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AUTHOR Tornquist, Kristi; And Others
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ABSTRACT

A study was done of the transfer of knowledge between academic and firm scientists. Beginning with theories of university and university scientist behavior and a theory of firm and firm scientist behavior, the research used a bibliometric analysis of articles prepared by firm-based scientists within the computer equipment and aircraft industries. Preliminary results indicate that the rate of university collaboration by firms in these industries is 12 percent and that the rate of utilization of university research is 43 percent with university-based publications the most heavily cited of all author affiliation categories. University collaboration and utilization varied across industries and by firm size: the computer equipment industry had four times as many actively publishing firms as the aircraft industry. While individual article characteristics consistently had predictive value for firm publication practices, proximity to university research did not. In addition, industrial research drew on university produced papers more frequently for theoretical research than for applied work. Larger firms used university research, and produced and used theoretical work more often than smaller firms while papers reflecting applied research were more often produced by smaller firms. Included are extensive tables of data in an appendix and 51 references. (JB)

FIRM UTILIZATION OF UNIVERSITY SCIENTIFIC RESEARCH

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Kristi Tornquist
Graduate Student in Higher Education and
Research Assistant, Management Information Division
University of Minnesota

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Correspondence should be sent to: Kristi Tornquist, Management Information Division, University of Minnesota, 40 Wulling Hall, 86 Pleasant St. S.E., Minneapolis, MN 55455 (612-624-1649)

ABSTRACT

This paper examines the transfer of knowledge between academic and firm scientists. The methodology employed is a bibliometric analysis of articles prepared by firm-based scientists within the computer equipment and aircraft industries. Preliminary results indicate that the rate of university collaboration by firms in these industries is 12% and the rate of utilization of university research is 43%. University collaboration and utilization varied across industries and by firm size. While individual article characteristics consistently had predictive value for firm publication practices, proximity to university research did not.

University research is often perceived as an important ingredient in the development of new products and processes in the industrial sector. While several models of scientific and technological coupling have been proposed (Braun, 1985; Lieberman, 1978), the most popular perception is that industry draws upon theoretical scientific inquiry taking place in universities as a basis for its own, more applied, research (Dresch, 1988; Layton, 1971). This belief has motivated federal, state, and private sector university research funding initiatives since World War II (National Science Foundation [NSF], 1982). Only recently have sociologists and economists begun to study the actual connections between industry and university research activities, and it appears that the interaction between the two sectors is in flux and is more complex than was originally surmised (Knorr-Cetina, 1982; McGinn, 1991).

Numerous studies and reviews, as well as increased public attention, have been directed toward these changing relationships. Much of this interest in academic and industrial interactions appears to arise out of an enhanced concern over U.S. economic well-being and tightening budgets within academe (Matkin, 1990, pp. 2-3; Rogers, 1988, pp. 446-7). These studies have most often resulted in analyses taking the form of descriptions of past and current interactions (Geiger, 1992; Matkin, 1990), cautionary tales (Low, 1983, pp. 74-79; Varrin & Kukich, 1985), or suggestions for change (Abu-Laban, 1989; Powers, 1988). Certainly, cases of firm and industry cooperation abound (Konecci & Kuhn, 1985, pp. 224-6).

Amidst this scrutiny of scientific and technological interaction there is an unshakable faith that research taking place in universities "trickles down" to firms, providing benefits to society as a whole. Studies attempting to look at this trickle-down effect have relied most often on case studies (Goldhor & Lund, 1983; Johnson, Tornatzky & Schlaaff, 1984; NSF, 1973), surveys and interviews (Boyle, 1986; Johnson & Tornatzky, 1984; Matkin, 1990), or patent data (Jaffe, 1989), none of which is without limitations. Most note that there is a dearth of empirical work in this area.

Alternatively, our research uses bibliometrics (a term Pritchard applied to methodologies used in "studies which seek to quantify the processes of written communications," 1969, p. 349) in an endeavor to study at a detailed level the transfer of research knowledge from the academic to the industrial sector. In doing so we examine the concerns being raised today by government officials, taxpayers, and industry: Does university research, particularly that taking place in the hard sciences which receives enormous external funding (NSF, 1989), really make its way to the private sector? Further, what factors have a bearing on how this research is transferred? Bibliometrics, as a methodology, has been applied only on a limited basis to these questions (as reported by Small & Greenlee, 1979), although it has been used widely in the examination of journals, disciplines, and specialties (Schubert, 1988).

In this study, then, we attempt to make inferences about the extent to which firms utilize university research using publication and citation analysis in order to answer the following questions:

1. Is the research taking place within universities used by firms? Specifically, what percentage of citations of papers written by scientists within the aircraft and the computer equipment industries are made to university-affiliated work? How frequently do firm authors coauthor with university personnel?

2. What types of research do firms utilize? Do firms tend to cite theoretical or applied university research more often?

3. What factors influence firm usage of research? Specifically, what impact do characteristics of research endeavors, firms, industries, and proximate universities have on the publication practices of firm scientists?

Theoretical Context

Two theoretical arguments drive this study: first, a theory of university and university scientist behavior and second, a theory of firm and firm scientist behavior. Both of these theories are framed within the context of research incentives and the transfer of scientific knowledge. Knowledge transfer has two components: dissemination and utilization (Havelock, 1969). Given the nature of this study it is sufficient, from the university perspective, to consider only knowledge dissemination practices (i.e., the ways in which university and university scientists make research knowledge generated in these institutions available to the outside world, in this case, to industry). On the other hand, an analysis of firm knowledge utilization customs only is not enough given the selection of publications as a measure. Hence, firm dissemination practices are considered as well.

An additional component of scientific knowledge transfer is also of interest. The literature indicates that scientists make use of formal and informal channels of communication in varying degrees for both information dissemination and utilization purposes (Garvey, 1979; Nelson & Pollock, 1970). Thus, we consider university scientists' informal and formal knowledge dissemination, firm scientists' informal and formal utilization of this knowledge, and finally the propensity of firms and firm scientists to formally disseminate their research results.

