company subsidiaries and divisions was mapped back to the parent firm. A three-year span of funding was chosen to smooth out transitory differences in university accounting practices. Data for several universities were excluded from the analysis because of unavailability of data extending back to 1988, resulting in a sample of 61. Approximately 290 parent companies headquartered outside the U.S., industry trade associations, and firms involved in significant reorganization were dropped from the analysis. In addition, a few firms recorded as funding a negative amount were dropped from the sample; these transactions likely reflected adjustments to previous funding amounts. Sample statistics for the variables (in non-log form) appear in Table 2.

TABLE 2: SAMPLE STATISTICS FOR REGRESSION DATA SET

SAMPLE STATISTICS FOR SET OF PUBLICLY-TRADED FIRMS

N=213

Variable	Mean	Std. Dev.	Max.	Min.
UNIVRES	$1.1 mill.	$3.5 mill.	$45.1 mill.	$500
MARKSH	0.16	0.29	1	0.0002
CONC	0.39	0.26	1	.033
EMP	39600	74000	813400	60
DIVERSITY	11.6	12.4	76	1
RNDSTK	$747 mill.	$2 bill.	$18 bill.	$1
SELXSTK	$4 bill.	$8 bill.	$92 bill.	$1
EQSTK	$142 mill.	$188 mill.	$953 mill.	$1 mill.
PACE	1.60	0.37	2.37	1
PERSGRO	2.07	0.38	3.98	1.65
RESCOM	52400	57000	210700	1
TECHOPP	0.84	0.16	1.21	0.58

The cross-sectional analysis includes only 213 firms out of the 5600 in the database because of various restrictions resulting from data availability. Within the 1988-90 timeframe of the analysis, only 3306 firms sponsored research from 1988-90; the remaining 2300 firms in the database were not recorded as funding academic work in those years. Of these 3306 firms, approximately two-thirds (2200) could not be identified in business directories (In Chapter II, I described the process of identification). Second, constructing measures based on R&D figures required that subsidiaries and divisions be mapped back to ultimate companies, reducing the sample by another 300 entities. And of these ultimate parent companies, many were not publicly traded, or were not covered in the available Compustat tapes. Though the sample of 213 firms represents approximately 7% of all firms funding in 1988-90, they account for over 30% of all funding in that time period and about 60% of all funding by identified firms.

Econometric estimation of the cross-sectional equation presents several issues, including omitted variables, endogeneity, heteroskedasticity, and multicollinearity. Each will be discussed in turn.

In Chapter I, I provided several explanations for sponsored research, including some not related to appropriability, such as philanthropy and taxes. Many of these other factors hypothesized to affect university-industry research support cannot be tested in the cross-sectional regression. In other cases data are not available or the factors are not readily quantifiable. If factors other than appropriability truly do affect sponsored research expenditure levels, then omitted variable issues arise. If the factors are correlated with the included variables, then ordinary least squares (OLS) estimates will then be biased, but no ready remedy exists.

A further potential violation of the classical econometric assumptions results from the endogenous nature of research with market and firm characteristics, as envisioned by Schumpeter. In the long term, university research expenditures may be endogenous with quantities such as concentration, profitability, and total R&D, causing OLS estimates to be asymptotically biased. Concerns of this sort may be alleviated by the timeframes used in the construction of independent variables. In particular, variables such as PACE and TECHOPP measure quantities of interest up through 1986, so that they do not overlap with the 1988-90 timeframe of the dependent variable.

Heteroskedasticity can arise in our cross-sectional data set, for large firms may have greater variation in university research than small ones. However, the White test could not reject the null hypothesis of homoskedasticity for the main estimations (the regression in the rightmost column of Table 3 and the quadratic specification inTable 7). Details of these tests are described together with the results description for the estimation. Because the White test is a very general one, I also account for the possibility of heteroskedasticity by presenting calculating the t-statistics using heteroskedasticity-consistent standard errors.

Finally, as pointed out in the descriptions of several variables, several independent variables employed may have approximately linear relationships. Any multicollinearity present generally results in large estimated variances in the collinear variables, causing some hypothesis testing based on OLS standard error estimates to suffer from lower power. From previous discussions, there is some reason to believe that multicollinearity may exist between certain pairs of variables, such as CONC and MARKSH, and PACE and TECHOPP. However, an examination of simple correlation coefficients found no indications of strong multicollinearity. The next sections present estimation results of Equation (1).

Cross-sectional Results

I estimated Equation (1) for a sample of 213 publicly-traded firms for which data was available to construct all 12 independent variables. Results of this cross-sectional estimation appear in Table 3. Coefficients significant at the 10%, 5% and 1% level are starred, double-starred and triple-starred respectively. T-statistics appear in parentheses.

In the first set of results, the coefficients for the variables EMP, DIVERSITY, RNDSTK, TECHOPP, PERSGRO, and EQSTOCK proved significant at the 10% level or better and had the predicted positive signs. These results are consistent with economic explanations of appropriability advantages conferred by size (EMP), as described in Hypothesis 3. Further, another dimension of firm size, its product line diversity (DIVERSITY), provides greater likelihood of utilizing the potentially wide-ranging results of basic research, in support of Hypothesis 4. It also appears that firms can appropriate non-proprietary technical knowledge through their own stock of knowledge acquired from past R&D efforts (RNDSTK).

The regression results also support theories of special university characteristics motivating university-industry research relationships, especially those due to the university's ability to help industry exploit technological opportunity (TECHOPP), to share research equipment costs (EQSTOCK), and to a small extent access technical personnel. In particular,

Table 3: Results of Cross-Sectional Analysis

Dependent Variable:
Log(firm's total university research dollars from 1988-90) with n=213

Variable	Eq. 1	Eq. 1	Eq. 1
Log MARKSH	0.024 (0.21)	0.11 (0.91)	0.024 (0.21)
LogCONC	-0.14 (-0.68)	-0.26 (-1.26)	-0.17 (-0.81)
LogEMP	0.49*** (3.67)	-1.35*** (-2.88)	-1.05** (-2.50)
$LogEMP^2$		0.098*** (3.78)	0.059** (2.06)
LogDIVERSITY	0.27* (1.82)	0.26* (1.75)	0.18 (1.35)
LogRNDSTK	0.074*** (3.23)	0.076*** (3.33)	-0.19* (-1.72)
LogSELXSTK	-0.046* (-1.69)	-0.046* (-1.69)	-0.074 (-0.57)
LogAGE	0.057 (0.25)	0.17 (0.79)	0.12 (0.58)
LogTECHOPP	2.02*** (3.43)	1.91*** (3.45)	2.02*** (3.26)
LogPACE	-2.47*** (-2.75)	-2.69*** (-3.04)	-2.75*** (-3.12)
LogPERSGRO	1.54* (1.72)	1.77** (2.15)	1.26 (1.54)

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Table 3: Results of Cross-Sectional Analysis
(continued from previous page)

Dependent Variable:
Log(firm's total university research dollars from 1988-90)
n=213

Variable	Eq. 1	Eq. 1	Eq. 1
LogEQSTOCK	0.38***	0.38***	0.37***
	(4.05)	(4.17)	(3.78)
LogRESCOM	0.042	0.039	0.038
	(0.84)	(0.79)	(0.71)
LogEMP * LogRNDSTK			0.028**
			(2.23)
LogEMP * LogSELXSTK			0.0040
			(0.27)
Constant	4.94***	12.91***	13.99***
	(3.02)	(5.40)	(7.21)
R^2	.479	.507	.532
R^2 (adjusted)	.448	.475	.496
SSR	455	481	505
SSE	494	468	444
F Value	15.35	15.74	14.91

T-statistics are in parentheses. Coefficients significant at 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

the high and significant coefficient for TECHOPP suggests that technology-driven motivations play a key role in university-industry research relations, in support of other findings in the literature.

No statistically significant explanatory effects were found for firm age (AGE) or for size of academic research community (RESCOM). The variable AGE shows a weak effect on academic research, likely because patenting level changes (measured by TECHOPP) likely prove a better measure of firm technological opportunity. In addition, the relation between firm age and technological opportunity weakens as established companies move into new lines of business. Finally, the statistical insignificance of RESCOM is not surprising given the theoretical ambivalence about its expected sign. The sheer size of the research community may not drive industry funding at universities as much as the quality of the research community.

In Table 3, the statistically significant negative coefficients of SELXSTK and PACE are unexpected given Hypotheses 6 and 7. The negative coefficient of SELXSTK results partly from the presence of utility firms which sponsor large amounts of university research, but conduct minimal marketing. As described in Section III.5, PACE proxies for the growth of university research areas affecting a firm's industry. The negative relation between total and industry university research funding within a discipline suggests that industrial and other sources of university research funds are substitutes, consistent with what the data overview in Chapter II has found[2].

The second set of results in Table 3 presents results from estimating Equation 1 with the addition of a quadratic term for employee size, to explore for any non-linearities in the size relation. Adding the quadratic term reverses the sign on the variable EMP to negative, but results in a positive sign for the square of the log of EMP. This finding suggests

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2 The negative sign of PACE is not due to the presence of TECHOPP, for PACE is still negative and statistically significant with TECHOPP excluded from the specification.

significant non-linearities in the relationship between firm size and university research sponsorship, with large firms funding more academic research. Using the coefficients presented, I estimate the elasticity of academic research sponsorship with respect to firm size ranging from 0 for small firms (fewer than 1000 employees) to over unity for large ones (over 200,000 employees). For the average-sized firm in the sample, the elasticity of university research with regard to firm size is 0.73.

Finally, the rightmost column in Table 3 presents results of a specification adding interaction terms between size and technical absorptive capacity, and between size and complementary marketing assets[3]. The interaction terms test whether technical capacity or marketing may enhance appropriability as firm size increases, because the R&D or marketing functions may be better developed in larger firms. In general, results are generally similar to those of the previous specification, except that here the size and technical capacity variables seem to act in a positive manner, indicating that large firms with technical capacity have appropriability advantages above and beyond those conferred by just size or technical capacity alone[4].

The negative coefficient of the EMP and the positive coefficient of the EMP^2 variable in the results suggested a U-shaped relation between firm size and research support, that somehow small and large firms sponsor more research in absolute terms. A literal attempt to verify this relationship would involve splitting the sample of 213 firms into two

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[3] The White heteroskedasticity test for the specification with interaction terms produced a test statistic of 101.6 with 91 degrees of freedom, which is not significant at the 10% level. Further, a F-test on the combined significance of the industry dummy variables produced a test statistic of 1.39, below the F(10,187) value of 1.90 at the 5% level. Hence, industry dummies are not included in further analyses.

[4] The results concerning firm size are not due to the presence of a few outliers. Eliminating the four companies with more than 200,000 employees from the analysis (including the most prolific sponsor of university research, IBM) did not change the results in any significant manner. It did however, reduce the adjusted R-squared from 0.448 to 0.420.

subgroups -- the large and the small. Afterwards, a regression (without the quadratic term) would be run, producing a negative size relation for the "small" firm subsample together with a positive size relation for the "large" firm subsample. I choose a cut-off point of 5000 employees, a small size that still provided reasonable sample sizes (other cut-off points yielded similar results). Results of this split sample analysis appear in Table 4. Heteroskedasiticity-robust standard error estimates appear in parentheses. Though the results of the split-sample analysis may appear to suggest that small and large firms sponsor university research for different reasons, a Chow test for parameter equality showed otherwise[5]. Nevertheless, the amount of research sponsorship by smaller firms is less readily explained by available data on firm characteristics.

The analyses just conducted focused on a data set of 213 publicly-traded firms, a small fraction of the 5000 firms in the database sponsoring academic work. Privately held entities, foreign corporations, and start-up ventures were excluded. In addition, sponsorship from corporate subsidiaries and divisions is treated as if it resulted from the overall parent company, thereby increasing the effective "size" of the sponsor. In particular, the criteria of being publicly traded (in order to obtain data on R&D and marketing expenditures for variable construction) excludes over 600 parent firms from the sample, out of a total of 814 identified. Table 5 shows the extent to which limiting the regression sample to publicly-traded firms understates the university research activity of small companies.

5 Regression results for the Chow test produced a test statistic of 1.03, far below the F(15,183) critical value at the 10% level needed to reject the null hypothesis of identical coefficients for large and small firms.

Table 4: Results of Split-sample Analysis

Dependent Variable: LogUNIVRES=
Log(firm's total university research dollars from 1988-90)

Variable	Eq. 1 split 51 parent cos. with EMP<5000	Eq. 1 split 162 parent cos. with EMP>=5000
Log MARKSH	-0.20	0.074
	(-1.08)	(0.45)
LogCONC	0.65	-0.24
	(0.94)	(-1.03)
LogEMP	-0.095	-0.35
	(-0.18)	(-0.73)
LogDIVERSITY	-0.038	0.29**
	(-0.13)	(2.14)
LogRNDSTK	-0.025	-0.12
	(-0.071)	(-0.37)
LogSELXSTK	-0.12	-0.36
	(-0.32)	(-1.18)
LogAGE	-0.073	0.085
	(-0.19)	(0.32)
LogTECHOPP	0.87	1.97***
	(0.41)	(3.60)
LogPACE	-0.88	-2.71***
	(-0.32)	(-2.89)
LogPERSGRO	2.05	1.35
	(0.73)	(1.47)
LogEQSTOCK	1.52**	0.37***
	(2.30)	(3.43)

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Table 4: Results of Split-sample Analysis
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Dependent Variable: LogUNIVRES=Log(firm's total university research dollars from 1988-90)

Variable	Eq. 1 split 51 parent cos. with EMP<5000	Eq. 1 split 162 parent cos. with EMP>=5000
LogRESCOM	-0.65	0.037
	(-1.62)	(0.66)
LogEMP * LogRNDSTK	0.0063	0.022
	(0.22)	(0.70)
LogEMP * LogSELXSTK	0.011	0.031
	(0.37)	(1.06)
Constant	10.47***	13.00**
	(2.88)	(2.55)
R^2	.175	.567
R^2 (adjusted)	-0.146	.526
F Value	0.55	13.74

T-statistics are in parentheses. Coefficients significant at 10%, 5%, and 1% levels are *, **, and ***, respectively.

Table 5: Extent of University Research by Small, Private Firms

Employees	set of 213 publicly traded cos.	set of 814 public and private cos.
1-49	0% of set	17.5%
50-99	0.5%	7.0%
100-199	1.4%	7.0%
200-299	0.5%	6.0%
300 +	97.6%	62.5%

Over a sixth (17.5%) of the identified firms sponsoring university research have fewer than 50 employees, while almost a quarter of them have fewer than 100. Practically none of these smaller firms show up in the set of 213 publicly traded companies. In addition, almost 40% of the 5600 business entities in the database have not been identified through checking in business directories. This suggests that over 2000 academic research sponsors may be too small to even be included in these directories. Restricting the sample to publicly-traded entities allows the benefit of testing all hypotheses, but entails the costs of doing so only for a relatively few larger firms.

III.6.2 Cross-sectional Analysis Including Privately-held Firms

In this section of the chapter, I examine some of the hypotheses developed in Section III.2, based on a larger number of firms in the database. In particular, I delete two variables available only for publicly-listed firms in order to enlarge the sample from 213 to 814 firms. These variables involve R&D expenses and selling expenditures. Their omission can lead estimated coefficients to be biased due to omitted variables. However, expanding the sample allows the inclusion of privately-held and publicly-traded ultimate parent companies in the regression analysis. Table 6 provides sample statistics for this larger data set. The 814 firms in this data set (a quarter of all firms funding in the time period) were responsible for approximately half of all funding. The average firm in this set has approximately half the market share and employee count as the average firm in the publicly-traded firm data set from Table 2.

Table 6: Sample Statistics

SAMPLE STATISTICS FOR SET OF PUBLIC AND PRIVATE FIRMS

N=814

Variable	Mean	Std Dev	Max	Min
UNIVRES	$463,000	$2,040,000	$45.1 mill.	$524
MARKSH	0.0692	0.206	1	$5.69*10^{-7}$
CONC	0.358	0.211	1	.0327
EMP	14000	44300	813400	2
DIVERSITY	5.53	8.48	76	1
EQSTK	$202 mill.	$262 mill.	$953 mill.	$1 mill.
PACE	1.64	0.40	2.37	1.00
PERSGRO	2.17	0.58	3.98	1.65
RESCOM	57500	67000	210700	1
TECHOPP	0.85	0.16	1.21	0.58

The basic equation to be estimated is thus the following one, similar to Equation (1):

$$(2)\mathrm{UNIVRES}_i= \beta_j+\beta_1\mathrm{MARKSH}_i+\beta_2\mathrm{CONC}+\beta_3\mathrm{EMP}_i+\beta_4\mathrm{DIVERSITY}_i+\beta_5\mathrm{PACE}+\beta_6\mathrm{TECHOPP}_j +\beta_7\log\mathrm{AGE}_i+\beta_8\log\mathrm{PERSGRO}_j+\beta_9\log\mathrm{EQSTOCK}_j+\beta_{10}\log\mathrm{RESCOM}_j+u_i$$

Once again, variables are expressed in natural logarithmic form. Table 7 displays the estimates of Equation (2) using data on 814 firms sponsoring research from 1988-90 at 61 universities in the database, as well as estimates with a quadratic terms and with a split-sample. Heteroskedasticity does not

Table 7: Results of Analysis on Larger Set of Firms

Dependent Variable: Log(UnivRes from 1988-90). N=814

Variable	Eq. 2	Eq. 2
Log MARKSH	0.11**	0.15***
	(2.14)	(3.02)
LogCONC	-0.13	-0.20
	(0.97)	(-1.61)
LogEMP	0.20***	-0.49***
	(3.74)	(-4.14)
LogDIVERSITY	0.38***	0.23***
	(5.03)	(2.89)
LogAGE	-0.071	-0.025
	(-0.831)	(0.29)
LogTECHOPP	1.58***	1.55***
	(4.00)	(4.11)
LogPACE	-1.32**	-1.42***
	(-2.46)	(-2.71)
LogPERSGRO	1.11***	1.18***
	(2.80)	(3.06)
LogEQSTOCK	0.27***	0.30***
	(4.85)	(5.57)
LogRESCOM	0.022	0.020
	(0.67)	(0.64)
$LogEMP^2$		0.050***
		(6.43)
Constant	8.61***	10.67***
	(14.39)	(16.03)
R^2	.291	.325
SSR	973.06	1088.67
SSE	2376.21	2260.61
F Value	32.88	35.11

T statistics are in parentheses. Significant coefficients are denoted by stars.

appear to present a problem in the two estimations presented in Table 7[6].

Despite the differences in average firm size in the relevant regression sets, a comparison of results in Table 3 with those of Table 7 reveals similarities. Once again, firm size alone has a statistically significant positive effect when specified in the basic specification (no quadratic term). However, adding a quadratic term reveals statistically significant non-linearity in the relationship. However, in the analyses with the quadratic term added, the elasticity of academic research with respect to size is almost 0 (at 0.002) for the average firm, compared with 0.71 for the (much larger) average firm in the smaller data set. A major change appears with the inclusion of small firms: the market share measure (MARKSH) becomes significant and positive, in agreement with theoretical predictions on appropriability. Size relative to market, rather than absolute size, also plays an important role in securing research results. However, use of the very broad 3 digit SIC industries here means that the relative size measures are well correlated with absolute size measures. Another change between the regressions of Table 3 with those of Table 7 involves the PERSGRO variable, which has acquired more explanatory power. For the larger sample of firms, the positive coefficient is consistent with the notion that firms in industries with greater technical personnel growth seek to access these personnel through academic research relationships.

