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# THE NBER-RENSSELAER SCIENTIFIC PAPERS DATABASE: FORM, NATURE, AND FUNCTION

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## ABSTRACT

This article is a guide to the NBER-Rensselaer Scientific Papers Database, which includes more than 2.5 million scientific publications and over 21 million citations to those papers. The data cover an important sample of 110 top U.S. universities and 200 top U.S.-based R&D-performing firms during the period 1981-1999. This article describes the file system which comprises the database, explains the variables included in the files, and discusses the functions of the various files. It includes numerous descriptive tables, as well as graphs of the data in the time series dimension. In addition, it discusses limitations and strengths of the data as well as some questions that the data might be used to address.

The data discussed in this paper can be found at http://www.nber.org/RPI-sci-pap

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# I. Introduction

The following article discusses a large database of scientific papers, assembled and processed over a period of time, which might prove useful in understanding the role of science in the economy. The study of science is interwoven with the study of industrial innovation (Jaffe, 1989; Adams, 1990; Mansfield, 1991). Furthermore, it is clearly in the air that the economic role of science, measured by its role in commercialization, has increased markedly during the 20th and 21st centuries (Audretsch and Stephan, 1996; Narin, Hamilton, and Olivastro, 1997; Zucker, Darby, and Brewer, 1998; Adams, Chiang, and Starkey, 2001), suggesting that a country's scientific research is increasingly a key to growth. At the same time, the precise role of science in industrial invention and new product development remains largely unknown. Given the differences between scientific discovery and industrial innovation, controversy continues to surround the question as to whether the knowledge contained in papers matters to the same degree as the scientific training and human capital of industrial researchers. We hope that the database described in these pages will contribute to an eventual resolution of this and other puzzles concerning the economic role of science.

We refer to the collection of files and data as the NBER-Rensselaer Scientific Papers Database. Included are more than two million papers, written to varying degrees in the United States during 1981-1999, as well as citations made to and received by the papers. The institutions whose scientists and engineers author the papers consist of top U.S. universities and R&D-performing firms. The data also include collaborations between scientific institutions. This is significant because co-authorships typically indicate large investments of time and resources in the production of scientific research. Finally, the

data incorporate our efforts to fractionalize papers and citations, thereby reflecting collaborative research and avoiding multiple counting of scientific output in the economy as a whole.

Questions that the data could be used to address include the following: Who thinks about whose research, and in what fields? Who works with whom, and Why does this happen? What are the effects of thinking about and working with other scientists and engineers on invention and real output? How do these behaviors and their outcomes change over time?

This project originated in conversations between one of us (Adams) and the late Zvi Griliches as to how one might undertake database construction on the economics of science that would promote research on the topic at the NBER and elsewhere. It was an honor to be recruited in this way by so peerless an economist, as those who know best must realize. Later, Adams was fortunate in bringing Clemmons on board. Clemmons' skill in handling data, his insistence on asking the right questions, and his work ethic have kept the project going when it would otherwise have ended badly.

In many ways the project was intended to parallel and complement the research on patents that had been ongoing at NBER over a period of time, as this is reflected first in Griliches (1986) and later in Jaffe and Trajtenberg (2002). It was immediately understood that the project would be risky and that it would not be fashionable. The idea of working with citations is of course, not new. To our knowledge, maps that link industries together go back to at least Terleckyj (1974) and Scherer (1982a, b). However, the development of citations in economics to measure the importance of ideas and their

flow is contained in the work of Trajtenberg (1990) on CT scanner patents and the compendium of work in Jaffe and Trajtenberg (2002).

Papers that have used the data include Adams, Clemmons and Stephan (2004 and forthcoming 2006; and 2006), Adams, Black, Clemmons, and Stephan (2005); and Adams and Clemmons (2008a, 2008b; and forthcoming 2009). The reader may find additional information concerning the data in these papers.

The rest of the paper consists of three sections. Section II describes the data from several perspectives. In part A. of the section we discuss the form and function of the files comprising the database. Part B. discusses the distribution of papers by fields of science, and it does so separately for the top 110 U.S. universities and the top 200 U.S. R&D-performing firms. The papers data are graphed in Part C., the citations data are graphed in Part D., and finally, Part E. presents graphs of the collaborations data. Section III is a discussion and assessment of limitations and strengths of the data. Section IV concludes.

# II. Description of the Database [1]

## A. The File System

The database consists of eight files. Table 1 provides an overview, listing file names, numbers of observations, and file functions. We shall keep referring to this table as a means of organizing our tour of the data. The eight files are a careful reworking of archival data from Thomson-Reuters on scientific papers and citations. Arranged by publication date their time period is January 1, 1981 to December 31, 1999. The data begin in 1981, because in this year the company implemented a new and more comprehensive data processing system that is not entirely incompatible with earlier data.

[1] For access to the data, go to http://www.nber.org/RPI-sci-pap

The data end in 1999, because during the subsequent extraction process for the project, 1999 was the latest full year available.

The information specifically derive from Thomson-Reuters' Current Contents database, which at the time covered an expanding set of 5,507 journals across the sciences[2]. In addition, we use a set of 1,630 discontinued or renamed journals that were cited by Current Contents journals. Originally included are 2,836,700 scientific papers written in one or more of the Top 110 U.S. Universities, as well as 238,277 papers written in one or more of the Top 200 U.S. R&D Firms. Some overlap takes place between the universities and firms, because of scientific collaboration between institutions. A total of 21,386,007 citation pairs occur between *groups* of papers defined by citing and cited institutions, fields (defined below), and years[3]. Likewise 797,348 collaboration pairs occur between *groups* of papers, defined by collaborating and collaborated pairs of institutions, in turn arranged by field and year[4].