University Scientist Behavior

It is well known that university science faculty have incentives both to conduct research and to publish their results (Fox, 1983), hence the oft-repeated phrase "publish or perish." It is believed, on the other hand, that there is little incentive for this research to be of any practical use (Miller & Cote, 1985, p. 116). In fact, university scientists are often perceived to be functioning in an "ivory tower" (Boyle, 1986). Certainly the popular perception of university activity has been that of scientists conducting basic theoretical research disseminated via formal publications which industry may choose to access.

Recent studies of university-industry interaction indicate that this characterization is not entirely true (Logan & Stampen, 1985; Nelson, 1988, pp. 319-321; Peters & Fusfeld, 1982), a result, in part, of the rising expense of outfitting laboratories and purchasing equipment. With the costs of conducting basic research escalating, scientists must convince their own institutions and granting agencies of the possible benefits of their research in order to receive the funding they require. Indeed, Drew incorporates the "Proposal," "Submission" and "Funding Decision" as integral components in his model of "The Modern Scientific Research Process" (1985, p. 11). University research output is less frequently linked to the particular needs of an individual firm as a means of engaging external funding, although these associations do exist (Blumenthal, Gluck, Louis & Wise, 1986), and industrial support of university research is increasing (Matkin, 1990, p. 9). In addition, changes in patenting practices on campuses have opened up the doors for science faculty to pursue more marketable research endeavors (Powers, Powers, Betz & Aslanian, 1988, pp. 190-194).

Still, there are several obstacles to university faculty actively collaborating with firm scientists (Peters & Fusfeld, 1982, p. 112) that are based on commonly held traditions of university scientist activity. The first obstacle, as mentioned above, is the perception that university scientists are more apt to conduct theoretical or "basic" research as opposed to being involved with more applied or developmental activities, although this distinction is somewhat arbitrary (Rosenberg, 1990, p. 169). A second obstacle is that university scientists most often function within the boundaries of a discipline (Tornatzky & Fleischer, 1990, p. 59-60). Neither of these conditions would appear to be the most conducive to product and process development activity (Allen, T. J., 1986; Miller & Cote, 1985). Finally, since the primary means of recognition and promotion for most university faculty is publications, collaborative endeavors with firms that entail publishing restrictions or delays could be at odds with an academic career (Zinser & Lewis, 1988, pp. 240-248). A related deterrent arises out of academic freedom concerns and conflict of interest issues at the level of both the individual and the institution. Thus, while university scientists are motivated to conduct research and disseminate their results, there still may exist limited incentives to direct their research toward industry needs.

Three primary vehicles by which university-generated knowledge is conveyed are the faculty (acting in a consultant role), graduates (hired as new employees), and publications (Matkin, 1990, p. 6). In order to obtain university-generated information, external agents must either pay the wages associated with the hiring of consultants and employees or expend the time and energy to scan the information available in publications. While it is possible, at least in part, to restrict knowledge conveyed by a person, knowledge in the form of publications is viewed as a public good. In addition, publications serve as the predominant formal means of communication both among academic scholars and between the academic community and researchers in other institutions (Fox, 1983).

Firm Scientist Behavior

Scientists within a firm, like those in universities, also have incentives to conduct research. However, their final outcomes, unlike their university counterparts', are not necessarily publications (Marquis & Allen, 1966, p. 1055), but instead, the discovery of results leading to the development of new products and processes that, it is hoped, will contribute to the financial well-being of the firm. Indeed, a firm's knowledge may only be disseminated through the new products and/or processes it markets. Thus, the rate of formal and informal dissemination of firm research may differ quite extensively from university knowledge transfer behavior (Price, 1965; Rosenbloom & Wolek, 1970).

Scientific research, in both the academic and industrial sectors, is a knowledge-based activity (Allen, T. J., 1986, p. 212; Tornatzky & Fleischer, 1990, p. 12). Hence, it would be expected that a scientist or group of scientists within a firm would rarely conduct research in an information vacuum. In particular, research endeavors build on past experience and training that are part of an individual's and/or firm's knowledge base (Nowotny, 1990, p.337). When considering new research and development, a firm and its scientists must evaluate their knowledge base and weigh both the time involved in and the costs of gathering or creating the information they need (Perez & Soete, 1988). While it is difficult, of course, to determine the value of knowledge, and the associated collection costs (Rosenberg, 1990, p. 166), these are, in part, a function of the rate at which the technologies in which the firm is involved are changing (Allen, T. J., 1986, p. 214).

When the costs of outside information retrieval are believed to be low, we expect the firm will look outward for information useful to its current research endeavors. In particular, when expected information gathering costs are perceived to be less than the expected information creation costs, we surmise that firms will be more apt to use externally generated research (Mowery, 1983a). This may take various forms: contracting with outside scientists or labs, using work that has been done by other firms or agencies (gathered from journals, patents, conferences, conversations), garnering knowledge in book format, hiring people with the requisite knowledge base, etc.

As one means of decreasing knowledge-gathering costs, one might speculate that the proximity of university research to a firm may impact the research the firm is doing, the information it uses for this research, and the informal and formal dissemination of the results (Miller & Cote, 1985; Perez & Soete, 1988, p. 468; Rogers, 1988). Certainly the preponderance of high-tech firms in the "Silicon Valley," along Massachusetts Route 128, or within the Research Triangle Park region, all located near major research universities, would suggest such interaction is taking place.

It is also conceivable that with changing technologies and increasing ease of transportation, physical proximity is becoming less important. In fact, Johnson, Tornatzky, and Schlaaff in their case study/survey research found that informal interaction was frequently utilized by cooperating scientists. This interaction took place by phone or meeting and "transcended organizational boundaries and distance" (1984, p. vi).