Table 8 shows results of split-sample analysis using the 814 firms. The regression on small firms was estimated using the 560 firms with fewer than 5000 employees, while the regression on large firms featured the 254 firms with at least 5000 employees. The choice of 5000 employees as the cut-off point allowed for the sample to be divided into two roughly equal portions, and also was the same cut-off point used previously. Just as in the previous split-sample analysis (Table 4), regression analysis

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6 For the first specification, the White test statistic is 79.49 with 65 degrees of freedom, which is not significant at the 10% level. Similarly, for the specification with the quadratic term, the test statistic is 84.20 with 77 degrees of freedom, which is also not significant at the 10% level.

Table 8: Results of Split-Sample Analysis on Larger Set of Firms

Dependent Variable: Log(UnivRes from 1988-90)

Variable	Eq. 2 split 560 small cos.	Eq. 2 split 254 large cos.
Log MARKSH	0.102*	0.30***
	(1.71)	(3.22)
LogCONC	-0.13	-0.29*
	(-0.61)	(-1.71)
LogEMP	0.076	0.57***
	(1.15)	(4.75)
LogDIVERSITY	-0.062	0.47***
	(-0.57)	(4.26)
LogAGE	-0.090	0.14
	(-0.96)	(0.91)
LogTECHOPP	1.43***	2.05***
	(2.96)	(3.66)
LogPACE	-1.16*	-3.01***
	(1.81)	(-3.52)
LogPERSGRO	0.96**	2.07***
	(2.10)	(2.87)
LogEQSTOCK	0.29***	0.50***
	(4.23)	(6.08)
LogRESCOM	-0.036*	0.067
	(-0.89)	(1.64)
Constant	10.00***	3.44***
	(14.96)	(2.40)
R^2	.0918	.471
SSR	155.57	515.48
SSE	1540.68	579.36
F Value	5.54	21.62

T-statistics are in parentheses. Coefficients significant at 10%, 5%, and 1% levels are denoted by *, **, and ***, respectively.

can explain five times more of the variance in university research funding for large firms (R squared of .471) than for small ones (R squared of .0918), suggesting size differences in the motivations for these relationships. In this case, a Chow test rejected the hypothesis that the coefficients of estimation for small firms were equal to those for large firms, with the F(11, 790) test statistic of 7.12 exceeding the critical 5% significance value. Unlike Table 4, the regressions in Table 8 included many more small, privately-held firms, enabling differences due to size to become apparent.

In particular, in regression analyses including privately-held small firms, there appears a slight effect of small firms to sponsor academic research in areas where fewer academicians exist. This could be indicative that these firms fund university work to capitalize on developments in emerging fields. Several other variables become significant in the large firm sub-sample, but TECHOPP and EQSTOCK are the only ones significant in both the comprehensive sample of 814 firms and the restricted one of 213. No evidence of a U-shaped relationship between university research funding with firm size emerges from this analysis. The slope increase (coefficient of EMP) from a statistically insignificant 0.076 for small firms to 0.57 for large firms does suggest that the relationship can be characterized as generally positively-sloped and concave.

Having explored some key findings from cross-sectional analysis, I now turn to the panel data set. This permits checking the robustness of cross-sectional results and in determining the extent to which variation in university research sponsorship occurs between or within firms.

III.6.3 Analysis of Panel Data

The cross-sectional regression analysis previously presented has found evidence in support of some of the eleven hypotheses on university industry research relationships developed in Section III. In this part of the chapter, I use the panel data set described in Section III.1 to exploit the potential offered by the longitudinal nature of my data set, which tracks the university research funding of several hundred firms over the period 1975-

1990. The temporal element of panel data allows the tracking of effects *within* firms that change over time.

I assume that the determinants of a firm's expenditures for academic investigations in science and engineering can be expressed in the following manner:

$$(3) UNIVRES_{it}=\beta_i+\beta_1 EMP_{it}+\beta_2 EMP^2_{it}+\beta_3 RNDSTK_{it}+\beta_4 SELXSTK_{it}+ \beta_5 EMPGROW_{it}+\beta_6(EMP_{it}*RNDSTOCK_{it})+ \beta_7(EMP_{it}*SELXSTK_{it}) +\psi_t+u_{it}$$

Equation (3) differs from Equations (1) and (2) in that it only includes variables readily available over time. Variables are again expressed in natural logarithmic form. Subscripts for firm and time are denoted by i and t respectively. Firm effects are denoted by firm dummies β_i, while time effects are denoted by the year dummies ψ_t. Fixed firm effects assume that differences across firms can be captured via differences in the intercept term; these differences could stem from unobservable quantities that remain relatively constant over time, such as management philosophy or a proximity to institutions of higher education. Time effects affecting all firms could result from legislative or technological changes affecting the demand for R&D. As in the cross-sectional analysis, the EMP measures firm size. A measure of the stock of accumulated R&D capital, RNDSTK proxies for the firm's technological capacity. Similarly, SELXSTK, a measure of accumulated selling expense capital, approximates the firm's complementary assets in marketing and support. EMPGROW indicates the firm's recruitment needs based on changes in the log of its employee count. Quadratic and interaction effects involving the variables EMP, RNDSTK, and SELXSTK are also explored. I include the interaction terms to assess whether the marginal effect of technical ability (or complementary assets in marketing) on a firm's academic research demand increases with firm size. The error term u_{it} is assumed to have mean zero, though I do allow for contemporaneous correlation across firms, which may produce consistent but not efficient estimators. Variable construction details appeared in Section III.5. Sample statistics appear in Table 9.

Table 9: Sample Statistics for Panel Data Set

N=3440 (344 FIRMS FOR 10 YEARS)

Variable	Mean	Std. Dev.	Max.	Min.
UNIVRES	$127,506	$694,402	$21,103,557	$0
EMP	32,242	65,625	876,000	0
thousand				
RNDSTK	$419 mill.	$1.40 bill.	$22 bill.	$0 mill.
SELX STK	$2.50 bill.	$5.85 bill.	$113 bill.	$0 mill.
LogUNIVRES	4.27	5.55	16.86	0
LogEMP	8.54	3.23	13.68	0
LogRNDSTK	12.17	9.05	23.84	0
LogSELXSTK	16.35	8.47	25.45	0
$(LogEMP)^2$	83.38	38.52	187.23	0
LogEMP*LogRNDSTK	112.60	97.55	323.28	0
LogEMP*LogSELXSTK	146.69	99.64	327.24	0

Data Issues

Historical data needed to construct the explanatory variables were obtained from Compustat's primary, secondary, and tertiary files. Because Compustat provides data only at the parent company level for publicly-traded corporations, the dependent variable UNIVRES had to be constructed at the level of ultimate parent company. Thus, company divisions and subsidiaries were mapped back to their ultimate parents. Parent companies involved in significant merger or reorganization activity (a total of seven), based outside the U.S., and with a trivial total amount of university research recorded (not more than $1000) were dropped from the sample. In order to obtain a balanced panel set covering 1980-89 to run Seemingly Unrelated Regressions, I also excluded firms that went public after 1980 from the sample. To alleviate incidents involving the logarithm of zero, I treated the remaining firms with observations of 'zero' in Compustat as equalling one dollar ($1). The final sample consisted of 344 publicly-traded companies that funded university research at any of the 65 universities in our database at any time from 1980 to 1989. Thus, for my panel data analysis, I estimate the determinants of corporate university research funding according to Equation (2) for 344 firms on an annual basis from 1980-89. In the next portion of the paper, I describe the results of these regressions.

Results of Panel Data Analysis

Table 10 presents three estimates of Equation (2) employing differing estimation techniques and assumptions. An important aspect of the panel data, as will be shown later, is that over 90% of the variation in university research sponsorship occurs between, rather than within, firms. The first set of results involves an exploratory model without firm or time effects estimated via pooled OLS. The coefficients for the size measure EMP is significant but has a negative sign. However, as in the cross-sectional results, an examination of the positive coefficients for the quadratic term EMP^2 suggests that large firms have proportionately greater demand for university research. Of special interest again is the positive coefficient for the interaction term EMP*RNDSTK , which indicates that large firms fund more campus scientific endeavors as their technical ability increases.

In the next set of regressions run, I use the Seemingly Unrelated Regressions (SUR) model to estimate Equation (2) by setting up a system of ten equations, one cross-section for each year in the data set. Assuming correlated disturbances across time, the parameters (except for the constant) across the cross-sectional equations are constrained to be equal, thereby linking the equations. In such systems, using SUR can increase the efficiency of estimators to that extent that errors are correlated across equations.

Results of the SUR regression with one fixed effect (for time) appear in the middle column of results in Table 10. They are consistent with those of the OLS regression, with the coefficients for EMP, SELXSTK, EMP^2, and EMP*RNDSTK statistically significant and very close to those from OLS. In the 344 firms in the sample, academic research increases almost proportionally with firm size, with an elasticity of 0.996 for the average

Table 10: Results of Regressions on Panel Data

Dependent Variable: $LogUNIVRES_{it}$=
Log of firm i's university research dollars in year t

	Eq. 3 pooled OLS	Eq. 3 SUR	Eq. 3 SUR
Fixed Firm Effects	none	none	present
Fixed Time Effects	present	present	present
LogEMP	-1.05***	-1.02***	-0.60*
	(-12.58)	(-7.31)	(-1.85)
$(\text{Log EMP})^2$	0.11***	0.075***	0.028
	(14.35)	(4.49)	(0.95)
Log RNDSTK	-0.046	-0.043	-0.035
	(-1.63)	(-1.05)	(-0.62)
Log SELXSTK.	-0.097***	-0.093*	0.026
	(-3.26)	(-1.92)	(0.26)
Log EMP GROW	0.0065	0.045	0.081
	(0.068)	(0.62)	(0.93)
LogEMP * LogRNDSTK	0.026***	0.023***	0.011
	(8.36)	(5.13)	(1.41)
LogEMP * LogSELXSTK	0.0021	0.0029	0.012
	(0.62)	(0.52)	(0.94)
Constant	0.92*		
	(1.87)		
adjusted R^2	.374		
system-weighted R^2		.092	.0020
Sum of Squares Reg.	39938		
Sum of Squares Error	65973		
F-Stat	129.5		
System MSE		1.005	0.899
		(3423 df)	(3423 df)

T-statistics appear in parentheses. Coefficient estimates significant at the 10% level are starred. Those significant at the 5% level are double-starred. Those significant at the 1% level are triple-starred.

firm. This elasticity is unexpectedly much larger than that of academic research with respect to R&D stock, which equalled only 0.24 for the average firm. An examination of the regression residuals found a general increase in the residuals over time. This indication of omitted variables is only expected given the fact that the specification of Equation (3) did not include many variables included in Equation (1). The variables not included in Equation (3) were those for which I did not have temporal data, including market share (MARKSH), concentration (CONC), diversity (DIVERSITY), and those involving "technological" characteristics, such as technological opportunity (TECHOPP) and equipment stock (EQSTOCK). Because some of these variables were statistically significant in estimations of Equation (1), omitting them in Equation (3) would cause omitted variable biases.

Finally, in the rightmost column of Table 10, I display estimated coefficients of a SUR estimation of Equation (2) with fixed time and firm effects. The resulting within-estimators thus control for temporal shocks affecting university research demand as well as for unobservable firm attributes, such as proximity to universities, management philosophy, etc. Only the size variable proves statistically significant, and then only at the 10% level, once firm and time effects are controlled for. Purging firm and time-specific attributes from the data results in a low system-weighted R^2 of 0.0020, suggesting that most variation in university research sponsorship occurs between firms, but that these firm-specific factors have not been captured by available measures. Calculations involving coefficients from a further regression (not shown) using between-firm effects indicates that over 90% of variation in university research funding is between firms.

The results of OLS and SUR estimation with time effects only seem to indicate that RNDSTK has insignificant explanatory power (except in conjunction with firm size) and that SELXSTK is negatively correlated with academic research outlays. However, results involving RNDSTK and SLEXSTK are sensitive to assumptions made in their construction. For example, if selling expense stock were assumed to depreciate at 25% rather than 15%, in the specification without firm effects, the SELXSTK variable loses significance while the RNDSTK variable becomes significant and negative. Findings about firm size are robust to changes in these assumptions, however. With changes in either direction in depreciation rates for R&D knowledge, the SELXSTK variable tends to become more statistically significant. As a result, conclusions based on these measures should be interpreted with caution.

In summary, from the estimation of panel data, I obtain results consistent with findings from cross-sectional analysis. The results support appropriability advantages due to size, and due to synergies between size and technical ability. Consistent with cross-sectional findings, it appears that a positive, concave size relationship is at work, with the very small and very large firms funding more academic research. A positive interaction effect indicates that firms with not only size but also R&D capability possess even greater appropriability advantages. I find no evidence that complementary assets in marketing help the firm appropriate knowledge in the public domain. Finally, most variation in corporate funding of university research occurs between firms, rather than within a firm over time.

III.7 Summary and Evaluation of Results

This chapter has examined corporate funding of university research producing non-proprietary results. In Sections III.2 and III.3, I developed a two-part explanation of this phenomenon. First, firms participate in university-industry research relationships because of characteristics that enable them to appropriate publicly-disseminated research results to a greater extent than rivals can. In addition, once appropriability concerns are mitigated, firms sponsor technical endeavors at universities because they seek to access the unique characteristics of the academic research environment. These hypotheses were tested through cross-sectional and longitudinal regression analyses.

Within the limitations of the data, the results support three key hypotheses developed from economic theory about the demand determinants of university research. In general, a firm's university research funding is positively related to its size, consistent with appropriability advantages in securing research results through scale or complementarity effects. However, the size-related effects are not straightforward. There are indications of a positive, concave relationship between university research funding and firm size, suggesting that research sponsorship increases at a greater rate than firm size does, *ceteris paribus*. This parallels some findings in the literature for the size relationship with total R&D (Bound, Cummins, Griliches, Hall & Jaffe 1984). Indeed, almost a quarter of industrial sponsors have fewer than 100 employees.

Further analysis suggested that firms vary in their motivations to establish campus research connections depending on their size. Exploiting technological opportunity from their patents seems the domain of large firms in particular. I suggest that a few large firms sponsor extensive amounts of university research across many campuses as a complement to internal R&D to generate knowledge and maintain technical currency. They alleviate appropriability concerns through size, technical absorptive capability, and diversity.

However, alternate explanations for the findings about large firms need to be considered. Large firms may simply sponsor more research because they generally spend more on all activities, have greater margin of error for "speculative" expenditures, or have a greater need for public relations. In particular, the positive relationship between "R&D stock" and research sponsorship, which I have interpreted in terms of technical capability, may be due to diversifying project risk through running parallel efforts, enlarging R&D budgets for political purposes, etc.

The data are consistent with the hypothesis that small firms sponsor university work to share fixed research costs, although the data used are highly aggregated. These research benefits are highly appropriable by a small sponsor, as the benefits of shared equipment costs do not accrue to competitors reading journal articles or publications. However, to a large extent, the determinants of contract research outlays by small firms remain a puzzle, and merit further investigation in the future.

Viewing the diversity of a firm, I find that more diversified firms sponsor more academic research, consistent with hypotheses that they expect to be able to use directly more of the research results, in whatever area they may appear. However, an alternate explanation is that firm diversity is highly correlated with size or profitability. I also find that firms with greater technical absorptive ability sponsor more academic research, for they are better prepared to understand and utilize results that enter the public domain. From cross sectional analysis, it appears that this technical ability interacts with firm size in a positive manner in determining university research funding, suggesting that very large firms treat university research as a complement to internal R&D. However, results involving technical capability are fragile.

Finally, underlying technological considerations seem to affect a firm's demand for academic research. Firms in industries with high technological opportunity sponsor more academic research, even after controlling for firm-specific attributes. In addition, it appears that industrial and government funding are substitutes. Academic fields with greater growth in government research funds attract less industry attention, and vice versa. These two considerations suggest that university-industry research relationships are also driven by broad structural forces involving technology and not just firm-specific characteristics.

In conclusion, private sponsorship of university research represents a widespread and growing phenomenon. In this chapter, I have addressed the key economic issue posed by this research funding--why do firms do so if the results enter into the public domain? The evidence suggests that this knowledge is not a free good, but one which is appropriated unevenly. Using the best available data, I have found empirical support for some theories involving appropriability of R&D results within the context of academic research. I have also found a broader link between the industrial and academic sectors, a link based on technological factors.

Chapter IV: The Economic Geography of University-Industry Research Relationships

IV.1 Introduction
IV.2 Universities and Economic Growth
IV.3 Framework of Regional Research Effect
IV.4 Hypotheses
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IV.7 Construction of Variables
IV.8 Regional Effects in University Department Research
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IV.10 Conclusions

IV.1 Introduction

The contributions of university research to industrial innovation have been widely documented in the economics literature (National Science Board 1982, Jaffe 1989, Berman 1990, Mansfield 1991). It is also commonly-accepted wisdom that institutions of higher education contribute to this economic growth on a regional level (SRI 1986, Dorfman 1983, Malecki 1981, Saxenian 1989), with particularly noteworthy examples being the contribution of Stanford and MIT to California's Silicon Valley and Boston's Route 128, respectively. Yet this regional effect stands in contrast to the economics literature's emphasis on research and development (R&D) spillovers as being freely available to the entire economy. The contrast between theory and reality indicates that we know very little about the role that geography plays in the link between university research and industrial innovation. In particular, the role of geographic proximity between the academic and industrial sectors in technology transfer is poorly understood.

A study of the geography of university research and industrial innovation allows a greater understanding of several key economic and policy issues. First, it addresses issues in the economics of technological change and economic geography, particularly involving the university as an engine of regional economic growth. While economists have found evidence of the geographic mediation of university research outputs (Jaffe 1989, Henderson, Jaffe, and Trajtenberg 1990b), there has been little systematic study on how these research results become disseminated across distances, as well as how firms appropriate knowledge that has the nature of a public good. Second, an understanding of the characteristics of firms and universities behind local research interactions has important policy implications. A 1983 government survey found over 150 state and local initiatives in the United States designed to promote regional economic growth through high-technology, many assigning a key role to universities (OTA 1984). Based on hopes for new jobs in clean industries with high growth, these efforts are paralleled by those in several other countries (OECD 1984, Mackenzie & Jones 1985, McKinsey 1991). These initiatives may benefit from a better understanding of how firms interact with local universities.

This chapter thus addresses two related questions:

1. what determines the extent to which universities have research interactions with regional firms?
2. what types of firms sponsor university research at local institutions?

The chapter first lays out a framework for examining the economic impact of regional university research, a framework incorporating findings from the literature. It then uses cross-sectional data on industry-sponsored university research to examine hypotheses about the characteristics determining a university's impact on local firms, interpreting these determinants as keys to the success of an academic institution's contribution to local growth. University-industry research relationships, and in particular sponsored research, represent a means of "transporting" knowledge from university to industry laboratories through accelerating the dissemination of results, attuning faculty to industrial needs, and providing practical training for scientists and engineers. The presence of geographic correlations between universities and their private sector sponsors would suggest that the channels for benefitting from university research involve a direct, proactive involvement by the firm.

To address the second question, the chapter then uses cross-sectional data to test hypotheses concerning what types of firms sponsor academic research locally. The next section lays the foundation for answering the two key questions by examining the means by which universities and colleges serve the economy. This examination leads to a better understanding of how the benefits from academic institutions can accrue disproportionately to local firms.