The designation of Top 110 University is Thomson-Reuters'. It is based on publication volume, and indeed these universities account for the majority of academic papers written in the U.S. The list of Top 110 universities appears as Table A.1 of the Appendix.

The designation of Top 200 Firm was developed for this study. With one exception it refers to the 200 publicly traded corporations who performed the most R&D in 1998, that were based in the United States, for which histories of reasonable length

[2] At the start of the project, the consulting group in Evaluative Bibliometrics at Thomson-Reuters was known as the Institute for Scientific Information (ISI). We shall use this original name for the company from time to time.

[3] Put differently, the 21,386,007 citation pairs represent counts of citations at the *six*-dimensional level of citing and cited institutions, fields, and years. We discuss this in more detail below.

[4] Since papers are assigned to fields and years according to the journal where they appear, collaborations occur in the same field and year. This leads to a *four*-dimensional file classified by field, year, and collaborating and collaborated institutions.

could be constructed. The one exception is Bell Communications Research (Bell CORE; ticker BELLC), which spins off from AT&T in 1984. The list of Top 200 R&D firms appears as Table A.2 of the Appendix.

Divestiture (and acquisition) can change the nature and amount of scientific research in a firm. We note two major examples of this in the data. Table A.3 discusses the treatment of the AT&T and General Motors families of firms, for which the divestiture problem is paramount. This is because, for General Motors and AT&T, divestiture significantly alters the practice of science and R&D in each firm. Note that we treat papers and citations of Lucent (Bell Laboratories) and Bell Communications Research as separate from AT&T in all years and that we treat papers of Delphi Automotive Systems as separate from General Motors in all years. This strategy allows the user to construct the definition of the firm that is most suitable for them. One such definition, which we have used in our papers, retains spinoffs prior to divestiture as divisions of the main firm, and afterwards treats them as separate firms.

As we have said, Table 1 is an overview of the database. We discuss the eight files in order of their appearance. The first file, UNIVERSITIES, is described in Table 2. It includes three variables: STANDALONE, an indicator variable equal to one if a university is a standalone campus or zero if it is a multi-campus system; UNIVID, or the ID of the university; and UNIVNAME, the name of the university in NSF's CASPAR database. UNIVID is the modified Federal FICE Code for a given university. In its original sense, the FICE code is an identifier assigned by the Federal Interagency Committee on Education (FICE). As with any identification scheme, though, the coding system adjusts to suit the users. Our version of the FICE code harmonizes with the

CASPAR database of universities, a collection of university data assembled by the National Science Foundation. Thomson-Reuters also uses the CASPAR definitions of standalone campuses and university systems in building its institutional dictionaries for the Top 110 universities. The CASPAR FICE codes and university definitions are the ones used in the database.

The top 110 universities include 26 university systems. For these 26 universities the file UNIVERSITY_SYSTEMS includes three variables: BRANCH, the name of the branch campus included in each system; UNIVID, the university ID; and UNIVNAME, the university name. Since there are 142 branch campuses in the 26 systems, the average number of branches is 5.5. Table 3 describes the file UNIVERSITY_SYSTEMS.

The third file, UNIVERSITY_DESCRIPTION, summarizes the paper and citation statistics for the 110 universities. Table 4 shows that these statistics are arranged by university (UNIVID), Thomson-Reuters ISI 88 science field (ISI88), and publication year (YEAR). The number of observations is 143,119. Besides UNIVID, ISI88, and YEAR, the file includes ten variables. CITSFIRM is the total number of forward (future) citations received from firms for a given university, field, and year. The citations occur from the publication year through 1999. CITSFIRM is a citation window of variable length. The window shortens as publication year approaches 1999, so that forward citations, because they are right-truncated, must eventually decline. CITSFIRM5 is the number of forward citations received from firms starting with the year of publication and including the next four years. Since CITSFIRM5 is a fixed five-year window of citations and the data end in 1995, it is not defined after 1995. CITSFIRM5 has the advantage of

being a fixed window, but it has the disadvantage of truncating citations received, especially for longer-lived papers.

CITSUNIV is the total number of forward citations received from other universities arranged by cited university, field, and year. The citations occur from the publication year through 1999. Since the citation window contracts as the publication year approaches 1999, CITSUNIV eventually declines. CITSUNIV5 is the number of forward citations received from other universities, starting with year of publication and including the next four. Since CITSUNIV5 is a fixed five-year window, it is not defined after 1995. CITSUNIV and CITSUNIV5 exclude institutional self-citations from a university to itself.

The variable PAPERS is the total number of papers written in a university, field and year. Remaining variables are fractional counterparts to the previous variables. FRPAPERS is the "fractional" version of PAPERS. The relationship between the two is this: FRPAPERS is the sum over all papers of the institutional fraction for each paper that is accounted for by the university in question, for a given field and year. To understand this, consider some examples. If Harvard writes a paper by itself, it is assigned a fraction of 1.0. If it writes a paper with Yale and IBM, it is assigned a fraction of 1/3. And if it writes a paper with MIT, Princeton, Biogen, and Merck, then it receives a fraction of 1/5. Summing over paper fractions yields FRPAPERS. By definition this is less than or equal to PAPERS.

The same idea applies to citations. This yields FRCITSFIRM, the fractional version of CITSFIRM: fractional citations received from firms on each paper, summed over papers. Clearly FRCITSFIRM is less than or equal to CITSFIRM.