If, indeed, proximity is a factor in firm-university interaction, we conjecture that this interaction may take two different forms which are suggested by Mowery's discussion of the impact of firm size and research complexity on contractual relationships (1983b). One theory is that when firms and research universities are located near each other, scientists intermingle more frequently (information exchange costs are low), and the amounts and types of university research used are reflected in the citations that firm scientists make in formal publications. The expectation is that these person-to-person interactions would serve as conduits through which knowledge discovery, transfer, and interpretation could take place, and, in fact, Lieberman found that scientists who serve as an "intellectual bridge" between the scientific and technological sectors play an important role in knowledge transfer (1978). Firms far from university research, on the other hand, would be less apt to have this person-to-person interaction, less apt to inexpensively gather outside research, more apt to conduct their own in-house work, and less apt to cite external sources. In this version the formal means of communication are expected to mirror informal patterns.

An alternate hypothesis seems plausible as well. When firms and universities are co-located, personal interaction takes place, recent graduates are hired, and information can be perceived as an inexpensive collective knowledge pool to be dipped from whenever necessary. Formal acknowledgement in the form of citations to this type of information transfer may not be common. In contrast, firm scientists far from university research may be more apt to rely on journal articles and conference proceedings as information sources that, given their training in the scientific tradition, they then choose to cite. In this situation the formal and informal means of communication do not mirror each other, and instead take on distinct patterns. Jaffe gives credence to this second hypothesis in his discussion of "transport" mechanisms when he writes, "If the mechanism is primarily journal publications, then geographic location is probably unimportant in capturing the benefits of spillovers. If, however, the mechanism is informal conversations, then geographic proximity to the spillover source may be helpful or even necessary in capturing the spillover benefits" (1989, p. 957).

The above discussion suggests that university and firm scientists share some similar motivations to conduct research, but they may differ in their final products and communication patterns. In addition, the relationships between the sectors are complex and constantly fluctuating (Jaffe, 1989, p. 957; Miller & Cote, p. 116; Mowery, 1983a, p.31). It would seem that several interacting factors can affect associations between scientists in the two sectors and their resulting products as reflected in publication practices as well.

Method and Model

A random stratified sample of papers authored by firm-based scientists in the computer equipment and aircraft industries was taken. For this sample a set of equations was estimated to explain the occurrence of university co-authorship and the relative characteristics of the citations as functions of factors influencing the publication practices of firm scientists. These equations were derived from a general model predicated on the theory outlined above. With this model we explain not propensity to publish, but characteristics of firm-authored publications related to university utilization. Specifically we measure and explain publication variables reflecting interrelationships between research taking place in firms and in universities, including:

a) The occurrence of co-authorship of firm-based scientists with university-based personnel

b) The characteristics of the citations made by firm-based scientists including:

i) The number of citations per paper,

ii) The frequency of citations to university authored research,

iii) The combinations of theoretical and applied research that are cited, and

iv) The variation in time intervals between publication and citation.

Publications as a Measure of Knowledge Transfer

The dichotomous nature of formal and informal scientific knowledge transfer suggests a dilemma with the selection of publication practices of firm scientists as a proxy for university research utilization. In particular, much of the knowledge exchanged by scientists, especially by firm scientists, is often not expressed in journal article format, which is, at least, the conventional formal method of communication for university researchers (Allen, T. J., 197/, Garvey, 1979, p. 69). Still, studies confirm that scientists in nonacademic settings do indeed publish (Kraus, 1950, reported in Hagstrom, 1965; Metzler, 1956).

The fact that firm scientists publish their results less often than their university counterparts, effectively limits this study to a select set of researchers, firms, and industries. For example, Waldhart has shown that engineers who publish are more literature conscious than other engineers (1974). At the firm level, companies may vary because of proprietary interests in how restrictive their policies are towards employee publishing, limiting the companies we are able to include (Shrum, 1984, p. 80). In a similar manner, some industries publish more than others restricting our examination to those producing enough papers to reasonably study. This excluded the motor vehicle industry from our project, an industry which expends vast amounts of money on research and development (Powers, et al, 1988, p. 70) but seldom publishes.

An additional concern with publications as a measure of knowledge transfer is there is no guarantee that their content is in any way linked to an employee's work in a firm. It could well be that an article reports on "extracurricular" research conducted by the scientist or dissertation research that took place in a university setting prior to employment.

A further limitation is that publication characteristics, as we have made use of them, serve as proxies for several related scientific behaviors including both research utilization and dissemination practices and the idiosyncracies of individual scientists and the institutions in which they work. While these characteristics are not a pure measure of firm utilization of university research, they are, as a group, one of the few measures available for which data may be collected relatively inexpensively and unobtrusively on a large scale. Other measures (patents, surveys, case studies) have flaws as well, particularly in the level of detail at which publication and citation analysis excels. To study firm utilization of university research at a minute level, we have yielded some precision in our measurement device. That individual and firm citation and publishing practices are also included in the measure must be realized and considered in the analysis.

General Model

The general model appears as follows with appropriate variations given the dependent variable:

$P_{ijk} = f\{ A_{ijk}, F_{ij}, I_i, U_j \}$ where

i indexes the industry
j indexes the firm
k indexes the article

P_{ijk} are publication characteristics of paper k, from firm j, in industry i

A_{ijk} are characteristics specific to articles

F_{ij} are characteristics specific to firms

I_i are characteristics specific to industries

U_j are characteristics of universities located near firm j

The model is based on the assumption that four categories of factors (article, firm, industry, and university effects) influence the publication practices of scientists in firms. The first three are suggested in Tornatzky and Fleischer's (1990, pp. 66-67) review of industry/university cooperation; the fourth arises out of the above theoretical discussion.

Article effects (A_{ijk}).

At the most disaggregated level, individual differences among scientists and the "invisible colleges" (Crane, 1972) in which they interact effect whether they publish, with whom they coauthor, how frequently they cite, and who they cite (Fox, 1983). Certainly, as Rosenberg notes in his analysis of basic research activity in firms, "we have to distinguish between the motives of the individual scientists and the motives of the firm that employs them" (1989, p. 169). Variations in specific researchers and research endeavors are difficult to detect and expensive to measure at any meaningful level. Hence, we chose instead to use characteristics readily available from the sampled articles (number of coauthors, coauthor affiliations, and the theoretical or applied nature of the paper) as proxies for differences in research projects and the people involved.