IV.2 Universities and Economic Growth

This section summarizes some key modes by which universities contribute to industry and local economic growth, presenting a conceptual framework for the theory and literature on the topic. This framework is important in developing hypotheses and understanding the geographic effects of university research.

IV.2.1 HOW UNIVERSITIES IMPACT THE REGIONAL ECONOMY

In the story of academia and regional economic growth, the university serves as a fountain of new ideas that are transferred to local firms. These firms then innovate and prosper, eventually creating regional prosperity. The prototypical examples are Stanford University's relationship with firms in Silicon Valley and M.I.T.'s relationship with those along Route 128, in which the region's economic vitality in technology-intensive industries is attributed in large part to the local university. These celebrated examples have been amply chronicled (Rogers and Larsen 1984, Saxenian 1989, Dorfman 1984), so only the briefest sketch will be presented here.

In the lore, Stanford played a key role in transforming an unassuming agricultural region in California into a high technology technopolis. In the 1940s and 1950s, the confluence of government military funding and Stanford's aggressive efforts to recruit excellence made Stanford's electrical engineering department one of the country's best. To transfer the fruits of its academic laboratories, the university established the Stanford Industrial Park in 1951, the first of its kind. This park leased land to spin-off new ventures started by Stanford graduates, primarily in electronics. As the new ventures grew and prospered, they maintained close links with the university to the mutual benefit of both, as ideas and expertise were shared in a crucial personal network (Saxenian 1989). Eventually, the flourishing area attracted large, established firms. Before long, the area's agglomeration externalities spawned a concentrated region, a Silicon Valley, with unmatched vitality in electronics and semiconductors.

In contrast to the deliberate planning leading to Silicon Valley, the rise of the Boston-area's Route 128 region can be characterized as more spontaneous, with academic institutions playing a different role (Dorfman 1984). With long-established reputations, the area's leading educational institutions, M.I.T. and Harvard, generally played a more passive role in promoting regional economic growth. However, M.I.T. in particular received extensive government support during the 1940s and 1950s that led to many breakthrough developments. Some researchers established new ventures with their knowledge, supported by a local infrastructure that included a vital venture capital network. These entrepreneurs met their personnel needs from the local universities. The Route 128 area thus attracted few out-of-state technical personnel, but retained many graduates due to the proximity to leading academic institutions and cultural attractions. As the area's new firms exploited the market potential for new technologies in electronics and computers (particularly minicomputers), the area's ability to retain leading personnel and to encourage new start-ups grew.

In summary, examining the two oft-mentioned cases of Silicon Valley and Route 128 reveals different processes at work. In one, the university and the region rose to prominence together through deliberate efforts. In the other, established institutions served primarily as the training ground for entrepreneurs and their employees, who remained in an attractive, already industrialized area.

Common elements, however, underlie the success of the two high-technology areas. In both instances, university research (supported in large part by federal funds) enabled the birth and growth of new ventures poised to exploit technological breakthroughs. As the firms grew, a circular process began, in which regional economic advantages fed upon themselves to create additional ones. These agglomeration externalities meant that the universities and the small start-ups produced a skilled labor force. The area's skilled labor force made the region attractive for further growth. This further growth led to more support for academic laboratories, as well as more benefits for firms locating to the area.

As can be seen in this short summary, many related forces played important roles in the success of the two areas. In the following paragraphs, I disentangle the various manners by which the university can serve the industrial sector, both locally and globally.

<u>Knowledge Generation</u>

Academic laboratories play a key role in the discovery of new scientific and engineering knowledge, in expanding society's knowledge base. Rather than being specific market-ready innovations, these discoveries often become an economically useful input to more applied industry research efforts, opening further avenues for industrial R&D. Early economic analyses (Arrow 1962) viewed the R&D spillover process as rapid, costless, and global. An implication of this view is that firms should essentially be able to receive the results of academic research regardless of their distance from the university. There are two reasons why academic research may be perceived to have this global influence -- the university's research mission and the ease of results transmission.

As its most basic mission, the university serves to create, transmit, and preserve basic fundamental knowledge. This role is generally perceived to be a global one, for professors direct their efforts toward uncovering universal scientific truths, which then are broadcast through symposia, conferences, etc. Academic scientific and engineering undertakings tend to explore general matters not specific to any one place, but rather applicable as a general truth (Dasgupta & David 1991). As such, research findings can potentially be used across the globe. In order for this global usage to be possible, however, the university requires a means for its findings to be widely disseminated.

The scientific research community comprises just the mechanism to allow the broad diffusion of discoveries. It serves as a powerful and far-reaching network that provides individuals with incentives to disseminate their results quickly and broadly (Nelson 1990, Dasgupta & David 1991). Results of research undertakings enter into the global public domain through international seminars and international journals. In recent decades the global dissemination of knowledge has become more rapid, easier, and less costly. Advances in transportation and telecommunications have facilitated more frequent communication and interaction among faculty.

In summary, university research has a global influence because of two factors: the nature of problems explored and the mechanisms for results dissemination.

Provision of Expertise

The university also serves as a source of expertise, consisting of the knowledge embodied in its faculty, students, and researchers. While its knowledge can be and is distilled in publications, the university represents a wealth of experience and know-how that may best be tapped through personal interaction.

To apply this knowledge gleaned from cutting edge research to specific problems, universities provide technical expertise to industry, focusing on more specific technical matters. These interaction modes include faculty consulting, visiting or adjunct professorships, personnel exchanges, and industry-oriented seminars. In these interactions, firms establish relationships with university personnel to access knowledge not available internally or to obtain the impartial guidance of outside experts. Direct contact with personnel information sources has been shown to be an important element in the success of research projects (Allen, Tushman, Lee 1979). University researchers are rewarded with exposure to industrial knowledge and problems, which in turn may foster new lines of research. Academicians also stay close to industry needs.

Relationships featuring extensive interactions between industrial and academic researchers are commonly viewed as the most efficient means of university-industry technology transfer (NSB 1982, p. 18; Business-Higher Education Forum 1988). Nationwide surveys have found that these relationships are widespread: approximately 33-40% of faculty engage in some sort of paid consulting (Marrer and Patton 1976 as cited in Stankiewicz, p. 44, NSB 1982). Common wisdom holds that faculty consulting and similar modes of interaction are facilitated by proximity between firm and campus (OTA 1984). I conjecture that search costs and monitoring costs underlie many of the benefits to geographic proximity. Before interaction between the academic and industrial sector can occur, there has to be awareness of opportunities and benefits for doing so. Indeed, lack of awareness of opportunities is commonly cited as a barrier reducing interactions between the higher education and the commercial sectors (NSB 1982, MacKenzie & Jones 1985). Thus, firms incur search costs, which include those involved in identifying and evaluating opportunities for interaction. Such preliminary procedures likely require substantial contact between corporate and university personnel, involving the expenditure of time and funds. Further, once a relationship is established, the acquisition of benefits is not an automatic process. Research requires monitoring and feedback from the sponsor, which requires firm resources. Because direct personal interactions play an important role in both the searching and monitoring functions, universities generally emphasize the provision of expertise to those firms with low transportation and communication costs. These considerations of search and monitoring costs provide a theoretical basis for a greater provision of academic expertise to local firms.

Education and Training

The university also serves the private sector through a dual education and training role. First, it provides highly-trained graduates to meet the personnel needs of firms. Several corporate surveys and reports have emphasized the importance of a supply of technically-skilled personnel in the firm's siting decision (Conference Board 1986, Industrial Research Institute 1991), in the motivation to establish research linkages with academia (NSB 1982, Blanchard 1990, Link & Rees 1991), and in a region's technological vitality (an extensive literature summarized in Malecki 1981). Second, the higher education sector serves to update the skills base of a firm's existing employees through continuing education, executive education, and similar programs. The importance of these functions is larger the greater the pace of technological change in local industry, as technological change may create obsolescence of the skill base (Johnson 1984). Because most instruction still occurs in a face-to-face setting, the economic benefit to university education and training is mostly localized.

Technology Licensing and New Venture Formation

University laboratories have been responsible for numerous patents, which they then may license to firms. The licensing of these patents for industrial development and potential commercialization offers several possible benefits for both parties. For the university, licensing may bring royalty payments and researcher satisfaction in helping society. Licensing firms obtain a patented idea and the potential guidance of faculty in the commercialization process. Because patent licensing tends to be an activity initiated by universities as the universities seek out local potential licensors, the geographic impact of technology licensing is likely a local one.

Related to technology licensing, new business formation from academic laboratories represents yet another mode of technology transfer between campuses and firms. These spin-off firms may be located close to the campus spawning them. Colleges and universities have played a significant role in new venture formation, serving as sources of technology, ideas, and personnel for entrepreneurs. On occasion, faculty members are actively involved with a start-up venture (Brett, Gibson, & Smilor 1988). Other university roles include facilitating local entrepreneurs through technical evaluation or assistance. However, the evidence for these local benefits from new venture formation appears limited. Bania, Eberts, and Fogarty (1991) find some evidence that the amount of university research in a metropolitan area has a statistically significant positive effect on new business openings in the electrical and electronic equipment industries. For other industries, however, the effect was not significant. One study identified 623 firms spun-off from M.I.T. in Massachusetts alone (Preston, undated). In contrast, most other efforts involving universities as technology-transfer mechanisms have brought mixed results (Feller 1991, Miller and Cote 1987).

Infrastructure

In addition to spurring the creation of new ventures, an institute of higher education can induce firms to locate in a region by enhancing the attractiveness of the region's technological infrastructure (Krugman 1991, and OTA 1984). The literature notes that universities can somehow make a region more attractive in corporate location decisions. However, the literature does not distinguish the relative importance of various university attributes in firm decisions. There is common agreement, though, that firms see the university's provision of graduates, degree programs for employees, access to information, and cultural activities as desirable attributes affecting the facility location decision.

In particular, firms close to universities may benefit from access to academic facilities. These facilities may include the informational -- libraries, databases, and seminars -- as well as the research-oriented -- computers, laboratories, and equipment. The informational resources are likely very important. Academic library holdings of journals, technical reports, and on-line databases represent resources difficult to find internally in all but the largest firms. The institution of higher education thus serves as part of the information infrastructure, particularly when it serves as the focus of a small business incubator or research park (SRI 1986, Brett, Gibson, & Smilor 1988). Conversely, a company will often donate scientific equipment to local universities to foster community relations and to develop research efforts in areas of mutual interest.

In addition to the direct infrastructural benefits, the presence of a local university often signals the existence of indirect infrastructural benefits from the private and government sectors. The establishment of an institution or particular programs implies a regional commitment to spurring the success of local firms, a commitment which may manifest itself in other means such as tax concessions. Finally, the presence of a major university in a locale implies that a certain level of transportation, utility, and communication infrastructure is already in place.

Universities thus have the potential to provide the private sector with several benefits, including knowledge generation, expertise provision, education and training, technology licensing, and infrastructure enhancement. Realizing that potential, however, has proven elusive in many instances, as described in the paragraphs that follow.

IV.2.2 IN SEARCH OF REPRODUCIBILITY

As noted earlier, concerns about competitiveness have led to efforts to reproduce Silicon Valley. Viewing universities as an untapped store of knowledge able to boost local industry, policy-makers in almost every state have channeled funds and energy towards various university-industry initiatives.

However, these efforts to reproduce Silicon Valley have yielded mixed results. For every story of Stanford University bringing forth a Silicon Valley, there are dozens of disappointing efforts to boost regional economies (OTA 1984) or of successful R&D areas that exhibit characteristics very different from those of Silicon Valley (see Whittington's 1985 description of North Carolina's Research Triangle)[1]. As previously discussed, even in the celebrated cases of Route 128 and Silicon Valley, vastly different factors led to regional economic development, factors that make it unlikely that those two successes can be readily replicated. The special confluence of technological opportunity, regional characteristics, and other factors behind the two successes lead to the general consensus that duplication of Silicon Valley would be enormously difficult (OTA 1984, Miller and Cote 1987, Bania, Fogarty and Eberts 1991, Saxenian 1989, Dorfman 1984, Minshall 1983). Many of the disappointing efforts focused on universities as a growth engine, particularly as a means of technology transfer (Miller & Cote 1987, Feller 1990). The general difficulty of developing a formula for technology transfer from academia to industry has several causes.

First, the link between academic research and regional economic development is tenuous, making technology-transfer difficult. Not only do we lack a single theory on the growth of regions and solid quantitative evidence on the connection between high-technology development and regional characteristics, we know little on a systematic basis about how universities foster local economic progress. Though economists studying technological change have found survey evidence that university investigative efforts benefit firms (NSB 1982, Mansfield 1991), they have generally not examined the extent to which the benefit is local. This lack of more detailed examination likely stems from the nature of research outputs. Basic research results diffuse into several sectors of the economy, or even into several geographic regions. Even were these effects identifiable, they are not necessarily quantifiable (von Massow 1984) and are prone to the long lead times required to turn academic laboratory outputs into products or processes. Economists studying economic geography and regional economics have found several key factors for the

[1]In particular, though the Research Triangle has enjoyed success, it has not spawned new business ventures to anywhere near the extent that Silicon Valley and Route 128 have.

concentration of production factors in space. These include transport costs, proximity to inputs, and increasing returns (Krugman 1991), etc. Surprisingly, the literature on university-industry relations has not explicitly treated these considerations. Prior studies implicitly assume the existence of some company transport or communication costs in these relations, but do not probe the ways in which these costs operate.

Furthermore, the mechanisms underlying technology transfer from academia to industry (and also from industry to academia) remain poorly understood. Even if universities induce regional economic growth, we know little about how they do so. The literature on technological change has been nearly silent on the relative effectiveness and importance of various mechanisms that include research agreements, personnel transfer, patent licensing, faculty consulting, liaison programs, and many others. Researchers and managers have faced difficulty in assessing the contributions of university-industry research relationships to industry (Business Higher Education 1988, OECD 1984 p. 15, von Massow 1984), let alone ascertaining the determinants of success. In examining such questions, they have generally focused on particular examples or case studies (Dorfman 1983, Miller & Cote 1987, National Science Board 1982, Fusfeld and Haklisch 1984, Johnston and Edwards 1987), permitting little quantification or systematic analysis. In particular, we know little on a systematic basis about the characteristics of universities that spur local industry interaction. Although some observers have asserted that academic quality is vital for successful interaction with industry (OECD 1984), they have not provided supporting evidence. Indeed a counter-argument can be proposed that interactions with less prestigious institutions can provide the firm with greater faculty attention to its individual needs. The available evidence on regional effects has focused on one form of interaction, that involving knowledge embodied patents and patent citations. Using data on R&D expenditures and patents, Jaffe (1989) found evidence of the geographical mediation of academic research spillovers. Similarly, Henderson, Jaffe, and Trajtenberg (1990a and 1990b) discovered a strong pattern of R&D spillovers mediated by distance using university and corporate patent citation data. Yet how the knowledge gets transferred is still poorly understood; we do not know if it is by informal communications, journals, liaison programs, or other means. Thus, policy makers and university officials likely lack a fact-based foundation for deciding the relative resources to channel towards academic excellence, teaching and training, industry liaison, faculty consulting, patent licensing, and/or establishing technology parks.

Even if certain mechanisms are thought to be important, the difficulties of effectively implementing them can be formidable. Differences in culture, leadership, expectations and communications make technology transfer between industry and academia difficult (SRI 1986, NSB 1982, OTA 1984, MacKenzie & Jones 1985, Fusfeld & Haklisch 1984, Geisler & Rubinstein 1989). In an early survey (NSB 1982), the most commonly cited barriers to university-industry research interactions were institutional differences based on culture. These cultural differences result in different objectives and goals between industry and academia, administrative structures, and time horizons. From the university's perspective, efforts to serve the local community are effective if the institutions have entrepreneurial leadership, strong ties to the private sector, and special resources(SRI 1986, NSB 1982). Ideally, a key individual with technical as well as managerial capability drives the establishment and monitoring of the interactions. The maintenance of a long-term outlook and commitment on both sides is also important.

In summary, universities provide knowledge-generation benefits to firms both local and distant. They provide expertise-related and infrastructural benefits primarily to local firms. In the next section, I develop a framework describing how the different benefits of university research accrue non-uniformly to industry, depending upon firm involvement with and proximity to academic campuses. This framework provides a basis for understanding how universities aid local firms in a different manner than they aid distant firms.

IV.3 Framework of Regional Research Effect

In this section, I present a conceptual framework embodying many aspects of the economic geography of university research discussed in Section IV.2. To my knowledge, this framework represents the first explicit discussion of how geographic proximity affects the industrial benefits from academia. It explains how a simplistic view that universities can automatically stimulate the local economy can be misleading, because many benefits from academic research accrue to distant firms as well.

The framework assumes a single research university and four types of firms, as shown along the top row of Figure 1. The firms are characterized along two dimensions, local and distant, as well as active and passive, giving a total of four possible firm types. The exact definition of "local" is left rather arbitrary; for our purposes, a firm is considered to be local to a university based on some overall measure of transportation ease, communication ease, and economic proximity. Firms are actively involved in the university's research if they sponsor academic work, keep abreast of the university researchers' discoveries, or interact with the institution on some regular basis.

The university produces both direct and indirect benefits for firms, as shown along the leftmost column in Figure 1. The marks in the interior portion of Figure 1 indicate which benefits or costs (the leftmost column) accrue to which type of firm (the top row). Beneath each heading of benefit or cost (leftmost column) is a brief description of the quantities affecting the benefits or costs. For example, I conjecture that personnel access benefits accrue to local active firms and distant active firms only, and that the benefits to personnel access result from university size.

Figure 1: University Benefits and Costs Accruing to Different Firms

Type of Benefit/Cost	Type of Firm: Local Active	Local Passive	Distant Active	Distant Passive
Technical Knowledge University Quality	X	X	X	X
Personnel Access University Size	X		X	
Infrastructure University Research Volume	X	X		
Contract Costs Firm Size & Age	X		X	

All four types of firms can benefit from technical knowledge discovered in campus laboratories. This technical understanding focuses on fundamental scientific and engineering processes of widespread interest, and is often rapidly disseminated though journal articles and international symposia. Because such knowledge enters into the public domain, all firms in the economy can benefit from this university output, regardless of their proximity to the university and their interaction with the university. The quality and quantity of this knowledge generation generally depends upon the university's quality.

Companies may also benefit from access to university personnel. I posit that firms need to interact with universities to enjoy this access, regardless of geographic proximity. Through this access, firms can more readily seek technical expertise for problem-solving and identify promising people to hire. These companies may thus value access to larger universities more than access to smaller ones, all else equal.

Further, many firms receive indirect infrastructural benefits from the university, even though they may not establish direct connections with the higher education sector. In my framework, infrastructural benefits accrue solely to local firms. These benefits include cultural and educational benefits that enhance a firm's ability to attract, retain, and retrain workers. They also include the university's contribution to the informational infrastructure. Some of the university's information resources, such as libraries, are difficult to duplicate in all but the largest corporations. In addition, other infrastructural benefits are indirect. The presence of a sizable academic research community implies a well-developed infrastructure supporting the researchers (suppliers of research material, trade associations, industry meetings, etc.), which can benefit even local firms that do not directly interact with the researchers. As a result, I posit that infrastructural benefits are affected by a university's total research volume.