The same is true of FRCITSFIRM5 and CITSFIRM5, of FRCITSUNIV and CITSUNIV, and of FRCITSUNIV5 and CITUNIV5. Our reason for offering fractional counterparts to "whole" citations is simple: fractional citations preserve totals over the entire system of universities and firms, whereas "whole" papers and citations count papers and citations multiple times and overstate totals in the system as a whole.

The fourth file in Table 1 marks a transition from universities to firms. FIRMS lists the top 200 companies and Table 5 describes its contents. The three variables are FIRMID, the ticker symbol of the firm in 1998; FIRMNAME, the name of the firm in Compustat; and SIC4, the largest four digit industry of the firm in Compustat, based on the 1987 Standard Industrial Classification (SIC) classification system.

FIRM_DESCRIPTION appears fifth. It is the analogue of file UNIVERSITY_DESCRIPTION. As Table 6 explains, the file includes three classifying variables: FIRMID, ISI88, and YEAR, as well as descriptive variables. The latter include: PAPERS, the number of papers; CITSFIRM, total forward citations received from other firms; CITSFIRM5, forward citations received from other firms in the first five years; CITSUNIV, total forward citations received from universities; and CITSUNIV5, forward citations received from universities in the first five years. Included besides are five "fractional" descriptive variables: FRPAPERS, FRCITSFIRM, FRCITSFIRM5, FRCITSUNIV, and FRCITUNIV5. Since these variables are the same as those in UNIVERSITY_DESCRIPTION, we refer the reader to the discussion of Table 4 for further details.

The file FIELDS appears sixth in Table 1. FIELDS describes the 88 Thomson-Reuters (ISI) field codes that we use throughout the database. These are known

collectively as ISI88. The table maps the detailed 88 field codes into more aggregative CASPAR NSF12 and NSF20 field codes, and describes the codes[5]. Table 7 lists the variables in FIELDS. Appendix Table A.4 records field codes and descriptive labels.

In Table 7 ISI88_DESCRIPTION labels the variable ISI88. For the 12 main NSF fields in NSF12 we provide NSF12_DESCRIPTION. And for the details of engineering and earth science fields in NSF20, we provide NSF20_DESCRIPTION. It is inevitable that an element of judgment should enter the mapping between ISI88, NSF12, and NSF20. This is due to field overlap. The point is especially pertinent for the life sciences. The major fields of biology and medicine, for example, clearly share similar scientific research. The mapping that we offer is a compromise: it assigns agricultural ISI88 fields to agriculture, basic biomedicine in ISI88 to biology, and clinical biomedicine in ISI88 to medicine. Thus for example, we interpret the ISI88 field, CGX as the fundamental biology of cancer and ONC as clinical intervention and cancer treatment. Because of this overlap, it is important to take note of the following design feature. Since the data are classified throughout in term of the detailed ISI88 fields, the user is free to pursue an alternative mapping of detailed fields into aggregates than the ones we have chosen in Table 7 and Table A.4.

The final two files in Table 1 link citing-cited and collaborating-collaborated observations. CITATION_PAIRS does this for citing-cited observations. It consists of 21,386,007 observations in six dimensions consisting of citing and cited institutions, fields, and years. The file includes ten variables. These are: citations made, or backward citations (CITATIONS), and potentially citing and cited scientific papers (PAPERSCTG, PAPERSCTD) all by citing and cited university or firm (INSTCTG, INSTCTD), citing

[5] We thank Paula Stephan for discussions concerning the mapping procedure.

and cited ISI 88 field (ISI88CTG, ISI88CTD), and citing and cited year (YEARCTG, YEARCTD). In addition, it includes a character variable, CTG_CTD, which identifies the type of citing and cited institution, university (UNV) or firm (FRM). It follows, for instance, that to select a sample of firms citing universities, one would apply the substring operator to CTG_CTD to choose CTG='FRM' and CTD='UNV'.

COLLABORATION_PAIRS performs a similar linking function for collaborating-collaborated observations. It consists of 797,348 observations in four dimensions consisted of collaborating and collaborated institutions, field and year, since collaboration occurs in the same field and year. The eight variables consist of "collaborating" and "collaborated" institutions (INSTCLBG, INSTCBD), ISI 88 field (ISI88), and year (YEAR). Included are collaborations (COLLABORATIONS), numbers of potentially collaborating and collaborated papers (PAPERSCLBG, PAPERSCLBD), and a character variable, CLBG_CLBD, which identifies type of collaborating and collaborated institution, university (UNV) or firm (FRM). So to select a sample of universities collaborating with firms, apply the substring operator to CLBG_CLBD to select CLBG='UNV' and CLBD='FRM'.

## B. Distribution of Scientific Papers

Table 10 displays distributions of fractional and whole scientific papers in universities and firms[6]. This is done by the 12 main fields included in NSF12 in the National Science Foundation classification scheme. Field-specific totals and percentages are shown above; grand totals are shown in the bottom row.

[6] Recall that fractional papers are the sum of institutional fractions on all papers to which a university or firm contributes. Thus, for each paper, the fraction is 1.0 if the paper is written entirely within an institution, ½ if it is coauthored with another institution, and so on. Again, fractional papers are the sum of such fractions for a given "cell".

Notice that whole scientific papers overstate "true" scientific papers because of institutional collaborations. When we compare whole with fractional papers we see that 3,074,977 whole papers are written across all institutions and fields, but that the actual total, measured by fractional papers is 2,604,324. Thus whole papers overstate scientific "output" in the system as a whole by 18 percent (3,074,977/2,604,324≈1.18).