<u>Firm effects</u> (F_{ij}).

At the next level of aggregation, the atmosphere of the working environment is expected to influence scientific knowledge utilization and dissemination behaviors. It is proposed the size of the firm, in particular, effects research interaction behaviors (Blumenthal, Gluck, & Louis, 1985; Mowery, 1983b) and hence, information collection practices. As mentioned above, because of possible proprietary interests, formal distribution of research results may be encouraged, discouraged, or tolerated by the firm. Thus, we selected as firm variables several characteristics that we were able to both measure and collect (annual sales, breadth of activity, and number of employees).

<u>Industry effects</u> (I_i).

At a quite aggregated level, characteristics of the industry can be expected to create a research environment reflected in publication practices and university research utilization (Allen, R. C., 1983; Fusfeld, 1983, p. 13). The age of the industry, the rate of technological change, and the number of firms all may have some impact on research and publishing behaviors. As we examine only two industries here, these industry characteristics are encompassed in a simple dummy variable. If this project is expanded to include other industries, specific variables should be included.

<u>University effects</u> (U_j).

As discussed in the preceding section, we hypothesize that the amount of university research taking place in the vicinity of the firm will impact the amount of research and/or the publication and citation practices of scientists within a firm. Firms that are located in the same geographic area (the Boston vicinity or the Silicon Valley, for example) will have a similar set of proximate university research characteristics. Firms that are in other locales may have significant variation in possible university impact factors. We considered several measures as proxies for possible university influences on a firm (total R&D expenditures, subject area R&D expenditures, graduate level completions, total completions, and university presence).

Specific Equations

Based on the general model given above, the following specific equations (outlined in Tables 1A and 1B) were developed to explain the research/publication practices taking place in these industries. The unit of analysis in all cases is an individual paper.

$$P1 = f\{ A2, A4, F1, F2, F3, I1, U1, U2, U3, U4 \} \qquad (1)$$

In Equation (1), P1 is a dummy variable for the presence of a university coauthor in the sampled article (1 if yes), A2 is a dummy for the theoretical nature of the paper (1 if the paper is theoretical), A4 is the total number of authors of the paper, F1 is the average of the firm's 1986 and 1987 annual reported sales in millions of dollars, F2 is the number of SIC codes in which the firm was active in 1986, I1 is a dummy for the industry (1 if aircraft), U4 is the total amount of university research expenditures in thousands of dollars within 100 miles of the firm, U1 is the proportion of U4 taking place in universities within 25 miles of the firm, U2 is the proportion of U4 within 26-50 miles of the firm, and U3 is the proportion of U4 within 51-75 miles.

$$P2 = f\{ A1, A2, A4, F1, F2, F3, I1, U1, U2, U3, U4 \} \quad (2)$$

Equation (2) appears similar to equation (1) with appropriate changes in article characteristics. In this case, P2 is the number of citations to previous research, and A1 is the dummy for coauthorship with university personnel (A1 = P1).

$$P3 = f\{ A1, A4, F1, F2, F3, I1, U1, U2, U3, U4 \} \quad (3)$$

In Equation (3), P3 is the proportion of citations within a sampled paper that have at least one university coauthor. The article characteristics are (A1) and (A4).

$$P4 = f\{ A1, A2, A4, F1, F2, F3, I1, U1, U2, U3, U4 \} \quad (4)$$

In Equation (4), P4 is the proportion of the citations within a sampled paper that are theoretical. Three article characteristics are included: A1, A2 and A4.

P5 = f{ A1, A3, A4, F1, F2, F3, I1, U1, U2, U3, U4 }   (5)

In Equation (5), P5 is the proportion of the citations within a sampled paper that are applied. In addition to article characteristics A1 and A4, an additional dummy variable (A3) for the applied nature of the paper (1 if the paper applied) was added.

P6 = f{ A1, A2, A4, F1, F2, F3, I1, U1, U2, U3, U4 }   (6)

In Equation (6), P6 is the average time lag between when the citations listed in a paper were published and the date of publication of this sampled paper. As in Equations (2) and (4), article characteristics A1, A2, A3 were included.

The definitions of all of the dependent and explanatory variables are shown in Tables 1A and 1B.

Insert Table 1 about here

The choice of whether to use actual counts of citations with certain attributes, the proportion of the total cites, or some fractional counting method in Equations (3), (4), and (5) was a carefully considered decision. Anderson, et al, discuss at length the pros and cons of fractional versus whole-counting (1988) cautioning that the selection of the counting procedure is critical to citation analysis. A fractional counting scheme was not selected for use in this study because the presence of a university coauthor in a particular citation was of more interest than the relative number of such authors. Raw counts of each citation characteristic did not seem appropriate either since these are so heavily dependent on the total number of citations per paper. In order to incorporate this effect, the proportions of the total citations with the desired characteristics were selected as dependent variables.

Sampling Design

As the preliminary work for a more extensive project, this study examines only the "Aircraft" (SIC 3721) and "Computer Equipment" (SIC 3573) industries. These industries were selected on the basis of their substantial R&D expenditures (Powers, et al, 1988, p. 70), their relative difference in age of firms, their level of government funding and involvement, and their variation in composition with respect to the number and size of firms. A stratified random sampling procedure was used separately for each industry to provide variation across the range of possible university distance and expenditure combinations in order to tease out, if possible, the effect of geographically proximate university research on firm publishing practices. Specifically, each firm was placed in a research dollars/distance stratum for its geographically closest institution (See Table 2). Two papers, when possible, were randomly sampled for each firm in order to ensure variation within an industry. In addition, ten papers were sampled, when possible, from each stratum, but for R&D/distance

categories with more than ten firms and at least two papers per firm, more than ten papers were taken. The sample of original articles was drawn from the authors listed in the 1986 and 1987 editions of the Current Contents Address Directory for firms active in the aircraft and computer equipment industries during those years.