I have highlighted three main areas in which industry may benefit from academia, and that these benefits can accrue in a non-uniform manner to firms in the economy. The determinants of benefits are whether the firm interacts directly with academia and where the firm is located relative to the campus.

However, firms seeking to benefit directly from academia through active interaction must weigh the benefits against two major costs associated with academic research involvement -- contract costs and spillovers. First, there are contract, transport and monitoring costs associated with sponsored research. As described in Chapter II, sponsored research can involve considerable interaction over a multi-year period between industry and university investigators. Firms seeking these interactions may incur search costs to identify and evaluate promising partners, contract costs to ensure that their needs are met, and transport costs to meet university officials and researchers. Once the agreement is reached, corporations expend resources to monitor project progress and learn about results. These costs are assumed to increase with distance and contract size, but decrease with the resources of the firm. The firm's monitoring capabilities are hypothesized to be positively correlated with firm size and age. Larger firms are assumed to have greater resources and slack to monitor extramural work. Older firms may have more accumulated experience dealing with academia in various manners, and so may have established long-standing relationships. These relationships in turn can reduce the search and monitoring costs associated with sponsored research.

As previously noted, research projects sponsored by one firm can produce benefit for its competitors via knowledge spillovers. I assume that spillovers occur through sponsored researchers communicating with other investigators or working on projects for other firms. As a result, leakage increases with the number of researchers, and the total volume of industry-sponsored research in the department.

In the framework just described, the university's benefits to the regional economy depend upon the university's characteristics, while the costs depend upon the firm's characteristics[2]. The gross benefit for a firm sponsoring research at the university in the amount is thus the sum of knowledge benefits, personnel expertise benefits, and infrastructural benefits. The costs to the firm are contract costs. Firms thus benefit from the higher education sector in different ways depending upon their relationship with that sector. Conversely, universities contribute to the region differently depending upon their characteristics. The heterogeneity of this simple model thus allows for policy mixes tailored to specific needs.

Having developed a simple model of the regional benefits from an institution of higher education, I develop testable hypotheses in Section IV.4.

IV.4 Hypotheses

This section proposes hypotheses on the economic geography of sponsored research based on the framework of the previous section. The framework noted how both university and company characteristics can be important in the dissemination of academia's benefits to industry. Thus, some hypotheses concern the characteristics of universities, while others focus on those of firms. The hypotheses fall into three major sets. The first set (Hypotheses 1 through 3) treats the overall level of industry sponsorship, while the second set (Hypotheses 4 through 7) treats the level of sponsorship from local firms. The third set (Hypotheses 8 and 9) is concerned with a company's research sponsorship at local universities. In every case, the null hypothesis underlying this section is the following:

Hypothesis 0: The amount of industry-sponsored research at a department is unrelated to the department's characteristics. Furthermore, the proximity between a firm and the university at which it sponsors research is unrelated to the characteristics of the two parties.

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[2] I assume that costs charged by the universities (such as library usage fees) are minimal.

If the null hypothesis held, we would expect essentially random funding patterns. Excellent academic departments may or may not receive extensive industrial support. Firms sponsor research locally as well as globally, while academic departments perform research for firms far and near. This implies that localized university research spillovers are likely not due to any localized sponsored research effects, and that regional development efforts emphasizing universities may be fruitless.

However, if university-industry research relationships represent more than random, philanthropic-type activities, then the characteristics of the parties involved can be expected to affect the nature of the relationship. Common wisdom holds that, of these characteristics, one of the more important is academic quality. This view can be expressed as Hypothesis 1:

Hypothesis 1: A university department's industrial research funding is positively related to its quality.

In terms of the framework of Section IV.3, quality universities generate more valuable technical knowledge in their laboratories. Hence, firms can enjoy more substantial research results from sponsoring research by doing so at the top institutions.

Given a university department of predetermined quality, firms may receive greater benefit if the department is larger. Larger departments will tend to have more faculty available to interact with industry and offer more potential projects for the firm to sponsor. This benefit to quantity is expressed in Hypothesis 2.

Hypothesis 2: Industry sponsored research funding is positively related to a department's size.

Firms close to the university benefit from greater access to faculty and students, particularly if they sponsor research. However, the professors and students trained by the firm's research sponsorship may also provide benefits to competitors, through publishing papers, consulting for other firms, or becoming employed with them.

Questions of causality aside, having more faculty members means more capability to conduct work of industrial interest and to have more expertise to potentially access, hence inducing a greater amount of sponsored research. In addition, if firms rely upon universities to provide a trained supply of labor, then a larger student body means more potential employees, and hence more benefits to local industry from the university.

Hypothesis 3: Industry sponsored research funding is positively related to a department's spillover pool.

The effect of spillovers on research funding may be either positive or negative, a form of the classical question regarding spillover efficiency versus disincentive. Firms may sponsor contract research to increase efficiency of R&D efforts via accessing a pool of R&D spillovers and sharing costs. An increase in university research increases the efficiency of investigative efforts, but also augments the benefits accruing to competitors. If R&D spillovers enhance the productivity of own efforts, then one would expect firms to sponsor scientific investigations where extensive amounts of other research occurs (effect positive). I test whether the effect is positive.

The next set of hypotheses involves the role of geographic proximity between sponsor companies and universities. The null case is that distance is irrelevant. As described in the second part of Hypothesis 0, the null hypothesis is that proximity does not play a role in firm sponsorship of university research. In that case, the data would tend to show random geographic funding patterns, with firms equally likely to sponsor at universities next door as at those across the country. Global R&D spillovers in the manner traditionally conceived by economists would mean that the rapid and broad dissemination of research results make it irrelevant where the firm sponsors the work.

If cutting edge developments are more likely to occur at leading institutions (ignoring the question of how they became classified as "leading" in the first place), then we would expect these renowned universities to attract sponsors from both local and distant locales. This leads to Hypothesis 4.

Hypothesis 4: Top university departments receive more sponsored research funds from distant firms than do less-prestigious university departments.

As captured in the conceptual framework presented in the previous section, some university outputs are moderated by distance, particularly those related to personnel access and infrastructure. Thus, I conjecture that research sponsorship from local firms has additional determinants related to personnel access and infrastructure.

The next two hypotheses are similar to Hypotheses 2 and 3, only interpreting the "region" in a more narrow sense than before, namely as an area geographically close.

Hypothesis 5: A university department's local research funding is proportional to its size.

Hypothesis 6: University departments with a larger pool of research spillovers have more sponsored research support from local firms than do departments with a smaller spillover pool.

The next set of hypotheses deal with characteristics of the firm. I hypothesize that the extent of a firm's distant research sponsorship depends on its ability to identify and exploit knowledge from universities (Arora and Gambardella 1991). If more developed capabilities are needed to sponsor at distant locales, then it follows that firms with less-developed capabilities will sponsor locally. Firms lacking well-developed capabilities to identify, monitor, and benefit from academic research interactions may be expected to sponsor that work locally (where the strain on resources is less), if at all. Casual observation suggests that small and newly-established firms are those with lesser capabilities in this regard compared to larger firms. In addition, new business ventures may locate near universities to access research parks, industrial incubators, or related arrangements centered around a university. These considerations suggest the next two hypotheses.

Hypothesis 7: Smaller firms sponsor more local academic research.

Hypothesis 8: Younger firms sponsor more local academic research.

Having developed hypotheses, in the next section I describe what we know so far about these hypotheses based on available data. In Section II.1 I showed the literature's relative paucity of information on these hypotheses.

IV.5 Overview Using Aggregate NSF Data

This section reviews what aggregate data collected by the National Science Foundation (NSF) indicate about the geography of university and industrial R&D. The NSF data tells us that U.S. university research, and particularly industrially-sponsored university research, is a concentrated phenomenon. In particular, research performance is concentrated in a few states at a few universities.

The National Science Foundation (NSF) records 556 U.S. institutions of higher education that grant a science or engineering degree and/or perform at least $50,000 in separately budgeted R&D expenditures. These 556 institutions received $1.1 billion of industrial research funding in 1990. However, the distribution of funds received is highly concentrated. The top 40 institutions (9% of total) received over half of all industry funding, as shown in Table 1.

Table 1: Concentration of Industry Research Funding

Quantity	Cumulative $	Cumul. %
At top 10 instit. receiving funds	$256 million	23%
At top 20	$402 million	35%
At top 30	$514 million	45%
At top 40	$599 million	53%
At all 556 institutions	$1.1 billion	100%

This concentration suggests that a few key institutions may be responsible for much of the technology transfer to industry. Unfortunately, as noted in Chapter II, NSF data provide no disaggregation on the academic departments receiving the funding or the industries of the corporations involved. In addition, much industry research sponsorship is geographically concentrated. The following table, Table 2, presents the states with the greatest amount of industry-sponsored university research, based on totals for the 100 universities receiving the most industry funding.

Table 2: Geographic Concentration of 100 Top Universities

Total at 100 univs. receiving most industry funding=$916 million
Total at all univs. = $1.1 billion

State	No. of Univs.	Total Industry $	Cumul. Amount	Cumul. Percent
Pennsylvania	7	$94 mill.	$94 mill.	9.3%
Massachusetts	6	$82 mill.	$176 mill.	15.9%
California	7	$76 mill.	$252 mill.	22.8%
Texas	7	$62 mill.	$314 mill.	28.5%
New York	8	$58 mill.	$372 mill.	33.7%
Maryland	3	$42 mill.	$416 mill.	37.7%
Michigan	4	$42 mill.	$458 mill.	41.7%
North Carolina	3	$39 mill.	$497 mill.	45.1%
Georgia	3	$34 mill.	$531 mill.	48.1%
Ohio	5	$33 mill.	$564 mill.	51.1%
Other States	44	$421 mill.	$965 mill.	100%

Over half of industry support of academic research goes to institutions in ten states, primarily located around the nation's periphery. If corporate funding of this research facilitates technology transfer, then in absolute terms, the universities of a few key states play a large role in industrial innovation. These states tend to be those which perform the most total corporate R&D as well. Table 3 ranks the states in terms of their total industry R&D. Comparing the locale of corporate R&D with industry-sponsored university research suggests an aggregate state-level relationship between total industry activity and industry relationships with academia. In particular, California, New York, Texas, Massachusetts, and Pennsylvania occupy prominent positions in both lists.

Table 3: States Performing the Most Industrial R&D

State	Total Industrial R&D $
California	$17,760 million
New York	$7,019 million
Michigan	$5,975 million
New Jersey	$5,547 million
Maryland	$4,951 million
Massachusetts	$4,173 million
Pennsylvania	$3,570 million
Texas	$3,492 million
Illinois	$3,231 million
Ohio	$2,847 million

The broad aggregate overview in this section has shown that firm funding of academic work tends to be concentrated in a few states, and that those states are also the site of much corporate R&D. These observations suggest a geographic connection between academic research and private R&D. The next section describes how the database described in Chapter II is used to examine hypotheses related to this connection.

IV.6 Analysis of Geographic Effects in Contract Research

Using firm-level and university-level data, in this section I examine hypotheses relating to the locality of academia and firms sponsoring research. The broad question I address is the following: what types of universities and firms enter into regional research collaboration?

<u>Focus on Sponsored Research</u>

I measure the impact of a university on local firms by using data on corporate sponsored research agreements. Such a measure has several advantages, as described in more detail in Chapter II. Sponsored research represents a purposeful, voluntary ex-ante attempt by firms to underwrite specific scientific investigations of interest, the results of which they would naturally be deeply interested in and likely to benefit from. As sponsoring research is voluntary, it can be assumed that, over time, firms do so if they actually obtain benefits from this activity. Firms may receive both earlier and more extensive information about laboratory results than non-sponsor companies. Before competitors learn about research results through conferences or publications, sponsor firms receive periodic progress reports from faculty and graduate students about the investigations, as well as direct access to the investigators for more detailed questions. As a consequence, firms participating in sponsored research not only provide more input into the process, but also receive more outputs as well. Thus, the location of sponsoring firms provide a measure of where the inputs to the research come from as well as where spillovers go.[3]

Unlike other forms of corporate research support, this form of interaction generally involves frequent personal interaction by firm personnel with the investigators to monitor progress and results (Johnson 1984, p. 27). Thus, there is some basis for theoretical considerations concerning transportation and monitoring costs to affect the geographic factors at work.

As described in Chapter II of the thesis, data on sponsored research was available for a total of 3853 business entities sponsoring research at the 65 universities at any time from 1988-90. Data on the locations (and zip codes) and characteristics of approximately three-quarters of the 3853 entities were available. On the university end, 52 universities provided detailed departmental-level data. With zip codes information on these universities, I ascertained the geographic relationship between the institution and the firms with which it interacts.

A limitation of the data set is that it does not include all universities, meaning that measurement of some geographic effects will be distorted.

[3] Berman (1990) has found a statistically significant relationship between industry funding of university research and subsequent increases in industrial R&D, suggesting that university-industry collaboration leads to innovation.

For example, some Massachusetts firms may interact with universities not in the database (such as Boston University), but not interact with those included in the database (such as MIT). Their involvement with local institutions of higher learning would thus be understated. This problem is not severe if we believe that the university decision to provide data for the database is uncorrelated with the types of firms sponsoring its research.

Location of Firm

The firm is assumed to be situated at the site of its headquarters, as described in Chapter II. In the case where data is available on company divisions and subsidiaries, research sponsorship will be assumed to emanate from the division or subsidiary headquarters. Certainly, concentrating all the firm within the locale of its headquarters understates the broad geographic presence of many firms. However, this acts as a reasonable first approximation if firms locate R&D laboratories close to headquarters. As learning from academia likely involves managerial and R&D functions more so than storage and distribution functions, the use of the corporate headquarters locale serves as a reasonable approximation for where the firm learns. One survey found that over half the firms questioned had a strong desire to locate R&D facilities "reasonably close" to their corporate headquarters (The Conference Board, 1986)[4]. However, assuming that a firm occupies a single zip code location can produce distortions in the case of large multinational corporations with regional headquarters and laboratories in several states. The approach taken understates the degree of local university research sponsorship for firms sponsoring local universities extensively through regional offices. It overstates the degree of local research sponsorship for large firms with headquarters close to universities in the sample.

The next section explores measures of geographic proximity.

4 "Reasonably close" meant up to 30 miles.

Measures of Geographic Proximity

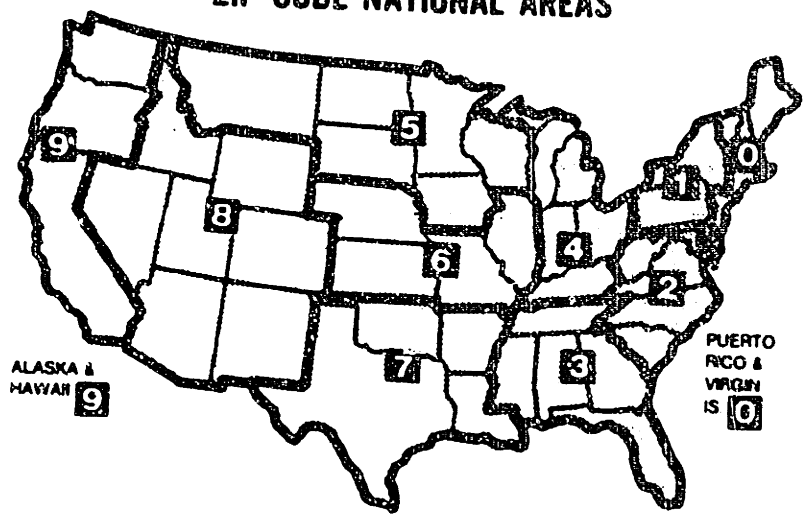
We are interested in the notion of the distance between a firm and the university with which it interacts. The best measure of distance varies. Geographic distance may be a natural and good first approximation. However, the ease of land or air transportation between two points is not necessarily a linear function of geographic distance. The ideal measure would thus account for some notion of economic distance. Regional economists have developed several measures of economic proximity such as Standard Metropolitan Statistical Areas (SMSAs), Functional Economic Areas, and urban fields. Though based upon measures such as economic, social, and transportation integration among areas, these measures suffer from conceptual difficulties due to arbitrary criteria for inclusion, measurement, etc. (Richardson 1978). Estimations using SMSA data[5] were also run for some analyses, but did not yield better results than estimations using the measure used and therefore not reported.

In the results presented, I use a measure based on five digit zip codes. A zip code is a numerical code that identifies areas within the U.S. to simplify mail distribution. The zip code areas do not necessarily correspond to the boundaries of cities, states, counties, or other jurisdictions. The first digit of a five-digit zip codes corresponds to a broad region of the country, encompassing several states (see the top portion of Figure 2). First example, the zip code area beginning with the digit 0 covers the New England states. The first two digits generally correspond to a major segment of a state. The bottom portion of Figure 2 shows a three digit zip code map of Massachusetts, which consists of the two digit zip code areas 01 and 02. The three digit level, as well as the smaller four digit and five digit areas, refers to a fairly small area, such as a city. Within Massachusetts, for example, the three digit zip code areas 020, 021, and 022 encompass the greater Boston area.

[5] Data needed to map my zip code areas to SMSAs was kindly provided by Dr. Neil Bania of the Case Western Center for Regional Economic Issues.

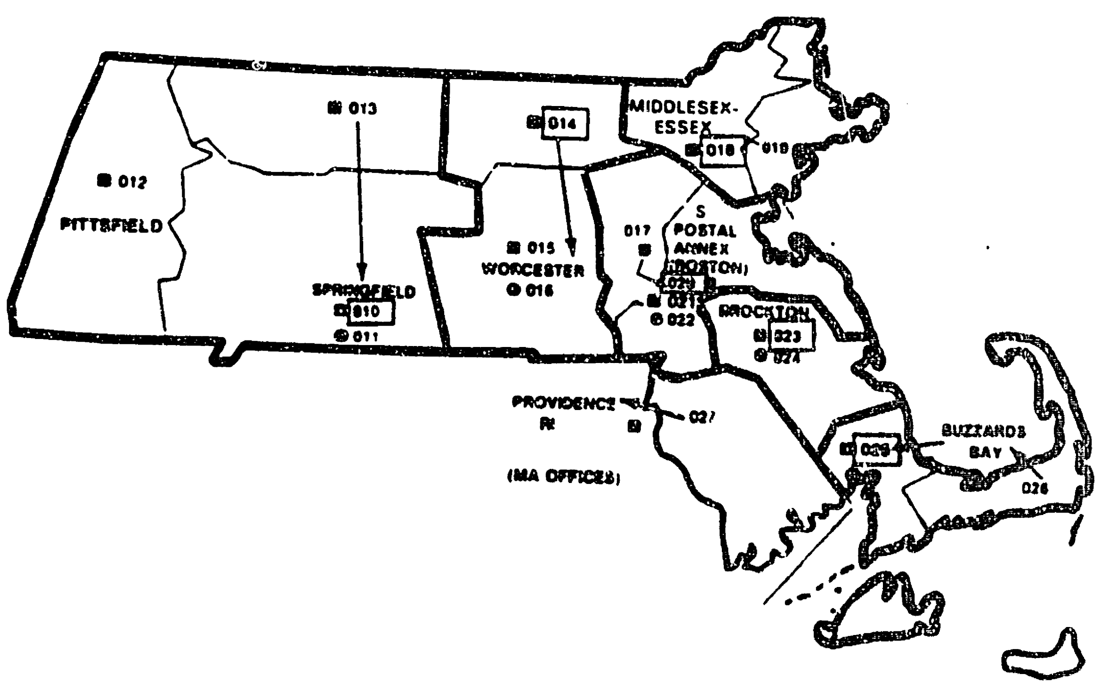
Figure 2

ZIP CODE NATIONAL AREAS



THREE-DIGIT ZIP CODE MAP

MASSACHUSETTS



As a result, the measurement of geographic proximity will be done by comparing the five digit zip codes of the university and the company's headquarters. Such a measure has the primary advantages of being readily available, even for small firms, and being based on actual transportation routes. Because zip codes are organized in a systematic manner for mail routing purposes, there is some basis for believing that they correspond in some way to ease of interaction between two points.