When we examine the university data by field, it is clear that most papers are written in the life sciences (agriculture, biology, and medicine). Together these fields account for 61.5 percent of all (fractional) papers. Second largest are papers in the natural sciences (chemistry and physics) and "technology" (computer science and engineering), which together account for another 24.8 percent. The remaining 13.7 percent of fractional university papers consists of astronomy, earth sciences, economics and business, mathematics and statistics, and psychology, which are trace elements in the universe of scientific papers. Note that percentages contributed by the fields of agriculture, chemistry, and engineering are higher among fractional than whole papers. Conversely, percentages of medicine and physics are lower among fractional papers than among whole. This is because institutional collaboration occurs less frequently than average in agriculture, chemistry, and engineering, while it occurs more frequently in medicine and physics.

Turning to the firm data, we observe a quite different distribution by field. Life sciences (agriculture, biology, and medicine) account for 31.4 percent of (fractional) industrial papers, compared with 61.5 percent in universities. Of course, the share of the life sciences in firm papers has increased in recent years, but overall the share is smaller in industry. Conversely, the share of natural sciences (chemistry and physics) and

technology (computer science and engineering) is 65.2 percent compared with 24.8 percent in universities. Observe that chemistry and engineering take up a larger share of fractional papers than whole papers, whereas the reverse is true of medicine. As before, this is because institutional collaboration is less common in industrial chemistry and engineering and more common in industrial medicine.

## C. Graphical Depiction of the Papers Data

The following sections present time series graphs consisting of Figures 1-9. Time is represented in calendar years or as a lag between calendar years. In several cases, when we wish to present the data by sector or science field, graphs appear as multiples. Primarily for this reason, the following sections contain 27 separate graphs of the data. Figures 1-3 pertain to papers and are discussed in this section.

Figure 1 presents time series of university and total (university plus firm) fractional papers on the left scale, and time series of firm papers on the right scale. Scientific publishing slows down in universities and as whole in the United States after 1992, and it falls in absolute terms in industry (Adams, 2007), reflecting the downsizing and disappearance of some large industrial laboratories performing basic science research during this period, notably AT&T Bell Laboratories.

Figures 2 presents shares in all papers of science fields for universities while Figure 3 does the same for firms. Fields appear as "strata" covering seven major areas (agriculture, biology, chemistry, computer science, engineering, medicine, and physics), plus a residual "other" field category. The flatness of the strata for universities suggests little change in relative shares during 1981-1999. And yet a slight increase in the share of

biology and medicine, a decline in agriculture's share, and an increase in the engineering and physics share can be seen in the university data.

Figure 3, for industry, stands in sharp contrast to Figure 2. The share of biology and medicine doubles from less than 20 percent of industrial papers in 1981 to almost 40 percent in 1999. Computer science also gains share though from a small base. And while the share of chemistry is stable, the share of engineering and most notably physics decline strongly in this picture. The topsy-turvy nature of the shares in Figure 3 is due to the rise of industrial scientific research in pharmaceuticals and biotechnology, and the decline in large industrial laboratories that specialize in natural science and technology.

## D. Graphical Depiction of the Citations Data

Figures 4-7 illustrate the citations data. Figure 4 depicts counts of scientific citations made (backward citations) and citations received (forward citations) over time. The figure covers all fields. It combines citations involving university papers on the left scale, with those involving firm papers on the right scale. Backward citations increase as time passes, because later papers have more generations of earlier papers to cite. This is partly an artifact of the left truncation of the data in 1981, since citations to papers before 1981 are eliminated. But it is partly real, reflecting the growth of fields and the growing ease of generating citations.

Citations received, or forward citations, at first grow and then decline. This is due to the combined action of three effects. As time passes the results contained in papers diffuse to readers, and this causes citations to go up. Second, the relevance of scientific research often decays, and this causes citations to decline. And third, right truncation of citations after 1999 eventually cuts citations received to zero in this window of data.

Figures 5A through 5G report the four curves in Figure 4 (citations made and received by universities and firms) separately for seven major fields. As before, the left scale refers to university citations made and received, while the right refers to firm citations made and received.

The general shape of the curves is similar across fields, but with some notable differences. The date at which citations received peak varies by sector and field. Peaking occurs sooner in sectors and fields where growth is less and where diffusion and decay are greater, and later when the reverse is true.

Figure 6 presents lagged or backward citation rate curves by the lag between citing and cited years. The figure covers all fields. To reduce complexity, the figure depicts citation curves within sectors (universities citing other universities, firms citing other firms), but the between sector curves appear very similar to those shown. The curves depict citation rates: these are citations made divided by papers that could be cited. It is thus a weighted citation rate, where weights are shares of potentially cited papers[7]. The university data are referred to the left axis, while the firm data are referred to the right. Note that both curves peak at a lag of two years. The university curve is higher because the aggregate citing population of university papers is larger relative to the number of papers that could be cited than is true of firms.

Figures 7A through 7G are graphs of the citation rates for seven major fields ranging from agriculture to physics. Consider Figure 7A. The figure shows that university citations to agriculture peaks in the third year after publication—slower than

[7] The reader needs to be aware that entire families of citation curves exist. The particular family depends on the level of aggregation, the sectors involved, and whether the data are weighted or un-weighted, so that the appearance of the curves can vary markedly. All the curves shown in this article are weighted curves that pertain to all fields within a sector or to individual fields within a sector.

average. The firm citation curve choppy and irregular and exhibits multiple peaks. This occurs because citing observations are few, especially at long lags. Other features of the field-specific diagrams are that citation rates in physics, biology, and chemistry peak more rapidly, that citation rates in technology, defined as computer science and engineering, peak more slowly, and that citation rates in rapidly peaking fields decay at a higher rate and conversely, at a lower rate for slowly peaking fields.