Insert Table 2 about here

Data Sources

Several areas were problematic in data collection which has been true for similar studies as well (Jaffe, 1989; Small & Greenlee, 1979). Decisions were often imposed by limitations of the data sources. First, as noted above, the sample of articles was drawn from firms publishing in 1986 and 1987 because 1987 was the last year the source for sampling papers was available. Firms were selected on the basis of their inclusion under the two designated SIC codes in either the Million Dollar Directory (1986) or the Directory of Corporate Affiliations (1986). From the original sample of articles written by authors associated with these firms, items were deleted for which citation lists could not be located in Science Citation Index or by accessing the original article either in the University of Minnesota library, the Minneapolis Public library, or through interlibrary loan. These items tended to be obscure conference proceedings and, when possible, additional articles were sampled to replace them. The resulting sample consisted of 336 papers from 139 firms split between SIC codes as indicated in Table 3.

Insert Table 3 about here

Once a sampled paper's list of citations was located, these, along with the original paper, were searched in computerized data bases to determine author affiliations (Firm, University, Government, or Institute) and the applied/theoretical nature of the publication (labeled "treatment classifications"; see the Appendix for further explanation). When complete author information was not available, the original publication was sought in the University of Minnesota and University of Maryland libraries and in the Library of Congress. In this manner, it was possible to collect author affiliation information for 90% of the citations and treatment classification information for 68% of the citations.

Non-publication variables had data collection limitations too. Firm data, in particular, were difficult to locate since private firms are not required to report information, and in several cases, firms had suspended operations near the time of publication. Consequently we relied on a variety of sources for firm variables including 10K and annual reports when available, Ward's Business Directory, The Manufacturing Sector Master File: 1959-1987 produced by National Bureau of Economics Research, a computer industry reference publication entitled Data Sources, and, as a last resort, telephone calls to the various corporations. Through this process we were able to include annual sales, total SIC codes in which the firm was active, and number of employees as collectable and applicable firm variables.

University research expenditures data were obtained from the National Science Foundation publication, Academic Science/ Engineering: R&D Funds Fiscal Year 1987 (1989). Universities selected for our study included all those enumerated in this book in the total research categories and appropriate subject categories (environmental sciences, psychology, social sciences, and "other" sciences categories were not used). In addition, any universities not already selected but contained in the Carnegie Institute's list of Research I and II institutions or the U.S. Department of Education's list of doctoral institutions were added. The names of the 45 universities graduating the most students in bachelor's and graduate programs were appended if they were not already included. The list was completed by adding ten Canadian universities located near the U.S. border that matched the other criteria. The final compilation consists of a total of 265 colleges and universities.

Concentric distance circles were drawn around the location of each firm, and universities selected for the study were matched to the firm and placed in distance "bands" (1-25, 26-50, 51-75, and 76-100 miles). University total R&D expenditures for a firm within each of the distance categories were then computed. Further calculations were performed on these distance category sums to create the explanatory variables incorporated in the equations. This was done because it was not only gross dollars expended that was of interest, but also a weighting of these expenditures by distance to the firm. Hence, variables were required that provided information on how university expenditures were dispersed among the four bands. To create these measures, the amount of university research expenditures within one hundred miles of a firm was calculated by summing the amount in the four bands, then the proportion of this total was determined for the research expended within each band. The resulting proportions for the first three bands and the total university expenditures are the four university proximity variables incorporated in the equations. Graduation rates and subject area research expenditures were also considered as possible university variables, but because they were so highly correlated with university total research expenditures (correlations significantly ranging from .82 to .95), only the total dollars calculations were included.

Results

Variation in publishing practices between industries as measured by articles and references is presented in Table 3. The computer equipment industry had four times as many actively publishing firms as the aircraft industry, two thirds again as many sampled papers, and yet only two thirds the number of citations.

Insert Table 3 about here

Table 4 summarizes by industry the author affiliation and applied and theoretical nature of the sample. Of the total sample, a little over 12% of the papers had university-affiliated coauthors but this varied significantly by industry. As measured by citation practices, 43% of the cited papers had university coauthors, the largest of any author category, and this did not vary by industry. The applied and theoretical designations of both the papers and the citations also varied significantly by industry. Finally, government coauthorship of citations showed significant variation by industry as well.

Insert Table 4 about here

Table 5 splits the citations into categories by author affiliation and the applied and theoretical nature of the citing article. University-authored citations tend to be more theoretical, while those with firm and government authors are more evenly split between the two categories. Citations with institute authors (a catch-all category for all items not clearly falling into one of the other three) were more theoretical as well.

Insert Table 5 about here

Since the literature suggests that firm size may impact research practices and outside collaboration behavior, an analysis by size of firm was conducted. Table 6 splits the sampled papers and their citations into two categories selected on an obvious breaking point in firm sales ($0-999 million and $1000 million or more). Categories were not chosen on the basis of frequency, thus firms are not evenly distributed between the groups. At the paper level and, in a more muted form, at the citation level we see similar patterns based on firm size. The percentage of university authors, university coauthored cites, and theoretical characterizations of the papers increased with size of firm. The production of applied papers decreased with increased firm sales.

Insert Table 6 about here

Specific information about authors with respect to country and institution of affiliation is available from the data set as well. The sampled articles were selected on the basis that at least one author was affiliated with a firm located in the United States. The coauthors of these papers came from three countries: the United States, the United Kingdom, and Canada. The university affiliated coauthors of these papers were located in only the United States and the United Kingdom. The citations had authors located in 43 different countries. Restricting the examination to only university-authored citations shortens this list to 32 countries.

The literature indicates that the preponderance of university research dollars are concentrated in relatively few post-secondary institutions in this country (Tornatzky & Fleischer, M., 1990, pp. 57-58). Thus, the universities drawn upon by the firms in these two industries were also of interest. Approximately 40 different universities were represented by article coauthors and about 200 universities appeared in the citations; these included both foreign and U.S. institutions.