Firms and campuses located next to one another will have all five digits of their zip codes matching. Firms a bit more distant from the university will have the first four digits matching, but not the fifth. In contrast, distant research partners will not have even the first digit matching. Thus, the zip code metric I use has the advantage over other measures (such as states or SMSAs) in being more than a simple binary measure. In addition to being able to say whether a firm and university are in the same "area" or not, the zip code metric can change the size of the area being considered. We can thus approximate whether two organizations are virtual neighbors (zip code match at 4 or 5 digits), in the same city-area (match at 3 digits), part of the state (2 digits), or region of the country (one digit).

I thus use the zip code matching approach to develop a simple metric of whether a firm is "local" to the university. This simplification has a shortcoming. Using zip code boundaries as a distance measure produces discontinuities. Adjoining regions may have the first digit of their zip codes differ, while those several hundred miles apart (such as Seattle and Los Angeles) will share the same first digit. The questions raised by these discontinuities, however, also exist in other measures of regions, such as SMSAs and states. Further, unlike other measures, the zip code measure allows the definition of a "region" to be quickly redefined to be larger or smaller.

As a result, I present results using both broad (one digit zip code) and narrow (two digit zip code) definitions. Having now discussed the basic approach toward proximity determination, I now turn to a discussion of the method used in the first portion of the study.

IV.7 Construction of Variables

This section describes the construction of variables used for econometric hypotheses testing in Sections IV.8 and IV.9. The main variables of interest are those measuring funding levels--TOTIND, FEDRES, LOCIND, LOCPER, FEDPER, COLOCPER, and COLOCTOT. The paragraphs that follow describe each variable individually.

TOTIND (Total industry interaction with academic department) -- The variable TOTIND measures total industry sponsored research at a university department. It is based on department-level figures from the database on industry-sponsored research described in Chapter II. The department is not based on university-specific nomenclature, but on a mapping of university departments into broad NSF technical fields, as also described in Chapter II. I calculate the nominal amount received by the department from 1988-90 in sponsored research funding. This measure does not include industry support such as unrestricted grants, gifts, and equipment donations that represent additional important modes of interaction. To the extent that a firm's characteristics or distance from the university are uncorrelated with its mode of academic interaction, the variable TOTIND produces unbiased results.

LOCIND -- This variable measures a university department's research funding from local firms. It is calculated as the portion of TOTIND accounted for by firms local to the university. Geographic proximity is calculated via zip codes, as described in Section IV.6. In some regressions, proximity is calculated using a two-digit zip code area, while in others, it is calculated using a one-digit area.

NLOCIND -- This is the amount of a university department's research funding from non-local firms. Because all firms are classified in a binary system as local or non-local, NLOCIND is the difference between TOTIND (total industry funding) and LOCIND (local industry funding).

LOCPER -- This is a department's funding from local firms as a fraction of its funding from all firms, or LOCIND/TOTIND.

QUAL (university department quality) -- The measure of a university department's science and engineering quality is based upon the rankings of the prestigious Gourman Report (1989). This well-established report ranks U.S. graduate programs based on several criteria, including experience level of the program, faculty qualifications and attainments, records of student graduates, and standards. The Gourman rankings are widely accepted, and firms have been known to support academic research based on rankings (not necessarily Gourman rankings) of institutions (Gjostein 1991).

I use the rankings to construct a measure of department quality, with a national number one ranking translating to a quality measure of 20, number two ranking to a quality measure of 19, etc. This means that the number 20 department in the country has a quality measure of one, while departments not in the top 20 receive a measure of zero. The departments I use are the following: biochemistry (proxy for biological sciences), chemistry, computer science, aerospace engineering, chemical engineering, civil engineering, electrical engineering, mechanical engineering, mathematics, physics, and medicine. To the extent that aggregation of individual departments is not severe, this variable is fundamentally sound.

FAC (department size) -- I measure a department's size by the number of faculty members, both full and part-time members. This measure was obtained from "Peterson's Directory of Graduate Programs" (1990 and 1991) and supplemented by telephone verification with selected departments. I believe this variable to be fundamentally sound.

STATRND (state industry R&D) -- STATRND is the total industry R&D performed within a state in 1985, the most recent year for which data was available from the NSF (1989a). The STATRND variable controlled for spurious "regional" effects in university research and served as an instrument. For my analysis, the ideal measure of where R&D is conducted would be industry R&D performance broken out by zip code area. As the best available measure, the breakdown at the state level leads to potential biases within large or small states such as California and Rhode Island. Such size differentials may lead to erroneous measures of the R&D intensity of a university's region.

FIELDRND (company-financed R&D in a field) -- This variable represents the amount of company-funded R&D expenditures in 1986 applicable to an academic field. The National Science Foundation (1988) provided figures on R&D expenditures for broad industry groups (often two digit SIC). These broad industry groups were subsequently mapped into the broad NSF academic fields as shown in the following table:

Industry	1986 R&D $ million	Academic Field(s)
Food, etc.	1083	Agricultural Sci.
Textiles	157	Agricultural Sci.
Lumber, etc.	175	Agricultural Sci.
Paper, etc.	887	Agricultural Sci.
Industrial Chemicals	3812	Chemistry, Chem. Eng.
Drugs	3785	Biol. Sci., Medical Sci.
Other Chemicals	1176	Biol. Sci., Medical Sci.
Petroleum Ref.	1867	Earth Science, Oceanography, Chem. Eng.
Office, computing machines	6876	Electrical Engineering, Computer Sci.
Other machinery	2364	Mechanical Eng.
Electrical equipment	10460	Electrical Eng., Aerospace Eng.
Motor vehicles	7253	Mechanical Eng.
Other transport. equip.	137	Mechanical Eng.
Aircraft & missiles	4141	Aerospace Eng., Computer Sci.
Scientific Instruments	4576	Astronomy, Physics, Atmospheric Sci.,

		Medical Sci.
Nonmanufacturing	1099	Civil Eng.

Though prone to aggregation biases and difficulties in mapping (such as the industry corresponding to civil engineering), this variable captures the notion that an academic field's industrial research funding may depend upon the amount of total R&D conducted by the industries funding that field.

GSP (gross state product) -- GSP is the gross state product in 1986 (data from NSF [1989b]) of the university's state. The variable serves as an instrument in estimating the university department's funding from local firms. It is plausible that states with higher levels of commercial activity have more firms sponsoring university research, and that this funding may accrue to local universities.

POPGRO (population growth) -- The state's population growth is an instrument in the non-local industry funding equation. A university's research funding from distant firms may be related to the number of new residents of its state. Academic research relations may be established based on personal connections and information networks. When a person relocates to another part of the country, this person may inform former colleagues of research opportunities in the new locale. If so, then universities in states with high workforce mobility may become more widely known across the country, and hence receive more distant funding. POPGRO is calculated as the increase in population of the university's state from 1980 to 1990. Though the timeframe ending in 1990 is not consistent with explaining university funding in 1987, limitations on census data precludes a better measure. Because my regression analysis uses natural logarithms of variables, I needed to account for negative values of POPGRO (states with a net outflow of people). I "normalized" POPGRO so that it was a positive value for all states. Because the state with the greatest population loss in my sample (West Virginia) had a loss of 156,000 people, I added 157 (thousand) to all figures to make them all positive.

FEDRES (federal research dollars) -- FEDRES is the federal government's expenditures for research at the university department in 1987 (the year before the 1988-90 timeframe of university research funding examined), according to the NSF. If spillovers within an institution are important, then the presence of government funds may induce industry to support work as well. I thus use federal research dollars to proxy for department spillovers. These federal dollars account for a substantial portion of the academic research effort, and are generally deemed reliable, subject to the limitations of NSF surveys described in Chapter II.

FEDEQ (federal research equipment expenditures) -- I constructed FEDEQ using NSF figures on a department's federal current fund expenditures in 1987 for research equipment. I hypothesize that political reasons may underlie federal expenditures on research equipment received by a particular institution. Unlike research project funding, research equipment funding produces highly visible and long lasting results, results of the sort that engender political good-will. However, the assumption that these equipment expenditures represent political motivations may be questioned.

FEDPER (federal percentage) -- FEDPER measures a department's dependency on federal funding. It is calculated as the ratio of federal research funding to the sum of federal, industrial, and other research support. Data on other research support sources for 1987 was obtained from the NSF surveys.

U (university dummies) -- Universities may have specific attributes influencing its impact on local economic growth, such as special programs, missions, proximity to particular industrial centers, and culture. I use university dummy variables to capture these not-readily observable effects, aggregating all the S.U.N.Y. campuses into one and both University of Maryland campuses into one. To avoid perfect singularity, I excluded dummy variables for some universities from some regressions.

F(technical field dummies) -- Academic technical fields vary in their contribution to industry R&D efforts (Jaffe 1989, Mansfield 1991). I use dummy variables for four major groupings, based on NSF areas, to control for these discipline-specific factors affecting research amount. The areas are the following: Engineering, Science, Computer Science, and Biology. Engineering includes aeronautical, chemical, civil, electrical, and mechanical engineering. The sciences include astronomy, chemistry, physics, atmospheric science, earth science, and oceanography. Computer science includes both mathematical science and computer science. Biology includes agricultural science, biological science, and medical science. Once again, to avoid perfect singularity, I exclude some dummy variables from some regressions.

I (industry dummies) -- Industry dummy variables were constructed for nine broad industry groups based on SIC codes. The chart below maps a firm's SIC code to the industry group:

Chemical	SIC 281, 282	Aerospace	SIC 372
Drug	SIC 2833 - 2836	Instruments	SIC 38
Machinery	SIC 35 except 357	Utilities	SIC 491, 493
Computer	SIC 357, SIC 36	R&D Labs.	SIC 873
Telecomm.	SIC 481		

COLOCTOT (company local funding total) -- This variable measures a firm's total sponsored research amount with local universities over 1988-90. It only covers universities in the database. The definition of a "local university" is based on zip code concordance and varies depending upon the analysis run.

COLOCPER (company local percentage) -- This variable measures the percentage of a firm's sponsored research funding that goes to local universities.

EMP (number of employees) -- Firm size is measured by the number of its employees, as obtained from business directories in the manner described in Chapter II. This quantity is important if we believe that firm size affects a firm's costs of gaining benefit from academia. A measure based on number of employees rather than sales or profits may capture the notion of firm costs more accurately. Having more employees may mean having more potential employees to monitor research agreements and to interact with faculty. Refinements on this measure would be some indication on technical staff within a firm.

AGE (firm age) -- Firm age is calculated in years as of 1990 from information in business directories, as described in Chapter II. This quantity is important if a firm's age affects its costs of searching for, monitoring, and exploiting benefits gaining from academia. The AGE measure is quite imprecise, in terms of what it proxies for and in terms of measurement. It is well-known that many new business ventures start from university laboratories, so that search and monitoring costs may be minimal. In terms of measurement, firm age may not be very meaningful for firms with many divisions and subsidiaries. Further, business directories occasionally provide slightly different dates of corporate founding.

COMPETRES (competitor research funding) -- COMPETRES measures the university research funding of a firm's competitors within the firm's region. A firm's competitors are defined at the 3 digit SIC level. After identifying a firm's competitors in the database, I total the 3 digit SIC industry's funding at universities within the firm's region, before subtracting the firm's own local funding. Thus, each 3 digit SIC industry has a university funding total for each university/firm region, while each firm has a unique competitor funding total. Though basically sound, this measure suffers from the definition of what a "competitor" is and the relevant geographic area to cover. Further, the data focus on sponsored research may lead to bias if competitors interact with academia in other means, such as faculty consulting.

R (region of country) -- I assign firms into country regions based on the first digit of their zip codes. I combine regions 0 and 1 in the northeastern

United States because of the extremely small size of region 0 in comparison with the other regions.

A correlation matrix of these variables appears in Appendix A. The next section uses some of the variables described above to examine the regional effects of a academic department's undertakings.

IV.8 Regional Effects in University Department Research

Methodology

In this section, I empirically examine the geographic nature of university research using the university department as the unit of observation. The main question is the following: what are the characteristics of a university department's impact on industry, particularly local industry? I cannot directly observe all the ways in which a firm obtains benefits from academic efforts and resources. Instead, I assume that university-industry research relationships represent a means of technology transfer between the two sectors, so that by observing the pattern of a department's university-industry research relations, I can indirectly measure a department's impact. This approach assumes that an academic department's contributions to the local community is related to the amount of its voluntary research funding from industry (and vice versa). I do not address the temporal element of whether the firm does so because of expected or previous benefits.

Using the university department as the unit of observation has two advantages over using the entire university as a unit of observation. Certain academic fields play a disproportionately greater role in industrial innovation than others (Jaffe 1989, Mansfield 1991, and Chapter II of this thesis), thereby suggesting an analysis disaggregated by technical field. Further, many factors affecting university research sponsorship, such as researcher excellence and state of equipment, differ significantly across departments even within a single institution. Also, using data specific to departments overcomes data problems from the different organization of universities. For example, if a university's size in science and engineering is an important aspect of its regional economic effect, then it is difficult to see why aggregate university size data that includes liberal arts departments accurately captures that size effect. Use of disaggregated data permits greater distinction of department versus university characteristics.

The next section describes the assignment of university-furnished information into technical fields for analysis.

Departmental Mapping

As described in Chapter II and in the methodology section, the detailed nature of the data set allows an examination of corporate funding of university departments. A department-level analysis should not use too fine a level of detail. To the extent that many research projects do not fall neatly into one box in a university organization chart, but rather draw on insights from related departments, a more appropriate unit of study is thus a broader one based on logical linkages among departments. In this chapter, I thus take the numerous department names supplied by the universities and map them into broad scientific and engineering fields. The process was described in Chapter II and briefly reviewed here.

For the universities in my database that reported research interactions by department, I mapped the 594 department names furnished by the universities to one of the sixteen standard NSF technical fields. Of the 65 universities in the database on university-industry research relationships, 52 provided information at the department-level of detail. Of those 52 universities, 37 had non-trivial industrial funding and usable data for the analysis of this chapter. Information to construct all variables was available for 230 broad university departments at these 37 institutions. Table 4 shows the distribution of technical fields among the 230 departments.

Table 4: Distribution of Technical Fields in Analysis

Technical Field	Number
Aero/astronautical engineering	9
Chemical engineering	21
Civil engineering	20
Electrical engineering	21
Mechanical engineering	15
Astronomy	1
Chemistry	22
Physics	24
Atmospheric sciences	4
Earth sciences	16
Oceanography	1
Mathematical sciences	5
Computer sciences	18
Agricultural sciences	10
Biological sciences	26
Medical sciences	17
Total	230

Thus, the analysis includes engineering as well as science departments encompassing the range of technical fields.

Statistical Overview

The universities represented in the analysis include 37 institutions from 18 states, both public and private, as shown in the Table 5:

Table 5: Universities Included in Analysis

Brown	Colorado State	Georgia Tech
Indiana	Johns Hopkins	Louisiana State
New York Univ.	Princeton	Purdue
Rutgers	Stanford	SUNY Albany
SUNY Binghamton	SUNY Buffalo	SUNY Stony Brook
SUNY Brockport	SUNY New Paltz	Texas A&M
Texas Tech	UC Berkeley	UC Irvine
UCLA	UC San Diego	U of Maine Orono
U Mass	U Maryland Balt	U Md. College Park
U Missouri Columbia	USC	U Arizona
U Iowa	U Oklahoma	U Pennsylvania
U Pittsburgh	U. of Texas Hlth Sci. Ctr.	
Utah State	West Virginia	

Table 6 presents a summary of the variables used in the analysis and sample statistics.

Table 6: Summary of Key Variables

Summary Description of Variables

Variable(s)	Short Description	Measured by:
TOTIND	department's industry funds	sponsored research funds
LOCIND	dept. local funding amount	sponsored research funds
LOCPER	dept. local funding percentage	LOCIND/TOTIND
FEDRES	dept. federal funding	federal research dollars
QUAL	department quality	Gourman report rankings
FAC	department size	department faculty
STATRND	state's industry R&D	state's industry R&D
FIELDRND	technical field company R&D	technical field co. R&D
GSP	state commercial activity	gross state product
POPGRO	labor force relocation	population growth
PUB	public university	dummy variable
FEDEQ	political factors	fed. equipment funds
FEDRND	federal research in field	U.S. federal R&D in field
FEDPER	dependence on federal funds	federal funding percentage
U	university-specific factors	set of dummy variables
F	academic field factors	set of dummy variables

Sample Statistics of Key Variables

N=230

Variable	Mean	Minimum	Maximum
TOTIND	$897,000	$2000	$11,067,000
LOCIND (2 digit)	$105,000	$0	$2,968,000
LOCIND (1 digit)	$239,000	$0	$5,549,000
LOCPER (2 digit)	0.140	0	1
LOCPER (1 digit)	0.285	0	1
PUB	0.678	0	1
QUALITY	2.5	0	20
FAC	76	3	1195
STATRND	$5.5 billion	$48 mill.	$17.8 billion
GSP	$221 billion	$15 bill.	$554 billion
POPGRO	1.82 million	1,000	6.24 million
FIELDRND	$7.53 billion	$1.10 bill.	$17.34 billion
FEDRES	$5.4 million	$0	$78.2 million
FEDEQ	$375,000	$0	$5.8 million
FEDPER	0.581	0	0.969

The average research field at a university received $897,000 in industry funding over the 1988-90 period, with over a quarter of the funding coming from a one-digit zip code proximity. Of the 37 universities, 67.8% were public institutions. The average department was ranked 17th using the Gourman report and had 76 faculty members. A correlation matrix of the variables in logarithmic form appears in Appendix A.

We are now interested in econometrically assessing the determinants of a university department's sponsored research funding from industry. As a first step, I examine the department's research funding from all industrial firms, before exploring whether funding from local firms has different characteristics.

Estimating Total Industry Support

In Section IV.4, I developed hypotheses involving the determinants of total industry funding. The web of causality relationships affecting a university department's industry funding, federal funding, size, and other factors suggests a systems approach. In particular, I initially estimate the determinants of university department i's total industrial and federal research funding as a system:

(1) $TOTIND_i =$

$$f(QUAL_i(+), FAC_i(+), FEDRES_i(?), PUB(?), FIELDRND_i(+), U, F)+u_t$$

(2) $FEDRES_i =$

$$g(QUAL_i(+), FAC_i(+), TOTIND_i(?), PUB(+), FEDRND_i(+), U, F)+w_t$$

The random disturbance terms u_t and w_t are assumed to be independently and identically normally distributed, uncorrelated with the exogenous variables, but possibly correlated across departments. Expected signs of the variable coefficients appear in parentheses after the variables. Variables are expressed in logarithmic form, with observations of a zero value set equal to one.