For computer science in universities the citation curve reaches a plateau that is almost unchanged between lags of four and ten years. At long lags the firm-firm computer science curve exhibits the same choppiness as agriculture. This occurs for the same reason, that there are relatively few industrial papers at long lags.

## E. Graphical Depiction of the Collaborations Data

Figure 8 presents line graphs of institutional collaborations between universities, between universities and firms, and between firms over time. The figure covers all fields of science. The university-university curve exceeds the university-firm curve by tenfold. The height of the university-firm curve is again ten times that of the firm-firm curve. These size differences dictate the logarithmic scale on the vertical axis of the figure. Underlying these differences is the fact that academic papers are ten times as many as industrial papers. Thus, a roughly similar propensity to collaborate results in a collaboration count among university papers that is ten times the count among firm-university papers. For the same reason, university-firm collaborations are ten times the firm-firm count, where one tenth as many papers are potentially collaborating with one tenth as many papers. Figure 8 is steeply trended, with trends about the same in the

different curves, but the small number of firm-firm collaborations, some of them initiated in graduate school, suggests that such collaborations are a second order phenomenon.

Figures 9A to 9G describe similar graphs for the seven major fields of science. The field-specific curves are in the same order as for Figure 8, with relative differences depending on comparative frequency of collaboration across sectors. Figure 9D illustrates for computer science. Firm collaboration counts are more than a tenth of university counts, and thus the university-university and university-firm curves are closer than average. Also, university-firm collaborations grow more rapidly, so the curves converge over time. In Figure 9F, for medicine, the two curves are further apart than average, but converge over time. These patterns and those in other figures largely reflect field-specific publication frequency in firms and universities as well as changes in these frequencies.

## III. Discussion, Comparison, and Assessment

Having described the data, we would like to assess their limitations and strengths. We can think of two important limitations. First, we would like to point out that each of the roughly 7,000 journals is assigned to a single science field. This assignment is accurate for the vast majority of specialized journals. But the method does produce serious errors for up to one percent of journals (approximately 70) that fall into Thomson-Reuters' Multidisciplinary category, some of which are highly influential. The category is treated as part of biology, because biology accounts for the largest fraction of papers. To see why the problem matters, note that Multidisciplinary journals include **Nature**, **Science**, **Proceedings of the National Academy of Sciences USA**, and **Philosophical Transactions of the Royal Society**. Clearly wholesale assignment of articles here to

biology is wrong. But to correct the problem would require article (not journal) assignment to fields. Moreover, some Multidisciplinary journals really are linked to biology. Therefore, the problem applies to less than one percent of ISI journals[8].

The main alternative to journal-field assignment is to assign papers according to perhaps multiple fields of the authors. But current practice effectively rules this out[9]. This is unlike patents, where multiple class assignments are common. To carry out such assignments would require clear criteria that would have to be acted on by a single Scientific Papers Office, much like the Patent Office does today. In the near future neither condition will be met.

A second limitation is that science citation data include publication date but not the date of first submission, or even better, the date of completion of the research. Use of publication date produces an upward bias in the observed lag between citing and cited papers. The true lag is the gap between cited publication date and citing first submission date. The extra "frictional" lag, between first submission and publication date of the citing paper, necessarily overstates the lag in scientific influence. Moreover, the problem produces greater upward biases in fields with greater frictional lags.

Science citations refer to prior literature and yet their motivations for doing so are not always clear. For example, they could measure influence of earlier ideas or seek to place limits on the problem being addressed. They could seek to refute earlier findings or constitute a strategy to raise the odds of acceptance. Of these motives, the first two seem

[8] Examples include **Bioinformatics**, **Biomaterials**, **Biometrics**, **Biometrika**, **Journal of Mathematical Biology**, **Journal of Theoretical Biology** and many others.

[9] We tested an alternative method of assignment using roughly 100,000 Harvard papers. We tried to assign each paper to one of the NSF 12 main science fields using information on authors' departmental addresses. A third of the papers could not be assigned to a field using this information, leading us to abandon the effort. More could be done on this problem, provided that across science, journals were to adopt a uniform approach to encoding fields of authors.

most likely to truly represent scientific influence. Given negative or strategic citations of the last two types, however, we must regard science citations as measuring prior influence with error[10].

One strong point of the database is that science citations are controlled by authors. While referees and editors can suggest references, including them requires authors' assent, suggesting that observed references are known to authors. In contrast, patent citations are often suggested by examiners and attorneys and are unknown to inventors.

Suppose that science citations reflect credible investments of time in searching the literature for useful knowledge. What would the earmarks of such investments be? For starters, the number of citations would set the marginal benefit of another citation equal to its marginal cost. This suggests that citations would span larger fractions of smaller disciplines, since similar marginal benefit and cost relationships across disciplines would lower the proportion of large literatures that is cited. Furthermore, literatures that require larger investments of time per cited paper would yield a lower citation rate holding size of the literature constant. Adams, Clemmons, and Stephan (2004, forthcoming 2006) find patterns very similar to those suggested above.