Descriptive statistics for the variables used in this study are presented in Tables 7A and 7B. Equations (1) and (2) were regressed against all collected data (N=336). Equations (3) through (6) were regressed against only those papers that actually had citations (N = 205). Ordinary least squares was used in the analysis of Equations (2) and (6). Given the nature of the dependent variables for the other four equations (P1 is a dummy variable; P3, P4 and P5 are proportions), logistical analysis was selected. Tables 8A (OLS) and 8B (logit) present the regression results for each equation. Given the elaborate sampling scheme used, weights were applied to all equations based on the number of papers in each strata.

Insert Tables 7A, 7B, 8A and 8B about here

All equations taken as a group consistently had at least one of the possible four article variables significant. Firm and industry variables were only significant in Equation (2) (number of citations). University variables appeared with no consistent pattern, although all four were significant and negative in Equation (1) (university coauthor dummy). The three proportion equations, (3), (4), and (5), were dissimilar, although one article and one university variable were significant in each.

Discussion

Firms are using university research when measured by publication practices. As indicated in Table 4, the firms in this study that publish, cite university authors 43% of the time and there is no significant difference by industry. Indeed, university-based publications were the most heavily cited of all author affiliation categories. Collaboration exemplified by coauthoring practices in the sampled papers is 12%, and it does vary by industry. These two observations taken together suggest that citing practices are more consistent than collaboration practices across industry types.

Industrial research, as measured by publication practices, draws upon university produced papers more frequently for theoretical research than for applied work (Table 5). Larger firms use university research, and produce and use theoretical work more often than smaller firms (Table 6). In the same manner papers reflecting applied research are more often produced by smaller firms. This corroborates what has been predicted in the literature (Blumenthal, et al, 1985, p. 14-16; Peters & Fusfeld, 1982, pp. 48-49).

Also of no surprise is the variation in the percentage of government-affiliated coauthors by industry (Table 4): SIC code 3721 (aircraft) has significantly more government coauthors as would be expected given the large amounts of federal funding associated with this industry (Mowery & Rosenberg, 1982). Both the amount of applied and theoretical work produced and the amount of applied and theoretical work cited varied by industry as well. These results, while limited to only two industries, indicate, as anticipated, that similarities in firms developing comparable products are evidenced in the types of research conducted and utilized.

Turning then to the empirical results in Tables 7A through 8B, the consistent significant appearance of at least one of the four article variables in each of the six equations gives credence to the expected effect of type of research and collaborative efforts on firm research activity and resulting publication practices. Although not surprising, these results, when considered separately, were reassuring. For example, it is encouraging to learn that coauthorship with university personnel is linked to the citation of more recent research and may suggest to firms that university collaboration should be promoted as a way to increase the transfer of new knowledge. The only surprising result was that theoretical articles were not significantly associated with theoretical citations.

Compared with the appearance of at least one article variable in each equation, firm, industry, and university explanatory variables are noticeable in their relative absence. Separate conclusions can be drawn for each of the six equations. In the most glaring case, only the three included article variables are significant in the equation explaining time lag between citations and paper (Equation (6)). The lack of any other significant variables suggests that firm, industry, and proximate university research expenditures have no discernible effect on the age of the knowledge utilized.

Given the differences between industries already noted, the result that scientists in the aircraft industry cite (Equation (2)) more frequently than their counterparts in computer equipment firms was also to be expected. This is the only equation in which the industry dummy and the firm variables appeared significantly. Unexpectedly, the number of employees was positively correlated with number of citations while firm sales was negatively linked. The absence of these variables in the all of the other equations was surprising given the significant results in Tables 4 and 6.

The only equation in which all four university variables appear significantly is the one explaining coauthorship with university personnel (Equation (1)), and it is of particular interest that all four are negative. This would indicate that increases in university research expenditures anywhere within one hundred miles of the firm are associated with a decrease in university coauthorship, certainly an unexpected conclusion. By way of comparison, only one university variable was significant (and negative) in each of the proportion equations (Equations (3) - (5)), while none of them were significant in Equations (2) and (6).

Their consistent appearance in the collaboration equation (1) and not in any of the citation equations may provide support for Jaffe's statement that proximity is more of a factor in informal communication circumstances (represented by coauthorship) than when scientists rely on formal communication channels (represented by citations), even though the results were negative.

This surprising negative effect may be explained, in part, by the limited number of university coauthored papers (42 of 336), but concerns with the university proximity variables should be raised in light the results of the other equations as well. In particular, university influences as portrayed in this study incorporate number of firms, distance, and expenditure (or size) in four fairly crude measures. This, along with the inconsistency in their significant appearance and their fluctuation across equations, suggests more refined variables (or functions) should be developed. The model should then be retested to better understand university proximity's influence on firm research and publication behaviors.

This project represents a preliminary attempt at examining the trickle down effect of university research on a large scale. Additional investigations complimenting this research readily come to mind. Incorporating firms from other SIC codes would provide more explicit information on differentiation in university collaboration by industry. Studying firm knowledge gathering patterns outside of the borders of this country would be worthwhile, as well, given the increasingly global view of the economy. In addition, subject area influences both in the work produced and utilized by firms should be examined based on literature that suggests that university research is too discipline oriented to be of practical use to industry. Finally, qualitative studies based on this work, examining project and firm differences, in particular, would be beneficial.

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Appendix

Four online databases were accessed in this order:

INSPEC which covers Physics Abstracts, Electrical and Electronics Abstracts, Computer and Control Abstracts, and IT Focus

COMPENDEX PLUS produced by Engineering Information, Inc.

NTIS produced by the National Technical Information Service of the U.S. Department of Commerce

AEROSPACE DATABASE which covers International Aerospace Abstracts and Scientific and Technical Aerospace Reports

MATHFILE produced by the American Mathematical Society

Only the first two databases included treatment codes. These codes and our interpretation as to their applied or theoretical nature follow. In addition, citations listed as patent and reports were coded as applied, and dissertations were coded as theoretical.