There are thus two endogenous variables, TOTIND and FEDRES. I posit that overall industry research funding depends positively upon departmental quality and size. The effect of other federal research funding in the department (FEDRES) upon TOTIND is ambiguous. The presence of federal funds may either attract more company support seeking to tap into a greater spillover pool or create a disincentive to fund knowledge headed for the public domain. The total amount of company-funded R&D in industries related to a university department (FIELDRND) may influence the amount of corporate research in that particular department. I include a dummy variable PUB which is one if the university is public; some public universities may have been explicitly charged with aiding their regions' development, and hence may interact differently with industry than do private institutions. The effects of differing technical fields and university-specific characteristics in attracting funding are controlled for with vectors of dummy variables F and U respectively. The analysis in Chapter II found differences across technical fields in academic interaction, leading to the inclusion of the set of university dummies. In addition, I include the set of university dummy variables to test whether some universities seem to have a greater regional economic impact even after controlling for the size, quality, and other characteristics of their individual departments. The discovery of university-specific effects on top of department effects would imply that institutions of higher education are not simply a collection of departments. Universities may enjoy a research infrastructure, culture, or key personnel that make the overall institution greater than the sum of its parts.

A department's overall federal research support is as depending in large part upon the same variables thought to affect its total industrial support, namely QUAL, FAC, PUB, U, and F. In addition, since political considerations may affect federal research support, I include the variable FEDRND to capture the effect of "pork-barrel" politics. FEDRND is the total amount of federal support for a technical field at universities across the country. If it becomes politically important to fund defense-related work in electronics, for example, then we might see all electrical engineering departments affected. In these political processes, universities may receive federal research funding without much regard to quality or size.

Two econometric issues arise -- simultaneity and multicollinearity. The potential presence of simultaneity between industry research and federal research means that I estimate equations (1) and (2) as a just-identified two-stage least squares (2SLS) set of equations. FIELDRND is an instrument for TOTIND in the federal research equation, while FEDRND is an instrument for FEDRES in the industry-funding equation. The Hausman specification test showed the use of 2SLS to be justified[6]. Examination of correlation matrices (provided in Appendix A) did not find any reason to believe that a serious multicollinearity problem exists, because the highest correlation coefficient between regressors was 0.58 (between the logs of FAC and FEDRND).

Results from estimating equations (1) and (2) via 2SLS appear in Table 7. In general, total industrial research funding at a department (TOTIND) is only related to the amount of industrial R&D in the field (FIELDRND). Department excellence and size (akin to supply characteristics for academic research) do not have as much effect as an industry's overall demand for R&D in a particular field. Academic fields receive more research funding if the industries potentially interested in their work conduct more total R&D. Of the major technical fields, there is no evidence of differences once industry R&D is controlled for. As for the university dummy variables, none proved significant at even the 10% level. This suggests that

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6 The Hausman test rejected at the 1% level the hypothesis that total industry research and the error term in the federal research equation (equation 2) are uncorrelated. The coefficient for the fitted value of industry research (LTOTINDHAT) added to the federal funding equation was 2.62 with a standard error of 0.59, producing a test statistic of 4.58 distributed normally. The Hausman test also rejected at the 1% level the counterpart hypothesis involving total federal research and the error term in the industry research equation (equation 1). The coefficient for the fitted value of federal research (LFEDRESHAT) added to the industry funding equation was 8.20 with a standard error of 0.423 for a test statistic of 19.38. Details of the Hausman test appear in Appendix B.

Table 7: 2SLS Estimates of Department Total Funding Amount

N=230

Dependent variable:	Eq. 1 Log(TOTIND)	Eq. 2 Log(FEDRES)
Log(QUAL)	0.010 (0.19)	0.086** (2.29)
Log(FAC)	0.62 (1.33)	0.50 (1.32)
Log(FEDRES)	-0.0011 (-0.002)	
Log (TOTIND)		0.55 (1.01)
PUB	1.49 (0.91)	0.51 (0.21)
Log(FEDRND)		-0.44 (-1.05)
Log(FIELDRND)	0.38** (2.56)	
ENGINEERING	0.90 (1.20)	-2.19** (-2.19)
COMPUTER SCI.	0.26 (0.20)	-2.59*** (-3.56)
BIOLOGY	0.43 (1.17)	0.53 (0.88)
Constant	6.85 (0.97)	12.97*** (3.14)
University dummies	present	present
Root MSE	1.41	2.21
R-squared	0.413	0.493
Adjusted R-squared	0.303	0.398

T-statistics in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

"university effects" on top of departmental effects do not exist, that a university is simply a collection of departments. However, several university dummy variables nearly proved significant at the 10% level. A hypothesis test on the combined significance of the university dummy variables in the industry equation rejected the null of no joint effect[7].

The federal funding equation, equation (2), presents evidence suggesting that departmental excellence (QUAL) exerts a significantly positive effect on federal support. As in the industry equation, the department's size (FAC) is not a significant determinant of federal research support, which is unexpected. Running the regressions in Table 7 with size measured by the number of graduate students rather than of faculty produced almost identical results. Federal research support also depends on technical field. Just as in the industry funding equation, a hypothesis test on the combined significance of the university dummy variables rejected the null hypothesis of no joint effects[8]. Departments in the more-applied fields of engineering and computer science receive less federal funding than those in biology (shown) and medical science (not included in regression to prevent collinearity, and hence not shown). I now explore the determinants of that funding from local firms.

Local Industry Support Totals

Next, I estimate a system of three equations examining an academic department's levels of local, non-local, and federal funding. I again use two-stage least squares to account for the possible simultaneous nature of some key relationships. If a university has policies or leaders encouraging industrial interaction, it may first attract local industrial funding. This service to local firms may enhance its reputation and ability to attract the interest of non-local firms as well, raising simultaneity issues as a virtuous cycle develops. The amounts of local funding, non-local funding, and federal research are treated as endogenous. I posit the following system, with variables expressed in logarithmic form:

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7 The test statistic F(28, 193) of 3.51 was signifcant at the 1% level.

8 The test statistic F(28, 193) of 3.69 was significant at thte 1% level.

$$(3)\ LOCIND_i = f(QUAL_i(?), FAC_i(+), NLOCIND_i(?), FEDRES_i(?), GSP_j(+), STATRND_j(+), PUB_i\ (?), U, F) + u_i$$

$$(4)\ NLOCIND_i = g(QUAL_i(+), FAC_i(?), LOCIND_i(?), FEDRES_i(\ ?), POPGRO_j\ (+), FIELDRND_j\ (+), U, F) + v_i$$

$$(5) FEDRES_i = h(QUAL_i(+), FAC_i(+), LOCIND_i(?), NLOCIND_i(?), FEDEQ_i(+), FEDRND_i(+), PUB_i(?), U, F) + w_i$$

The subscripts i denote department-specific variables, while the subscripts j denote technical field or state variables. The set of equations includes three endogenous variables (LOCIND, NLOCIND, and FEDRES), two exogenous variables (QUAL and FAC), and six instruments (GSP, STATRND, POPGRO, FIELDRND, FEDEQ, and FEDRND), and dummy variables. The random disturbance terms u_i, v_i, and w_i are assumed to be independently and identically normally distributed, uncorrelated with the exogenous variables, but possibly correlated for a department.

Equation (3) is a just-identified local industry research equation. Similar to Equation (1), it features the university department's quality (QUAL) and number of faculty (FAC) as independent variables. The instruments for LOCIND in the non-local and federal research equations are the total industrial R&D conducted within the university's state (STATRND) and the gross state product (GSP). Local research funding may be greater in states where more industrial R&D is conducted and where the state's economy is larger, quantities which likely do not affect non-local funding. The amount of local industry research is also assumed to depend upon NLOCIND, FEDRES, type of university (PUB), technical field (F) and university-specific factors (U).

The over-identified Equation (4) describes the determinants (particularly quality and size) of a department's non-local industry research. FIELDRND and POPGRO serve as instruments for NLOCIND. Funding from non-local firms may be positively related to total nationwide company R&D expenditures related to the department and to the number of people moving into the state, widening information networks. Non-local industry funding may be linked to its local industry funding, if both are affected by departmental attitude, infrastructure and regulations toward industry interactions. In addition, a department's receiving significant amounts of local funding may attract more distant funding, and vice versa, as the department's reputation and experience grow within industry circles.

Finally, Equation (5) factors in federal government research funding at the department. To the extent that federal and industry funding are substitutes or complements, a system focusing on research funding sources needs to account for federal support. The just-identified Equation (5) uses the same variables as Equation (2) with the addition of a second instrument, FEDEQ for FEDRES. FEDEQ measures federal expenditures for research equipment at the department, which may be due to political processes more than FEDRES is.

In estimating Equations (3), (4), and (5), I control for the location of universities in R&D intensive locales and for differences in the propensity of fields to perform R&D, which may yield spurious findings if not controlled for. For example, it would be erroneous to attribute Californian universities' reception of sponsored research funds from Californian firms solely to geographic effects. Rather, as we have seen in Section IV. 5, California is responsible for twice as much industrial R&D than any other state. Even if no geographic effects exist and a firm's sponsored research locale were randomly distributed, we would still expect to see a large share of Stanford University's sponsored research coming from Californian firms. I thus include the variable STATRND to control for the geographic distribution of industrial R&D. Similarly, FIELDRND, and FEDRND account for the differing propensities for firms and government to conduct research in particular fields.

Results of regressions of (3), (4), and (5) estimated using 2SLS appear in Table 8. I define a firm and university as "local" if they share the same first two digits of the zip code. The Hausman test found some evidence of

Table 8: 2SLS Estimation of Department Local Funding Amount

N=230	Eq. 3 Log(LOCIND)	Eq. 4 Log(NLOCIND	Eq. 5 Log(FEDRES)
Log(QUAL)	0.059 (0.69)	-0.013 (-0.27)	0.042 (1.26)
Log(FAC)	1.33** (2.06)	0.19 (0.52)	0.31 (1.04)
Log(NLOCIND)	0.36 (0.57)		0.33 (0.66)
Log(LOCIND)		0.24 (1.37)	-0.087 (-0.55)
Log(FEDRES)	0.20 (0.76)	0.043 (0.29)	
Log (GSP)	-22.78 (-1.54)		
Log(POPGRO)		-0.060 (-0.22)	
PUB	-17.07** (-2.37)		-0.98 (-0.81)
Log(FEDEQ)			0.49*** (8.74)
Log(FEDRND)			-0.44 (-0.84)
Log(STATRND)	11.60 (1.15)		
Log(FIELDRND)		0.59** (2.32)	
ENGINEERING	1.12 (0.82)	0.89 (1.44)	-0.84 (-0.67)

(continued on next page)

Table 8: 2SLS Estimation of Department Local Funding Amount

(continued from previous page)

N=230	Eq. 3 Log(LOCIND)	Eq. 4 Log(NLOCIND	Eq. 5 Log(FEDRES)
COMPUTER SCI.	-0.13 (-0.097)	-0.051 (-0.065)	-0.94 (-1.44)
BIOLOGY	-0.16 (-0.14)	0.36 (0.58)	0.75 (1.31)
Constant	178.85* (1.73)	4.40 (1.42)	10.43*** (3.06)
Univ. dummies	present	present	present
Root MSE	4.91	2.73	1.79
R-squared	0.406	0.217	0.678
Adj. R-squared	0.292	0.071	0.615

T-statistics in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

simultaneity in the system[9], indicating that the use of two-stage least squares regressions is appropriate.

In explaining two digit local industry funding (LOCIND), I find that having a greater number of faculty (FAC) is significantly positively related to local industry funds, LOCIND. I interpret this finding as consistent with explanations of university-industry relationships as a means to provide technical expertise to local firms, a mechanism requiring extensive personal involvement by faculty. An alternate explanation is suggested by the survey finding that most university-industry research relationships are initiated by the university side (NSB 1982). Thus, larger departments may simply have more faculty "marketing" the benefits of sponsored research to firms in the area, and hence attract more local funds. The negative coefficient on PUB is unexpected, for we would expect public universities to be more likely to serve local firms. It may indicate intangible differences between public and private universities not yet observed, such as prestige.

However, Table 8 indicates that the determinants of non-local industry funding are poorly understood. In equation (4), FIELDRND is the only statistically significant variable; it has the expected positive sign. This result involving FIELDRND in Table 8 parallels that from Table 7, providing some evidence that technical fields in which industry conducts more R&D nationwide receive more sponsored funding.

The estimated federal funding equation (5) also finds a single significant variable (FEDEQ), while QUAL loses statistical significance. The results indicate a positive relationship between federal research with federal equipment support, which I interpret as indicating that federal research

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9 The Hausman test could not reject the null hypotheses that the error terms of the local research and non-local research equations are uncorrelated with NLOCIND and FEDRES, and with LOCIND and FEDRES respectively. The F(2, 190) values were 0.15 and 0.45. However, the Hausman test found that the error term of the federal research equation to be correlated with the endogenous dependent variables LOCIND and NLOCIND, with a test statistic of 7.00, which is significant at the 1% level. Details of the test appear in Appendix C.

support derives basically from political processes. Alternatively, the federal government may "bundle" research funds and equipment funds on the belief that one without the other is useless.

The regression analyses of Tables 7 and 8 suggest that department size (FAC) plays an important role in determining local, but not total, departmental industry funding amounts. I interpret this finding to mean that some departments interact more with local firms simply because they are larger. Size is not as crucial in attracting distant research sponsorship. I conjecture that the larger departments became that way through reputations for excellence, which in turn attracts government support through motivations to fund excellence and politically popular departments. The next section explicitly controls for size effects in search of geographic effects.

Department Local Percentage

This section examines hypotheses on the determinants of a department's local industrial funding as a *percentage* of total industrial funding. Estimating the total local funding level of a university department, as was done in the previous section, has strengths and shortfalls in determining local industry support. A department's total research support amount from local firms may be related to its absolute influence upon the local economy. However, an absolute measure also confounds size effects with regional economic effects. Large universities may naturally attract extensive corporate support for scientific investigations. Even small proportions of funding from local firms can represent large absolute amounts for these universities, even though the university is by no means "local." A relative measure, the percentage of all industry funds from local sources, avoids distortions due to university size and more accurately captures the determinants of a department as more local or more global in emphasis.

As such, I estimate the determinants of a university department's local firm sponsorship as a percentage of all industry sponsorship. The set of equations from the previous section then becomes the following, with variables (not including percentages) expressed in logarithmic form:

(6) $LOCPER_i=$

$$f(QUAL_i(?), FAC_i(+), FEDPER_i(-), STATRND_j(+), PUB_i(?), U_i, F_j)+u_i$$

(7) $FEDPER_i=$

$$g(QUAL_i(+), FAC_i(+), LOCPER_i(?), FEDEQ_i(+), PUB_i(?), U_i, F_j)+v_i$$

The two equations are estimated via 2SLS estimation with two endogenous variables (LOCPER and FEDPER), two exogenous variables (QUAL and FAC), two instruments (STATRND and FEDEQ), and dummy variables. The dependent variable LOCPER in equation (6) is the ratio of sponsorship from local firms (local once again referring to a two digit zip code concordance) to sponsorship from all firms. It would be redundant to have an equation for non-local percentage. The dependent variable FEDPER in equation (7) is the ratio of the department's federal research dollars to total research dollars from all sources; I hypothesize that departments relying heavily upon federal funds have little incentive to seek industrial (local) research funds.

Once again, I test the importance of department quality (QUAL) and faculty size (FAC) on local industrial support. I use STATRND as an instrument for LOCPER, and FEDEQ as an instrument for FEDPER. Total industrial R&D conducted within the state may affect local percentage funding at the university, while federal expenditures for research equipment may reflect political considerations affecting federal research expenditures. Other exogenous variables include the university's ownership mode (dummy variable PUB), the department's research field (dummy variables F), and intangible university-specific attributes (dummy variables U).

Two stage least squares estimates of equations (6) and (7) appear in Table 9. None of the estimated coefficients in either equation had statistical significance. I interpret this result to mean that after controlling for scale effects, university research does not exhibit geographic patterns. Furthermore, Hausman tests found some evidence of simultaneity in

Table 9: 2SLS Estimation of Department Local Percentage

N=230 Dependent variable:	Eq. 6 LOCPER	Eq. 7 FEDPER
Log(QUAL)	0.0011 (0.25)	0.0097 (0.38)
Log(FAC)	-0.014 (-0.60)	-0.093 (-0.46)
LOCPER		-5.83 (-0.56)
FEDPER	-0.070 (-0.43)	
Log(FEDEQ)		0.022 (0.56)
Log(STATRND)	-0.090 (-0.35)	
PUB	-0.25 (-0.65)	-0.95 (-0.45)
ENGINEERING	-0.057 (-1.18)	-0.37 (-0.64)
COMPUTER SCI.	-0.013 (-0.19)	-0.11 (-0.29)
BIOLOGY	0.0046 (0.079)	-0.036 (-0.10)
Constant	1.00 (0.47)	1.69 (0.72)
University dummies	present	present
Root MSE	0.245	1.43
R-squared	0.188	0.023
Adj. R-squared	0.037	-0.159

T-statistics in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

equations (6) and (7), indicating that the 2SLS estimation approach was necessary[10].

Adjusting the definition of locality to a one digit zip code concordance (a larger area) did not significantly change the results. Alternative estimates using different specifications left this basic finding unchanged. The results from Table 9 suggest that once size effects are controlled for, geographic effects in industry-sponsored university research do not exist for academic departments. Within the framework described in Section IV.3, I interpret this finding to mean that universities receive industrial contract research funds because such funds offer firms access to faculty members and graduate students. Thus, departments with more faculty members attract larger corporate interest. I now turn to a search for geographic effects using the firm as the unit of observation.

IV.9 Regional Effects in Corporate Research Sponsorship

We have previously hypothesized that firm characteristics play an important role in the economic geography of university research sponsorship. This section examines hypotheses about what types of firms sponsor academic research locally, hypotheses based on the view that distance affects the firm's costs of obtaining benefits from academic research collaboration. A company's attributes such as size and age may influence its ability to find, monitor, and benefit from collaboration opportunities with local universities. The next section provides an overview of the data.

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10 The test statistic of the fitted value of federal research percentage (FEDPERHAT) in the local percentage equation was only 0.091. The test statistic of the fitted value of local industrial percentage (LOCPERHAT) in the federal percentage equation was -1.51, which is significant at the 15% level, indicating that local industrial percentage is weakly correlated with the error term in the federal percentage equation.

Data Overview

This section examines the extent of local academic research sponsorship by the firm. The basic universe for this analysis is the set of all identified corporations in my database located close to a university. For these companies, I seek to explain their percentage of academic research at local universities as a function of company characteristics. Unlike the previous analysis, I treat the university as a single unit here, with no disaggregation to the department level. The question of interest involves the locale where a firm funds, and all departments for a given institution represent the same locale.

Over the period 1988-90, a total of 3853 firms sponsored research at one of the 65 academic institutions in the database. By "firm", I include the parent company, its subsidiaries, and its divisions. Of these, the analysis focused on the 961 identified firms located "close to" a university campus, meaning that they shared the first two digits of the zip code. Narrowing the sample in this manner means that each of the 961 firms had the potential to fund local university research observable in my data, reducing potential data distortions. Thus, I have eliminated firms that sponsor local research at a university not in my data set, as well as firms located extremely distant from any university. For the remaining firms, the key variables are summarized in Table 10.