While voluminous, the papers and citations data are only a window on scientific research. Since they are truncated on the left and right in time, we lack most citations to papers from the late 1990s, which are not yet observed. And we know little about papers that influence research in the early 1980s since citations to these papers are left truncated and missing. The data are limited besides by sector and country, since they must have at least one author from a top 110 U.S. university or a top 200 firm. Citations made and

[10] See Jaffe, Fogarty, and Banks (1998) for an analysis that uses a set of NASA patents, as well as expert opinion on the patents, to test the validity of patent citations, answered in the affirmative, as an indicator of the importance of patents.

received by papers wholly authored in non-U.S. institutions are excluded. And so many international interactions are left out of the analysis. But the science citations and papers data described here are still a substantial improvement over much of the evidence that we have had.

# IV. Conclusion

This paper has introduced a new database on academic and industrial science that covers the last two decades of the 20th century as well as a sample of the largest universities and R&D performing firms in the United States. Basic science and applied industrial research can and do overlap. It is for this very reason that the data described in this paper could make a difference to economic research devoted to the study of growth and technological progress. We sincerely hope that this is the case, and that these data will foster theoretical and empirical research into economic aspects of scientific research, both at the NBER and beyond, both now and in the future.

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**Figure 1--Papers of the Top 110 U.S. Universities And the Top 200 U.S. R&D Firms**

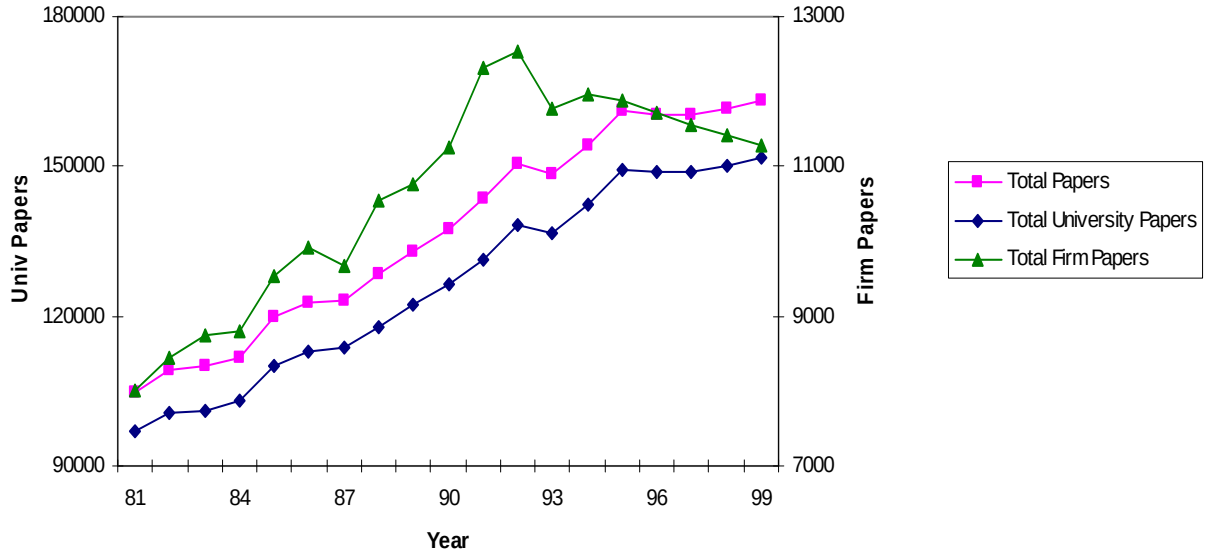
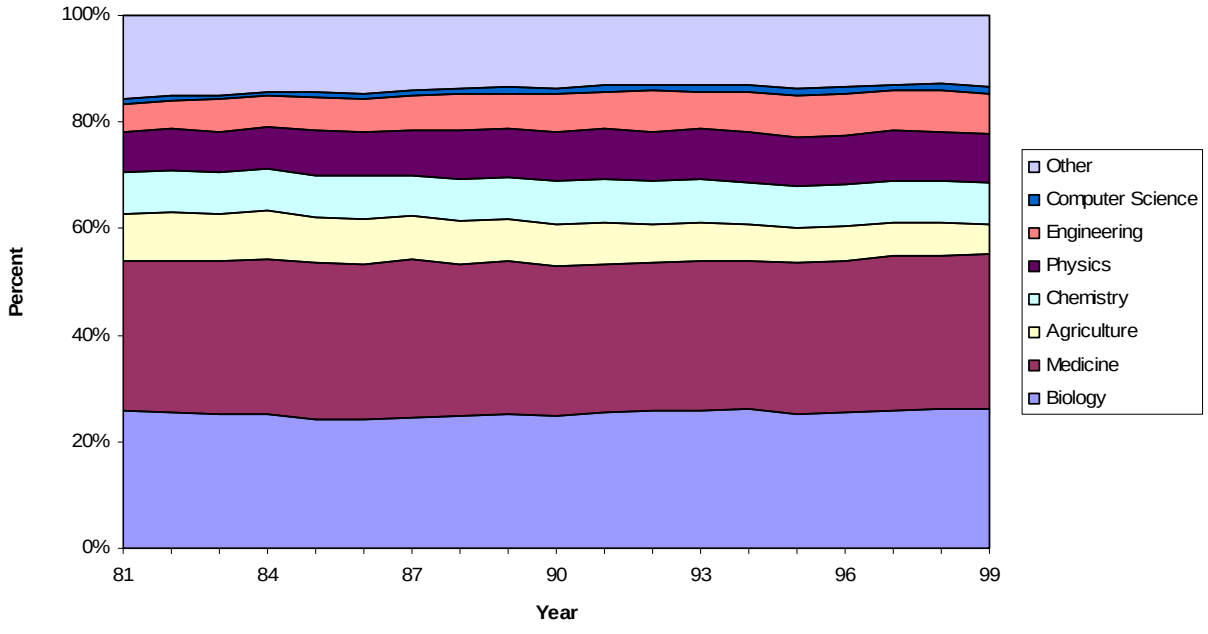