Online Database	Code	Applied/Theoretical
INSPEC	Applications	Applied
	Bibliography	Applied
	Economic Aspects	Neither
	General, Review	Applied
	New Developments	Theoretical
	Practical	Applied
	Product Review	Applied
	Theoretical	Theoretical
	Experimental	Theoretical
COMPENDEX	Applications	Applied
	Biographical	Neither
	Economic	Neither
	General Review	Applied
	Historical	Neither
	Literature Review	Neither
	Management Aspects	Neither
	Numeric	Theoretical
	Theoretical	Theoretical
	Experimental	Theoretical

TABLE 1A **Dependent Variable Definitions**

Dependent Variable	Notational Form	Data Source(s)	Equation
Dummy Variable for whether Article has a University Coauthor	P1=A1	Original Article or Online Databases	P1 = f{A2, A4, F1, F2, F3, I1, U1, U2, U3, U4} N = 336
Number of Citations	P2	Original Article or *Science Citation Index*	P2 = f{A1, A2, A4, F1, F2, F3, I1, U1, U2, U3, U4} N = 336
Proportion of Citations with a University Coauthor	P3	Original Article or Online Databases	P3 = f{A1, A4, F1, F2, F3, I1, U1, U2, U3, U4} N = 205 for P2 not equal t[illegible]
Proportion of Citations that are Theoretical	P4	Online Databases	P4 = f{A1, A2, A4, F1, F[illegible], I1, U1, U2, U3, U4[illegible] N = 205 for P2 not equal to 0
Proportion of Citations that are Applied	P5	Online Databases	P5 = f{A1, A3, A4, F1, F2, F3, I1, U1, U2, U3, U4} N = 205 for P2 not equal to 0
Average Time Lag Between Article and Citations	P6	Original Paper or *Science Citation Index*	P6 = f{A1, A2, A4, F1, F2, F3 I1, U1, U2, U3, U4} N = 205 for P2 not equal to 0

TABLE 1B **Independent Variable Definitions**

Independent Variable	Notational Form	Data Source(s)
Dummy Variable for whether Article has a University Coauthor	A1=P1	Online Databases or Original Article
Dummy Variable for whether the Article is Theoretical	A2	*COMPENDEX PLUS* or *INSPEC*
Dummy Variable for whether Article is Applied	A3	*COMPENDEX PLUS* or *INSPEC*
Number of Authors	A4	Online Databases or Original Article
Firm Sales (in millions of dollars)	F1	10K, Annual Report, NBER Database, *Ward's*, *Data Sources*, Phone calls
Total Number of SIC codes in which the Firm is Active	F2	*Million Dollar Directory* and *Directory of Corporate Affiliations*
Firm Employees	F3	10K, Annual Report, NBER Database, *Ward's*, *Data Sources*, Phone calls
Industry Dummy (1=SIC 3721)	I1	*Million Dollar Directory* and *Directory of Corporate Affiliations*
University Research Expenditures (in thousands of dollars)		NSF's *Academic Science/Engineering: R&D Funds Fiscal Year 1987*
Proportion of total $ within 25 miles of the firm	U1	
Proportion of total $ within 26-50 miles from the firm	U2	
Proportion of total $ within 51-75 miles from the firm	U3	
Total $ within 100 miles of the firm	U4	

TABLE 2 Sample Stratification

Distance Bands (in miles)	R & D Ranks of Universities				
	1-10	11-20	21-30	...	91-
0-10					
11-30					
31-90					
91-					

TABLE 3 **Sample Totals by Industry**

Description	TOTAL	Aircraft SIC Code 3721	Computer Equipment SIC Code 3573
Firms	139	26	113
Papers	336	128	208
Citations	2437	1461	976
Citations/ Paper	7.25	11.41	4.69

TABLE 4 Article & Citation Characteristics by Industry

Characteristic of Paper	TOTAL	Aircraft SIC Code 3721	Computer Equipment SIC Code 3573
Sampled Articles:			
TOTAL	336(100%)	128(100%)	208(100%)
University Coauthor ***	42(12.5%)	28(21.9%)	14(6.7%)
Applied ***	147(44%)	21(16%)	126(61%)
Theoretical ***	130(39%)	87(68%)	43(21%)
Citations:			
TOTAL	2437(100%)	1461(100%)	976(100%)
University Author	1042(43%)	610(42%)	432(44%)
Firm Author	899(37%)	541(37%)	358(37%)
Government Author ***	326(13%)	258(18%)	68(7%)
Institute Author	178(7%)	96(7%)	82(8%)
Applied ***	647(27%)	336(23%)	311(32%)
Theoretical ***	860(35%)	542(37%)	318(33%)

Notes: *** indicates proportions across industries are significantly different using Pearson's chi-squared test at .001 signficance level

TABLE 5 Citation Coauthors by Article Treatment Classification

Citation Author Affiliation	Theoretical	Applied
University Author	486	183
Firm Author	327	328
Government Author	90	103
Institute Author	88	30

TABLE 6 Article & Citation Characteristics by Firm Size

Characteristic of Paper	TOTAL	Firm Sales <$1000 M	Firm Sales >$1000 M
Sampled Articles:			
TOTAL	336(100%)	196(100%)	140(100%)
University Coauthor ***	42(12.5%)	14(7%)	28(20%)
Applied ***	147(44%)	111(57%)	36(26%)
Theoretical ***	130(39%)	41(21%)	89(63%)
Citations:			
TOTAL	2437(100%)	865(100%)	1333(100%)
University Author ***	1042(43%)	342(40%)	700(45%)
Firm Author	899(37%)	318(37%)	581(37%)
Government Author ***	326(13%)	82(9%)	244(16%)
Institute Author	178(7%)	79(9%)	99(6%)
Applied	647(27%)	263(30%)	384(24%)
Theoretical ***	860(35%)	265(31%)	595(38%)