Table 10: Summary of Key Variables

Summary Description of Key Variables

Variable(s)	Short Description	Measured by:
EMP	firm size	number of employees
AGE	firm age	age in years as of 1990
COMPETRES	competitor research in area	competitor (3 digit SIC) research in area
COLOCTOT	co. local funding	local funding amount
COLOCPER	firm local funding %	COLOCTOT/TOTIND

Sample Statistics for Key Variables
N=961 firms

Variable	Mean	Std. Dev.	Max	Min
TOTIND	$366,000	$2.0 million	$49 million	$0
COLOCTOT 2 digit	$72,000	$360,000	$6 million	$0
COLOCTOT 1 digit	$112,000	$458,000	$7 million	$0
COLOCPER 2 digit	29%	43%	100%	0%
COLOCPER - 1 digit	44%	46%	100%	0%
EMP	9731	37900	813400	2
AGE (years)	39	36	188	1
CHEMICAL	0.039	0.19	1	0
DRUG	0.107	0.31	1	0
MACHINE	0.039	0.19	1	0
COMPUTER	0.105	0.31	1	0
AEROSPACE	0.014	0.12	1	0
INSTRUMENT	0.123	0.33	1	0
UTILITY	0.042	0.20	1	0
TELECOM	0.012	0.11	1	0
R&D	0.074	0.26	1	0

Thus, the average firm sponsored $366,000 in nominal terms over 1988-90 in research at the universities in the study. Approximately $72,000 (20%) of this funding went to institutions local at the two digit zip code level, although the average firm sponsors 29% of its research at local universities. The industry dummy variables indicate that the sample firms come from many industries, with the instruments industry the most heavily-represented (at 12.3% of all firms).

The following table, Table 11, attests to the broad geographic distribution (by first digit of the zip code) of the firms involved, showing that the firms studied come from all parts of the country. The table also presents the percentage of all industry R&D performed in that sector in 1985 (NSF 1989). Comparing the two columns suggests that the distribution of firms in the sample roughly mirror the distribution of R&D performance; the simple correlation between the two quantities is 0.88.

Table 11: Distribution of Firm Locations by First Digit Zip Code

Zone	%of 961 Firms Located	% of All Industry R&D Performed
Zone 0	17.1%	16.2%
Zone 1	19.0%	14.9%
Zone 2	8.1%	4.7%
Zone 3	5.9%	4.3%
Zone 4	9.3%	13.6%
Zone 5	3.0%	3.9%
Zone 6	8.3%	6.2%
Zone 7	5.9%	5.2%
Zone 8	4.8%	4.5%
Zone 9	18.5%	26.4%

The next section describes the estimation using the data set outlined in the previous paragraphs.

Examination of Percentage Local Funding

The equation that follows examines the percentage of a firm's sponsored research going to local universities as a function of the firm's characteristics:

(8) $COLOCPER_i = f(EMP_i(-), AGE_i(-), COMPETRES_j(?), I, R) + u_i$

The dependent variable COLOCPER is a firm's sponsored academic research at local institutions as a percentage of its total sponsored research. This variable is hypothesized to be negatively related to firm size and firm age due to search and contract costs. Firm size is measured by the number of its employees (EMP), while age (AGE) is the number of years from its founding until 1990. COMPETRES, the competitor funding variable, refers to academic research sponsorship at a firm's region by local competitors. From the economic theory, the direction of this variable's effect is not clear. Construction of industry dummy variables I and country region dummy variables R is described in Section IV.7. The random error terms are assumed independent and identically normally distributed.

I initially use OLS to estimate Equation (8) and present results in Table 12, using two definitions of locality. T-statistics calculated using heteroskedasticity-robust standard errors appear in parentheses. Unlike the regressions on university department funding, it is difficult to imagine any significant simultaneity in Equation (8), making the choice of OLS reasonable. The first set of results uses a two digit zip code concordance. At the two digit zip code level, EMP is almost statistically significant, while the firm AGE variable has a significant negative sign, implying that younger firms spend a greater proportion of their academic research dollars at local institutions. The presence of competitor funding at universities local to the firm (COMPETRES) is positively related to the firm's own local funding. Thus, it appears that university research in particular fields may be concentrated at a few locales. These industry agglomeration effects may be due to positive R&D spillover externalities, to firm strategies monitoring competitors, or to the comparative advantage of regions in performing certain types of research.

In addition, an examination of the dummy variables reveals interesting industry differences. Drug and R&D firms -- which use technical knowledge that can be characterized as "science" -- have a greater tendency to sponsor at non-local universities. On the other hand, utilities -- which

Table 12 OLS Estimation of Firm's Local Funding Percentage

N=961	Eq. 8 COLOCPER 2 digit zip	Eq. 8 COLOCPER 1 digit zip	Eq. 8 COLOCPER 2 digit zip
Log(EMP)	-0.010	-0.013*	-0.064**
	(-1.42)	(-1.75)	(-2.48)
$Log(EMP)^2$			0.0041**
			(2.32)
Log(AGE)	-0.027*	-0.00088	-0.025
	(-1.66)	(-0.053)	(-1.54)
Log(COMPETRES)	0.0081***	0.0019	0.0081***
	(3.11)	(0.69)	(3.49)
CHEMICAL	-0.065	-0.12	-0.057
	(-0.97)	(-1.62)	(-0.85)
DRUG	-0.11**	-0.091*	-0.11**
	(-2.45)	(-1.71)	(-2.44)
MACHINE	0.042	0.058	0.050
	(0.59)	(0.76)	(0.71)
COMPUTER	0.032	0.097*	0.033
	(0.68)	(1.95)	(0.70)
AEROSPACE	0.011	-0.012	0.012
	(0.11)	(-0.11)	(0.12)
INSTRUMENT	-0.014	0.0042	-0.016
	(-0.32)	(0.084)	(-0.36)
UTILITY	0.20***	0.32***	0.21***
	(2.65)	(5.47)	(2.75)
TELECOMM	0.14	0.18	0.11
	(0.94)	(1.20)	(0.74)
R&D	-0.11*	-0.057	-0.10**
	(-2.32)	(-0.99)	(-2.14)

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Table 12 OLS Estimation of Firm's Local Funding Percentage
(continued from previous page)

N=961	Eq. 8 COLOCPER 2 digit zip	Eq. 8 COLOCPER 1 digit zip	Eq. 8 COLOCPER 2 digit zip
Constant	0.41***	0.55***	0.56***
	(6.93)	(8.61)	(5.90)
Geographic dummies	present	present	present
R^2	0.136	0.160	0.140
R^2 (adjusted)	0.117	0.142	0.121
SSR	23.69	32.74	24.53
SSE	151.13	172.43	150.29
F value	7.37	8.92	7.93

T-statistics in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

use knowledge more akin to "engineering"and have a limited operating area -- tend to rely more on local universities.

The next column in Table 12 presents results using a one digit zip code definition of locality. A one-digit zip code zone is a very large geographic area encompassing several states, thereby meaning that this type of funding can be characterized as funding universities in a section of the country. The results indicate that slightly different factors may be at work in corporate funding over a broader geographic area. Firm size (EMP) becomes statistically significant with the expected negative sign, while AGE loses significance. This indicates that the factors affecting the geography of sponsoring academic research vary according to the distances involved. Size plays a more important role than age in determining a company's funding within its one digit zip code zone. The variable COMPETRES becomes insignificant, suggesting that a firm's motivations to access directly spillovers from competitor R&D decrease with distance. Industry effects for drug firms and utilities are essentially the same as in analysis using a two digit zip code concordance. However, a weak COMPUTER effect becomes apparent. Finally, regional effects seem to be at work, as the regional dummy variables prove jointly significant[11].

In the regression described in the rightmost column of Table 12 , I add a quadratic size term to the specification and once again use the two digit zip code proximity measure. The results of Chapters II and III have found non-linearities in the relationship between research funding and firm size. Accounting for possible non-linearity in this section provides a surprising positive significant coefficient on the quadratic term. However, throughout the relevant range of the sample (from 2 to 813400 employees), the combined effect of the negative EMP coefficient and the positive coefficient on the quadratic term is negative, supporting the hypothesis that larger firms sponsor a lower proportion of research locally. Because

[11] The F test was used to examine whether all the regional dummy variables were zero. Test statistics for F(8,940) were 11.04 and 13.83 for the 2 digit and the 1 digit equations, respectively. These statistics strongly reject the null hypothesis.

adding the quadratic term provides a marginally better fitted estimation (2% more variance explained), I adopt the quadratic specification in the regressions that follow.

Table 13 presents estimations of Equation (8) with techniques that account for the limited dependent variable. The data set of 961 firms represents a sample of all firms that sponsored academic research, were identified, and were located close to a university. It features only firms that sponsored research somewhere, thereby resulting in some sample truncation in that we do not observe all firms in the economy. Of these firms sponsoring research, many did not do so locally, raising sample selectivity issues. In such cases, because OLS estimates may be biased, the Tobit model and Olsen two-step procedure can be used[12].

Table 13 first presents the results of Tobit estimation in the first two columns of results, which accounts for the limited dependent variable and for the truncated nature of the data set. The overall findings are consistent with the OLS results in Table 12, with generally stronger effects. Once again, larger firms tend to sponsor a lower percentage of academic research locally. At the two digit proximity level, the presence of competitor funding at a local university is positively related to the firm's own local academic support percentage. As far as industry effects, electric utilities tend to be local sponsors. Using a broader definition of locality, the one digit zip code concordance, does not produce any appreciable improvement in results. The rightmost column of Table 13 presents estimation results with the Olsen two-step procedure, which can provide consistent parameter estimates and, unlike Tobit estimates, can account for possible

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12 The Olsen two-step linear probability procedure is less commonly used than the Heckman procedure, but computationally more tractable within SAS. To attain identification, I dropped the firm age variable, which is not a dummy variable and which was statistically insignificant in other regressions. Only four of the 374 observations used in the Olsen analysis had predicted probability values falling outside the 0 to 1 range.

Table 13 Other Estimations Of Firm's Local Funding Percentage

Eq. 8 estimated	COLOCPER Tobit N=961 2 digit zip	COLOCPER Tobit N=961 1 digit zip	COLOCPER Olsen proc. N=374 2 digit zip
Log(EMP)	-0.17^{***} (-2.92)	-0.12^{***} (2.73)	0.070 (0.78)
$Log(EMP)^2$	0.014^{***} (3.20)	0.097^{***} (2.87)	-0.011 (-1.43)
Log(AGE)	-0.056 (-1.48)	-0.00043 (-0.015)	
Log(COMPETRES)	0.021^{***} (3.32)	0.0023 (0.47)	-0.011 (-1.02)
CHEMICAL	-0.064 (-0.37)	-0.16 (-1.16)	-0.15 (-1.59)
DRUG	-0.14 (1.14)	-0.064 (0.68)	-0.26^{***} (-3.64)
MACHINE	0.14 (0.84)	0.12 (0.94)	-0.056 (0.58)
COMPUTER	0.085 (0.78)	0.16^{**} (1.96)	-0.0022 (-0.037)
AEROSPACE	0.10 (0.37)	0.012 (0.054)	-0.091 (-0.60)
INSTRUMENT	0.015 (0.15)	0.044 (0.54)	-0.13^{**} (-2.36)
UTILITY	0.44^{***} (2.84)	0.49^{***} (4.09)	-0.087 (-0.50)
TELECOMM	0.14 (0.50)	0.19 (0.90)	0.26^{**} (2.10)

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Table 13 Other Estimations Of Firm's Local Funding Percentage

(continued from previous page)

Eq. 8 estimated	COLOCPER Tobit N=961 2 digit zip	COLOCPER Tobit N=961 1 digit zip	COLOCPER Olsen proc. N=374 2 digit zip
R&D	-0.076	0.037	-0.41***
	(-0.57)	(0.36)	(-5.20)
Constant	0.42**	0.63***	1.53***
	(2.00)	(3.91)	(3.85)
Olsen Variable: 1-fitted value			1.03
			(1.13)
Geographic dummies	present	present	present
Log Likelihood	-793	-877	
Adjusted R^2			0.32

T-statistics are in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

discontinuity in the dependent variable[13]. This set of estimations only includes the 374 observations in which the dependent variable is not zero. Only industry dummy variables are statistically significant, which I interpret to mean that the discontinuities in the dependent variable are not major. Even after controlling for size and age, DRUG, R&D, and INSTRUMENT firms seem to sponsor low percentages of their academic research at local institutions, while telecommunication firms sponsor high percentages locally.

To explore the absolute level of local research involvement, I next estimate the following equation:

$$(9) COLOCTOT_i = f(EMP_i(-), EMP^2_i(+), AGE_i(-), COMPETRES_j(?), I, R) + u_i$$

Variables once again were expressed in natural logarithmic form. This is the same specification as equation 8, only with addition of the quadratic term and with the dependent variable expressed in absolute dollar rather than in percentage terms. Results of estimations using Tobit and the Olsen procedure appear in Table 14.

The relationship between firm size (EMP) and absolute local research sponsorship is first negative (negative coefficient for EMP) before turning positive (positive coefficient for quadratic term). Using the estimated coefficients from the Tobit estimation of the two digit zip code analysis, I compute that the elasticity of local research funding with respect to firm size turns positive at approximately 200 employees and exceeds unity at over 20,000 employees. The finding of increasing absolute funding totals with size is consistent with the findings of Chapters II and III. Industry effects are less pronounced, with only utilities sponsoring more research locally after controlling for other characteristics. In the Tobit estimations, there are indications that utilities and R&D laboratories underwrite more local research. At a very local level (two digit zip code zone), the firms

13 Such discontinuity may result if firms only sponsor academic research projects in excess of a certain amount.

Table 14 Estimations of Firm's Local Funding Amount

Dependent Variable: Log(COLOCTOT)

	Eq. 9 Tobit N=961 2 digit zip	Eq. 9 Tobit N=961 1 digit zip	Eq. 9 Olsen proc. N=374 2 digit zip
Log(EMP)	-1.14***	-0.85***	0.24
	(-3.30)	(-3.03)	(0.44)
Log(EMP)^2	0.11***	0.084***	-0.013
	(4.16)	(4.02)	(-0.27)
Log(AGE)	-0.27	-0.023	
	(1.26)	(0.13)	
Log(COMPETRES)	0.14***	0.023	-0.054
	(3.81)	(0.78)	(-0.80)
CHEMICAL	0.094	-0.42	-0.45
	(0.096)	(-0.53)	(-0.81)
DRUG	-0.21	0.21	-0.042
	(-0.31)	(0.38)	(-0.10)
MACHINE	0.88	0.70	-0.37
	(0.92)	(0.92)	(-0.70)
COMPUTER	0.43	0.82	-0.60
	(0.69)	(1.59)	(-1.61)
AEROSPACE	0.76	0.22	-0.42
	(0.48)	(0.17)	(-0.76)
INSTRUMENT	0.34	0.49	-0.52
	(0.56)	(0.98)	(-1.56)
UTILITY	2.35***	3.02***	-0.32
	(2.59)	(3.68)	(-0.32)

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Table 14 Estimations of Firm's Local Funding Amount

(continued from the previous page)

Dependent Variable: Log(COLOCTOT)

	Eq. 9 Tobit N=961 2 digit zip	Eq. 9 Tobit N=961 1 digit zip	Eq. 9 Olsen N=374 2 digit zip
TELECOM	-0.024	0.57	-0.65
	(-0.015)	(0.41)	(-1.23)
R&D	0.55	1.36**	-0.33
	(0.73)	(2.17)	(-0.69)
Constant	1.77	2.78***	14.55***
	(1.48)	(2.81)	(6.26)
Olsen Variable: 1-fitted value			7.87
			(1.47)
Geographic dummies	present	present	present
Log Likelihood	-660	-688	
Adjusted R squared			0.167

T-statistics are in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

with greater competitor funding at local institutions also interact more with those institutions. However, within the larger geographic area represented by a one digit zip code area, COMPETRES loses statistical significance, just as in the company percentage estimations. Firms sponsor more research at university funded by competitors if the university is very close, but not if it is distant. This tendency suggests that spillovers from academic research are geographically mediated.

Tobit results using a one-digit zip code area produce results similar to those using the two-digit definition of locality. The Olsen procedure estimation found no statistically significant variables.

In summary, large firms and drug firms sponsor a lower percentage of their academic research at local universities, while small firms and utilities sponsor a higher percentage locally. The size finding is consistent with the hypothesis that search and monitoring costs limit small firms to local research sponsorship. There is only limited evidence to support the view that newly-established firms sponsor a greater proportion of their work locally. However, examining the absolute amount of local academic sponsorship seems to suggest that more complicated factors are at work, as the local research volume initially decreases with size, before increasing. Finally, the amount and percentage that a firm sponsors locally is positively related to the funding of its competitors in the region. This result is consistent with the notion that local firms enjoy infrastructural benefits from a high volume of academic research, and that research spillovers are localized.

IV.10 Conclusions

This chapter has examined the economic geography of university-industry research relationships from two perspectives. Using cross-sectional data on one form of these relationships, industry-sponsored academic research, I have examined two sets of hypotheses involving a university department's industrial funding and a firm's local research funding.

In the case of research funding from local firms, I found that the determinants of a university department's absolute funding level are more readily identified than those of the relative amount, with the key determinant of this local industrial funding level being faculty size. Larger universities interact more with local firms because they interact more with firms in general. This finding suggests that scale effects outweigh geographic effects in university research. Assuming department size to be endogenous, size effects may be important at the local, but not the global, level because firms are most concerned with the number of faculty members with whom they can interact frequently. An alternate explanation is that larger departments have more resources to solicit industry support. Departmental quality seems to only be significant in explaining federal research support funding.

In examining a corporation's research funding at local universities, I find evidence that small firms sponsor more academic research locally in percentage terms, possibly because they have lesser search and monitoring capabilities. Firms fund more academic research in geographic regions where their competitors do, indicating strong agglomeration effects by industry. This effect disappears when the geographic region in question encompasses several states. In addition, there are industry effects in localized academic research. Regional industries (electric utilities) as well as those emphasizing more applied work (computers) tend to use academic resources locally, though computer firms do so within a larger geographic region. In contrast, firms in the drug and R&D industries, where the knowledge is more basic and universal, sponsor a greater proportion of research globally.

The firm's funding of local universities is more readily explained as a percentage of its university funding than as an absolute amount. Firms may have distinct strategies governing their interactions with academia (Gjostein 1991) so that percentage measures may apply. Absolute dollar measures get confounded by the large differences in the total amounts that firms sponsor research. I conjecture that firms may set aside an amount for sponsored research, an amount dependent upon firm size, before deciding where to allocate it, an allocation dependent upon geographic considerations.

The chapter's findings have several policy implications. Having larger academic departments appears to foster more sponsored research with local firms, likely fostering technology transfer between university and industry. Having excellent departments, on the other hand, may attract sufficient federal funding to make or keep those departments large. Policy-makers may seek to target their efforts at the firms most likely to benefit from academic laboratories, namely the small firms, the newly-established firms, the utilities, and the computer firms. Industry-specific initiatives targeted toward the drug and R&D industries will likely benefit non-local firms to a large extent.

These results are consistent with the observation that no simple recipe exists for effective university-industry interaction, that promoting technology transfer and regional growth through academia is more of an art than a science. Many excellent universities have limited regional impact, while size coupled with quality may enhance impact. The effectiveness of universities in driving local economic growth also seems to be related to the characteristics of firms in the region.