**Figure 2--Shares of Fields in U.S. University Papers**



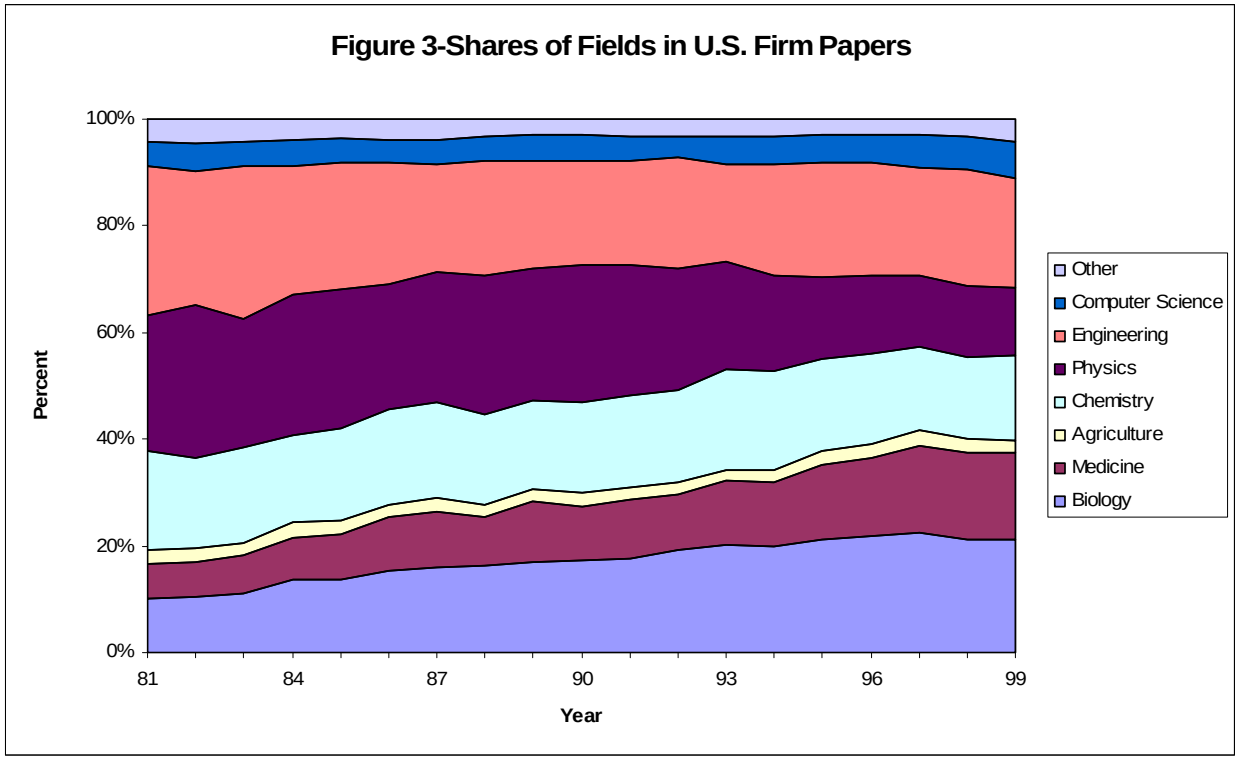


Figure 3-Shares of Fields in U.S. Firm Papers
100%
80%
60%
40%
20%
0%
Percent
81
84
87
90
93
96
99
Year
Other
Computer Science
Engineering
Physics
Chemistry
Agriculture
Medicine
Biology