Notes: *** indicates proportions across firm size are significantly different using Pearson's chi-squared test at .001 significance level

TABLE 7A Descriptive Statistics for All Papers (N = 336)

Variable	Regression Sample: Mean	Standard Deviation	Minimum	Maximum
P1 (Univ Author)	.13	.33	0	1.00
P2 (# Cites)	7.25	9.36	0	53.00
A1 (Univ Author)	.13	.33	0	1.00
A2 (Theoretical)	.39	.49	0	1.00
A3 (Applied)	.44	.50	0	1.00
A4 (# Authors)	1.92	1.53	1.00	16.00
F1 (Sales)	3711.76	11405.55	0	62430.50
F2 (Activity)	2.81	3.36	1.00	20.00
F3 (Employees)	22213.21	54307.21	12.00	396428.00
I1 (Industry)	.38	.49	0	1.00
U1 (0 - 25)	.52	.31	0	1.00
U2 (26 - 50)	.22	.28	0	0.92
U3 (51 - 75)	.14	.24	0	1.00
U4 (0 - 100)	450283.22	313547.00	2379.50	1142965.00

Notes: F1 is in millions of dollars; U4 is in thousands of dollars

TABLE 7B Descriptive Statistics for Papers with at Least One Citation (N = 205)

	Regression Sample:			
Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
P3 (Cite Univ)	.37	.29	0	1.00
P4 (Cite Theo)	.31	.30	0	1.00
P5 (Cite Appl)	.31	.28	0	1.00
P6 (Time Lag)	8.01	6.39	0	34.00
A1 (Univ author)	.20	.40	0	1.00
A2 Theoretical)	.60	.49	0	1.00
A3 (Applied)	.36	.48	0	1.00
A4 (# Authors)	2.15	1.67	1.00	16.00
F1 (Sales)	5052.57	13262.51	0	62530.50
F2 (Activity)	3.11	3.54	1.00	20.00
F3 (Employees)	29588.48	61334.10	46.00	396428.00
I1 (Industry)	.53	.50	0	1.00
U1 (0 - 25)	.54	.30	0	1.00
U2 (26 - 50)	.18	.26	0	0.92
U3 (51 - 75)	.16	.26	0	1.00
U4 (0 - 100)	459338.13	319643.78	2379.50	1142965.00

Notes: F1 is in millions of dollars; U4 is in thousands of dollars

TABLE 8A **Ordinary Least Squares**

Variable	Dependent Variable: P2 (# Cites)	P6 (Time Lag)
A1 (Univ Coauthor)	10.4884** (1.2683)	-2.3841** (.8046)
A2 (Theoretical)	6.8476** (1.16956)	3.4140** (.9358)
A3 (Applied)	———	———
A4 (# Authors)	-.2195 (.1665)	-.7560** (.1160)
F1 (Sales)	-.98699E-04** (.35384E-04)	.1757E-04 (.2476E-05)
F2 (Activity)	-.1886 (.1973)	-.0209 (.1382)
F3 (Employees)	3.4194E-05** (1.0442E-05)	.4130E-05 (.7418-05)
I1 (Industry)	2.7854* (1.1782)	.8833 (.8130)
U1 (0 - 25)	2.2456 (4.5417)	7.0675 (3.8246)
U2 (26 - 50)	-4.9239 (4.2594)	1.6160 (3.5538)
U3 (51 - 75)	5.7576 (4.5985)	7.4976 (3.8699)
U4 (0 - 100)	.2605E-05 (.2355E-05)	.7199E-07 (.1936E-05)
Constant	.8867 (4.5595)	.9950 (3.9766)
R^2	.40	.31

Notes: * significant at .05 significance level (two-tailed test); ** significant at .01 significance level (two-tailed test); standard errors are shown in parentheses below each estimated coefficient

TABLE 8B **Logistical Regression**

Variable	Dependent Variable: P1 (Art Univ)	P3 (Cite Univ)	P4 (Cite Theo)	P5 (Cite App)
A1	______	1.1770** (.3691)	.3943 (.3657)	-.2250 (.4395)
A2	1.7504** (.4730)	______	.1638 (.4241)	______
A3	______	______	______	1.3251** (.3949)
A4	.1075* (.04832)	-.01146 (.05407)	.1418* (.05716)	.08220 (.05534)
F1	.1297E-04 (.9276E-05)	.1809E-04 (.1017E-04)	.1275E-04 (.1004E-04)	.6746E-05 (.1292E-04)
F2	.02893 (.07627)	.6297E-02 (.061013)	.1306 (.06814)	.1219 (.7790E-01)
F3	-.7224E-05 (.6184E-05)	.4363E-06 (.3028E-05)	-.6689E-05 (.4490E-05)	.1720E-05 (.3328E-05)
I1	-.5008 (.4316)	.08673 (.3496)	-.1926 (.3904)	-.7055E-02 (.4154)
U1	-2.0751** (.5400)	-.9987* (.4739)	-1.0066 (.5515)	-1.2379* (.5905)
U2	-2.1159* (1.0484)	-.7299 (.9273)	-.8913 (.9919)	-1.4074 (1.0605)
U3	-3.6453** (.7506)	-.3607 (.5207)	-1.3535* (.5934)	-1.5066 (.6292)
U4	-.2157E-05** (.7844E-06)	-.2067E-06 (.6074E-07)	-.8219E-06 (.6730E-06)	-.9382E-07 (.6835E-06)

Notes: * significant at .05 significance level (two-tailed test); ** significant at .01 significance level (two-tailed test); standard errors are shown in parentheses below each estimated coefficient; no constant terms were included because of the weighting scheme

Variable Key:

A1	(Univ Coauthor)	F1	(Sales)	U1	(0 - 25)
A2	(Theoretical)	F2	(Activity)	U2	(26 - 50)
A3	(Applied)	F3	(Employees)	U3	(51 - 75)
A4	(# Authors)	I1	(Industry)	U4	(0 - 100)