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 230

	LTOTIND	LLOCIND2	LLOCIND1	LNLOCIN2	LNLOCIN1	LFEDRES	LQUAL	LFAC	LFEDEQ
LTOTIND	1.00000 0.0	0.27878 0.0001	0.19013 0.0038	0.10349 0.1176	0.09189 0.1649	0.22506 0.0006	0.32364 0.0001	0.07629 0.2491	0.20605 0.0017
LLOCIND2	0.27878 0.0001	1.00000 0.0	0.67170 0.0001	0.12533 0.0577	0.10167 0.1242	0.20918 0.0014	0.27303 0.0001	0.22148 0.0007	0.19823 0.0025
LLOCIND1	0.19013 0.0038	0.67170 0.0001	1.00000 0.0	0.26727 0.0001	0.13236 0.0449	0.11316 0.0868	0.27010 0.0001	0.19801 0.0026	0.07843 0.2361
LNLOCIN2	0.10349 0.1176	0.12533 0.0577	0.26727 0.0001	1.00000 0.0	0.87086 0.0001	0.17875 0.0066	0.22286 0.0007	0.22961 0.0004	0.15614 0.0178
LNLOCIN1	0.09189 0.1649	0.10167 0.1242	0.13236 0.0449	0.87086 0.0001	1.00000 0.0	0.24308 0.0002	0.19507 0.0030	0.22787 0.0005	0.17545 0.0077
LFEDRES	0.22506 0.0006	0.20918 0.0014	0.11316 0.0868	0.17875 0.0066	0.24308 0.0002	1.00000 0.0	0.27920 0.0001	0.44221 0.0001	0.78712 0.0001
LQUAL	0.32364 0.0001	0.27303 0.0001	0.27010 0.0001	0.22286 0.0007	0.19507 0.0030	0.27920 0.0001	1.00000 0.0	0.09559 0.1484	0.26389 0.0001
LFAC	0.07629 0.2491	0.22148 0.0007	0.19801 0.0026	0.22961 0.0004	0.22787 0.0005	0.44221 0.0001	0.09559 0.1484	1.00000 0.0	0.38501 0.0001
LFEDEQ	0.20605 0.0017	0.19823 0.0025	0.07843 0.2361	0.15614 0.0178	0.17545 0.0077	0.78712 0.0001	0.26389 0.0001	0.38501 0.0001	1.00000 0.0
LSTATRND	1.00000 0.0001	0.27878 0.0001	0.19013 0.0038	0.10349 0.1176	0.09189 0.1649	0.22506 0.0006	0.32364 0.0001	0.07629 0.2491	0.20605 0.0017
LFIELDRD	0.02617 0.6930	0.08622 0.1926	0.09960 0.1321	0.22558 0.0006	0.21993 0.0008	-0.01302 0.8443	0.18275 0.0054	0.06774 0.3063	-0.00779 0.9065
LFEDRND	0.09180 0.1653	0.06131 0.3546	0.10176 0.1239	0.12009 0.0691	0.11217 0.0897	0.35554 0.0001	0.00739 0.9112	0.58395 0.0001	0.35768 0.0001
LPOPGRO	0.69429 0.0001	0.23008 0.0004	0.17886 0.0065	0.09367 0.1558	0.09344 0.1578	0.17520 0.0077	0.25501 0.0001	0.07378 0.2651	0.12297 0.0626
LGSP	0.92983 0.0001	0.27484 0.0001	0.16732 0.0110	0.06718 0.3104	0.05583 0.3994	0.20321 0.0020	0.28980 0.0001	0.09779 0.1393	0.15105 0.0219
FEDPER	0.30748 0.0001	0.06793 0.3050	-0.03500 0.5974	0.04692 0.4789	0.08756 0.1858	0.56368 0.0001	0.32853 0.0001	0.07502 0.2571	0.53864 0.0001
LOC1PER	0.12247 0.0637	0.44998 0.0001	0.59828 0.0001	-0.31282 0.0001	-0.51255 0.0001	-0.10359 0.1172	0.06095 0.3575	-0.01294 0.8453	-0.08302 0.2097
LOC2PER	0.15547 0.0183	0.59175 0.0001	0.35662 0.0001	-0.51475 0.0001	-0.47081 0.0001	0.01046 0.7807	0.04504 0.4967	-0.04248 0.5215	-0.01148 0.8625

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 230

	LSTATRND	LFIELDRD	LFEDRND	LPOPGRO	LGSP	FEDPER	LOC1PER	LOC2PER
LTOTIND	1.00000	0.02617	0.09180	0.69429	0.92983	0.30748	0.12247	0.15547
	0.0001	0.6930	0.1653	0.0001	0.0001	0.0001	0.0637	0.0183
LLOCIND2	0.27878	0.08622	0.06131	0.23008	0.27484	0.06793	0.44998	0.59175
	0.0001	0.1926	0.3546	0.0004	0.0001	0.3050	0.0001	0.0001
LLOCIND1	0.19013	0.09960	0.10176	0.17886	0.16732	-0.03500	0.59828	0.35662
	0.0038	0.1321	0.1239	0.0065	0.0110	0.5974	0.0001	0.0001
LNLOCIN2	0.10349	0.22558	0.12009	0.09367	0.06718	0.04692	-0.31282	-0.51475
	0.1176	0.0006	0.0691	0.1568	0.3104	0.4789	0.0001	0.0001
LNLOCIN1	0.09189	0.21993	0.11217	0.09344	0.05583	0.08756	-0.51255	-0.47081
	0.1649	0.0008	0.0897	0.1578	0.3994	0.1858	0.0001	0.0001
LFEDRES	0.22506	-0.01302	0.35554	0.17520	0.20321	0.56368	-0.10359	0.01846
	0.0006	0.8443	0.0001	0.0077	0.0020	0.0001	0.1172	0.7807
LQUAL	0.32364	0.18275	0.00739	0.25501	0.28980	0.32853	0.06095	0.04504
	0.0001	0.0054	0.9112	0.0001	0.0001	0.0001	0.3575	0.4967
LFAC	0.07629	0.06774	0.58395	0.07378	0.09779	0.07502	-0.01294	-0.04248
	0.2491	0.3063	0.0001	0.2651	0.1393	0.2571	0.8453	0.5215
LFEDEQ	0.20605	-0.00779	0.35768	0.12297	0.15105	0.53864	-0.08302	-0.01148
	0.0017	0.9065	0.0001	0.0626	0.0219	0.0001	0.2097	0.8625
LSTATRND	1.00000	0.02617	0.09180	0.69429	0.92983	0.30748	0.12247	0.15547
	0.0	0.6930	0.1653	0.0001	0.0001	0.0001	0.0637	0.0183
LFIELDRD	0.02617	1.00000	0.16351	0.00478	0.04267	0.08620	-0.02214	-0.06031
	0.6930	0.0	0.0130	0.9425	0.5197	0.1927	0.7384	0.3626
LFEDRND	0.09180	0.16351	1.00000	0.00163	0.10710	0.21663	0.03541	-0.01626
	0.1653	0.0130	0.0	0.9803	0.1052	0.0009	0.5931	0.8062
LPOPGRO	0.69429	0.00478	0.00163	1.00000	0.71023	0.17264	0.07971	0.12735
	0.0001	0.9425	0.9803	0.0	0.0001	0.0087	0.2285	0.0538
LGSP	0.92983	0.04267	0.10710	0.71023	1.00000	0.25543	0.11062	0.17315
	0.0001	0.5197	0.1052	0.0001	0.0	0.0001	0.0942	0.0085
FEDPER	0.30748	0.08620	0.21663	0.17264	0.25543	1.00000	-0.04949	0.02797
	0.0001	0.1927	0.0009	0.0087	0.0001	0.0	0.4551	0.6730
LOC1PER	0.12247	-0.02214	0.03541	0.07971	0.11062	-0.04949	1.00000	0.70200
	0.0637	0.7384	0.5931	0.2285	0.0942	0.4551	0.0	0.0001
LOC2PER	0.15547	-0.06031	-0.01626	0.12735	0.17315	0.02797	0.70200	1.00000
	0.0183	0.3626	0.8062	0.0538	0.0085	0.6730	0.0001	0.0

Appendix B: Hausman Tests on 2SLS Estimation of Equations (1) and (2)

N=230	Eq. 1 Log(TOTIND)	Eq. 2 Log(FEDRES)
LFEDRESHAT	8.20*** (19.38)	
LTOTINDHAT		2.62*** (4.48)
Log(QUAL)	-0.70*** (-17.90)	0.057* (1.66)
Log(FAC)	-5.93*** (-17.14)	-0.84** (-2.05)
Log(FEDRES)	-0.014 (-0.51)	
Log (TOTIND)		0.036 (0.34)
PUB	1.49 (0.91)	-2.80 (-1.20)
Log(FEDRND)		-0.92*** (-2.91)
Log(FIELDRND)	0.71*** (8.97)	
ENGINEERING	10.27*** (20.35)	-5.00*** (-5.46)
COMPUTER SCI.	16.97*** (19.11)	-4.05*** (-6.05)
BIOLOGY	-2.14*** (-9.33)	0.071 (0.13)
Constant	-102.22*** (-18.03)	-1.91 (-0.38)
University dummies	present	present
Root MSE	0.82	2.02
R-squared	0.802	0.561
Adjusted R-squared	0.764	0.476

T-statistics are in parentheses.

Significant coefficients are starred.

Appendix C: Hausman Tests on Equations (3), (4), and (5)

N=230	Eq. 3 Log(LOCIND)	Eq. 4 Log(NLOCIND)	Eq. 5 Log(FEDRES)
LLOCINDHAT		-0.082	-0.038
		(-0.48)	(-0.30)
LNLOCINDHAT	-0.43		1.10***
	(-0.53)		(3.72)
LFEDRESHAT	-0.030	0.14	
	(-0.090)	(0.84)	
Log(QUAL)	0.10	0.020	0.020
	(1.19)	(0.42)	(0.65)
Log(FAC)	2.08***	0.65*	-0.22
	(2.99)	(1.79)	(-0.72)
Log(NLOCIND)	-0.028		-0.0028
	(0.20)		(-0.062)
Log(LOCIND)		0.00099	-0.014
		(0.027)	(-0.59)
Log(FEDRES)	0.027	-0.0055	
	(0.12)	(-0.049)	
Log (GSP)	-28.36**		
	(-2.16)		
Log(POPGRO)		0.093	
		(0.36)	
PUB	-16.78**		-0.53
	(-2.37)		(-0.52)
Log(FEDEQ)			0.46***
			(11.17)
Log(FEDRND)			-0.64***
			(-2.62)

continued on next page

Appendix C: Hausman Tests on Equations (3), (4), and (5)

(continued from previous page)

N=230	Eq. 3 Log(LOCIND)	Eq. 4 Log(NLOCIND)	Eq. 5 Log(FEDRES)
Log(STATRND)	15.67		
	(1.75)		
Log(FIELDRND)		0.56**	
		(2.43)	
ENGINEERING	2.14	1.50***	-2.33***
	(1.38)	(2.81)	(-3.22)
COMPUTER SCI.	-0.33	0.041	-1.32***
	(-0.24)	(0.057)	(-2.92)
BIOLOGY	-0.22	0.29	0.64
	(-0.20)	(0.52)	(1.54)
Constant	223.83**	2.95	5.66*
	(2.46)	(1.07)	(3.06)
Univ. dummies	present	present	present
SSE	4384.04	1153.84	445.78
SSE of constrained equation	4390.78	1159.28	478.62

T-statistics are in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.
The Hausman test is performed in this set of three equations as an F-test on the joint significance of the fitted values.

Appendix D: Hausman Tests on Equations (6) and (7)

N=230	Eq. 6	Eq. 7
Dependent variable	LOCPER	FEDPER
FEDPERHAT	0.021 (0.091)	
LOCPERHAT		-2.47 (-1.51)
Log(QUAL)	0.0009 (0.20)	0.0071** (2.32)
Log(FAC)	-0.014 (-0.61)	-0.044 (-1.53)
LOCPER		-0.034 (-0.69)
FEDPER	-0.073 (-0.69)	
Log(FEDEQ)		0.027*** (5.51)
Log(STATRND)	-0.093 (-0.36)	
PUB	-0.25 (-0.65)	-0.47 (-1.61)
ENGINEERING	-0.054 (-1.05)	-0.20** (-2.35)
COMPUTER SCI.	-0.00098 (-0.14)	-0.096** (-2.13)
BIOLOGY	0.0066 (0.11)	-0.076* (-1.78)
Constant	1.01 (0.47)	0.98*** (2.74)
University dummies	present	present
Root MSE	0.246	0.168
R-squared	0.189	0.624
Adj. R-squared	0.033	0.551

Test statistics are in parentheses. Significant coefficients at 10%, 5%, and 1% levels are starred, double-starred, and triple-starred respectively.

V. Concluding Comments

This thesis has conducted an empirical examination of one important form of university-industry interaction, that of sponsored research. It has used a new data set to examine the widespread and growing cooperation between the private and academic sectors, a cooperation with implications for firm innovation, academic research, and regional economics.

In Chapter I, I described these research relationships and important issues raised. A description of sponsored research and the data set appeared in Chapter II. The subsequent examination of key sponsored research characteristics at the firm and university department level of detail is new to the literature, to the best of my knowledge. In Chapter III, I explored the question of how firms may appropriate the results of the sponsored projects. I examined the economic geography of sponsored research agreements in Chapter IV. This chapter is the first known work to examine the role that university departmental characteristics play in regional impact to examine hypotheses on the research sponsorship locale of firms.

From these examinations, certain themes continually emerge, themes with implications for decision makers in all sectors.

Implications

The analysis in the thesis has implications for business executives, although a lack of output information precludes an evaluation of sponsored research effectiveness. The data examination and regression analyses indicate that university-industry research relationships are intimately connected with industrial technical developments, not with philanthropy or tax breaks. Firms in industries with a greater pace of technological progress, including drugs and electronics, sponsor more academic work. This industrial funding of academic research appears to be a substitute for government support of university laboratories. Thus, if they haven't already, executives in technology-intensive industries may benefit from explicitly formulating strategies on whether and how to interact with academia. They may need to consider the evidence presented in this thesis that companies seem to employ several different strategies in using academic research, including limited involvement with a single campus, extensive involvement with a few campuses, and extensive involvement spread across the country.

This thesis has implications for faculty members and university decision-makers. It seems that large technology-oriented firms in a few industries naturally represent the most promising prospects for fruitful research interactions. However, the extensive involvement by small service firms, such as architectural and engineering concerns, may indicate particular needs and oppportunities to be addressed. Much of the recent growth in university funding of academia seems to have resulted from a greater number of research sponsors becoming involved. To the extent that this trend may not continue, university officials may be wise to expand the benefits provided for existing sponsors. The large historical increase in the number of departments interacting with academia suggests that officials could explore expanding the departments involved with industry, a development that could offer firms a broader, multi-disciplinary approach to business problems.

Based on the findings of this thesis, policy-makers should emphasize faculty size rather than faculty quality in their efforts to boost university-industry interaction on a local basis. They might consider initiatives designed to free faculty time for interactions with companies and to promote corporate awareness of the practical aspects of academic research. Though the data set used in the economic geography analysis is not suited to answering questions of causality, university quality may be important in securing the federal funds needed to have larger faculty sizes. Finally, because small firms are the ones sponsoring high percentages of academic research locally, policy-makers concerned about regional economic growth may consider initiatives targeted toward small firms, as well as electric utilities.

The Future of University-Industry Cooperation

What next for the future of university-industry research relationships? Analysis of the data set has revealed important aspects of university-industry research relationships that shed light on possible developments. In this section, I conjecture about what the future holds for these interactions. My central assumption is that universities do react to environment, but very slowly. Their insulation from the direct, rapid, and merciless forces of market competition combined with the search for timeless principles make change in the higher education sector incremental at best. Nevertheless, universities are affected by fundamental forces within society, for the very nature of their mission involves understanding and contributing to that society.

Among the major forces likely to affect tomorrow's university are the end of the U.S. baby boom combined with continued federal and state budget difficulties. The reduced student enrollments and limited growth in government research expenditures likely mean that university budgets will face increasing budget pressures. While the controversies surrounding academic research overhead accounting and accusations of research fraud in the early 1990s will likely subside, universities will still need to respond to the fundamental stagnation of growth in government research and tuition funds. If the past is any indication, their response will come in the direction of seeking industry-support involving more firms, more modes of interaction, and more promises of assistance in the competitive struggle. These efforts have transformed the ivory towers of yesteryear into today's sophisticated enterprises keenly attuned to the needs of corporate managers and researchers. It is likely that, as universities place greater emphasis on industry needs and as industry realizes the potential from academic cooperation, the volume of industry support of university research will continue to increase. Eventually, however, the trend over much of the last two decades will level off because of two factors. From the university side, questions that polarized many campuses in the mid 1980s regarding faculty autonomy and conflicts of interest will arise again as the industry presence on campuses become more pronounced. From the industry side, if growth in research volume continues to result primarily from a greater number of sponsors, then the economy naturally has to reach a saturation point at which few additional firms want to fund academia.

In addition, the university funding base is a fragile one, with a high concentration of funding coming from a few large corporations. Any factors affecting the decision-making of these handful of corporations, such as change in leadership philosophy or financial viability, could adversely impact university investigators to a large extent. In addition to exposure to funding from a few firms, universities have been heavily dependent on research funding from industries with uncertain prospects. Political pressures to reduce healthcare costs may adversely affect the profitability of the main academic research sponsor, the drug-related firms. Similarly, global political developments have dampened prospects for another major group of research sponsors: the "defense" industry (comprised of substantial portions of the electronics, aerospace, and other industries) Finally, the substantial contract amounts accounted for by utilities are not likely to increase dramatically in the future. The growing emphasis on conserving energy conservation and deregulating energy markets means that overall utility growth will be modest in the future, and that appropriability advantages from monopoly power may become eroded. Firms working with emerging technologies may potentially represent the next major source of growth in these research relationships, though at this point their impact is not clear.

Turning to the role of academia in economic growth, there are several reasons that tomorrow's universities will likely have a smaller role in fostering regional economic growth. Declining student enrollments lead to reduced faculty sizes, which in turn limit the ability of an institution to interact with local firms via faculty consulting or technical guidance. Further, budget concerns will continue to lead to the consolidation of departments and entire campuses, further reducing the possibilities of boosting the regional economy. Finally, to the extent that R&D is becoming more of a global phenomenon (Westney 1991), overseas corporations will increase their involvement with U.S. researchers, tending to promote a global dissemination of knowledge.

Future Work

There are several natural extensions of the line of inquiry initiated in this thesis. First, the benefits to sponsored research can be evaluated. Because the existing data set only includes "cost" information, a more complete examination of university-industry research relationships would use data on the outputs of these relationships. The output data would likely include both invention measures of publications and patents resulting from interactions, as well as innovation measures such as products or processes. The modes in which different types of firms, particularly small ones, interact with academia represents an avenue yet unexplored. It would be interesting to examine appropriability mechanisms more directly (perhaps through case studies), and to explore to what extent these mechanisms vary differ between firms. Finally, the thesis has not explored other important means of interaction, such as faculty consulting and patent licensing. Though these interactions constitute important means of technology transfer between the academic and private sectors, we know very little about the characteristics of these other interaction mechanisms.

The possible extensions to this thesis described above are by no means exhaustive. Our understanding of the economics of university-industry research relationships is still in a preliminary stage. As a result, the topics discussed in this thesis offer many possibilities for further inquiry, both theoretical and empirical.

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