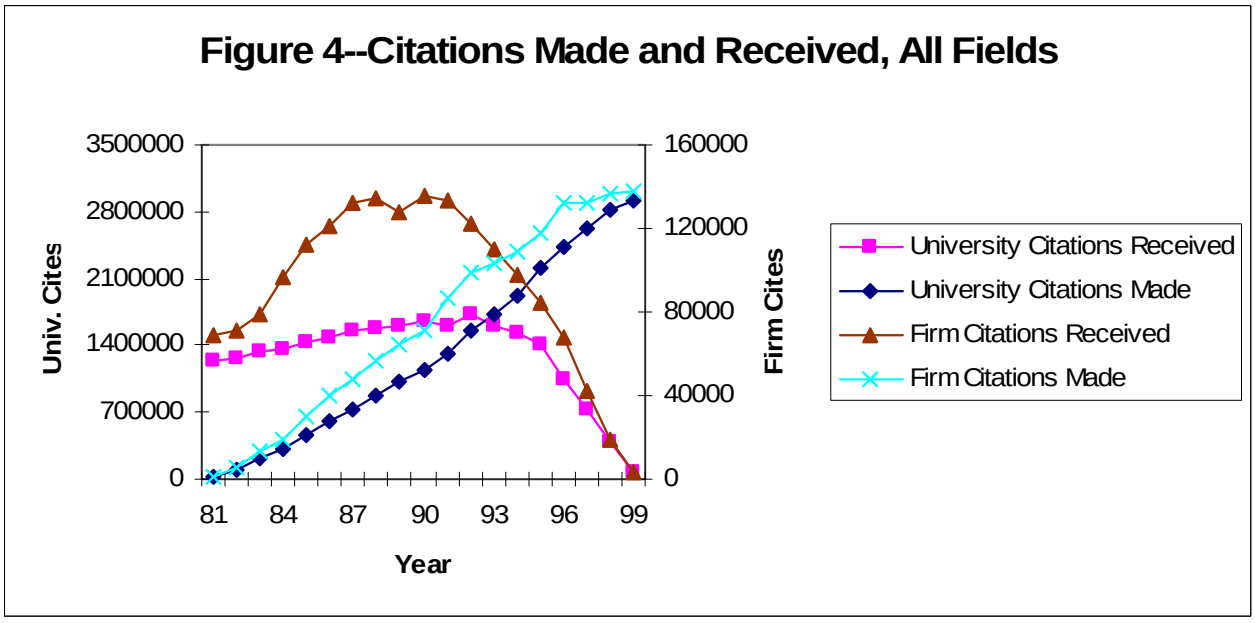


Figure 4--Citations Made and Received, All Fields
3500000
2800000
2100000
1400000
700000
0
Univ. Cites
160000
120000
80000
40000
0
Firm Cites
81
84
87
90
93
96
99
Year
University Citations Received
University Citations Made
Firm Citations Received
Firm Citations Made

**Figure 5A--Citations Made and Received in Agriculture**

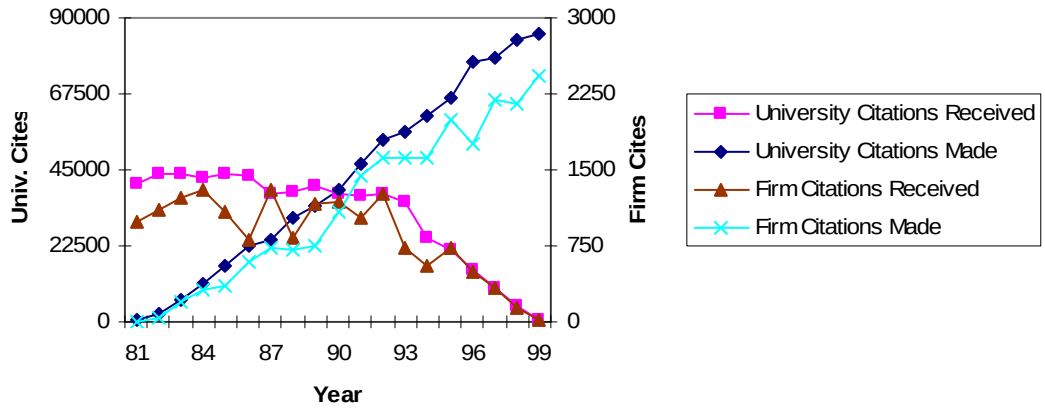



**Figure 5B--Citations Made and Received in Biology**

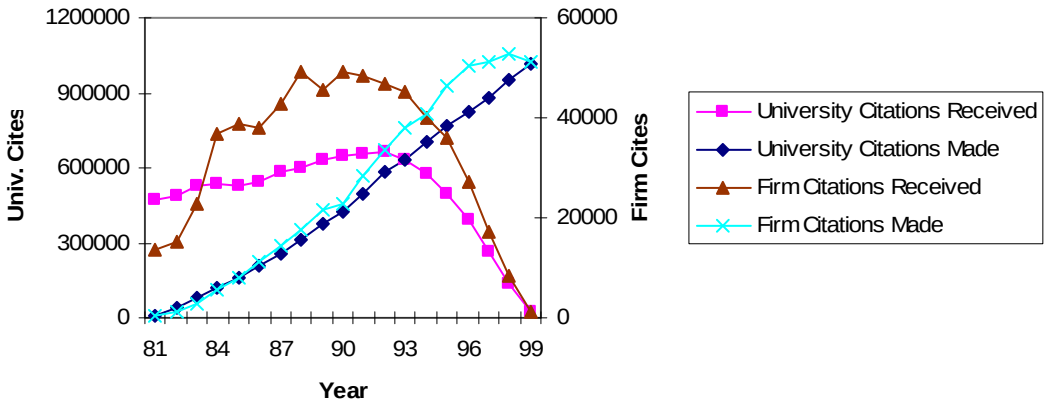



**Figure 5C--Citations Made and Received in Chemistry**

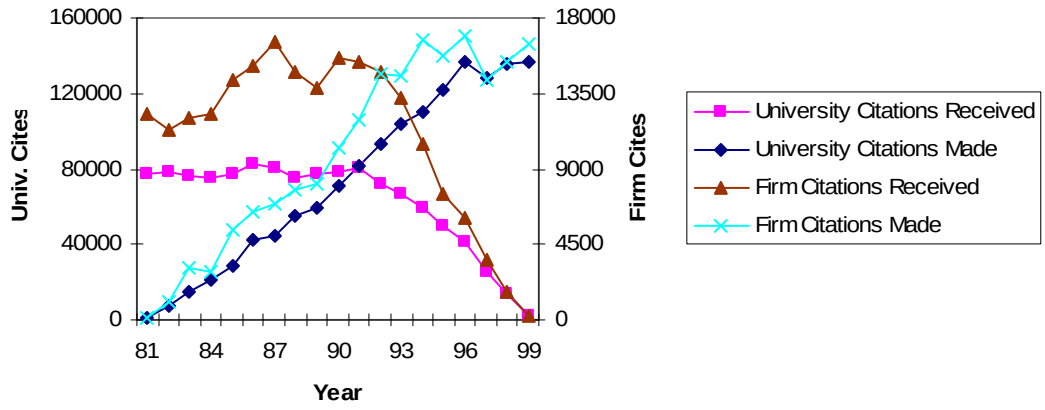


**Figure 5D--Citations Made and Received in Computer Science**

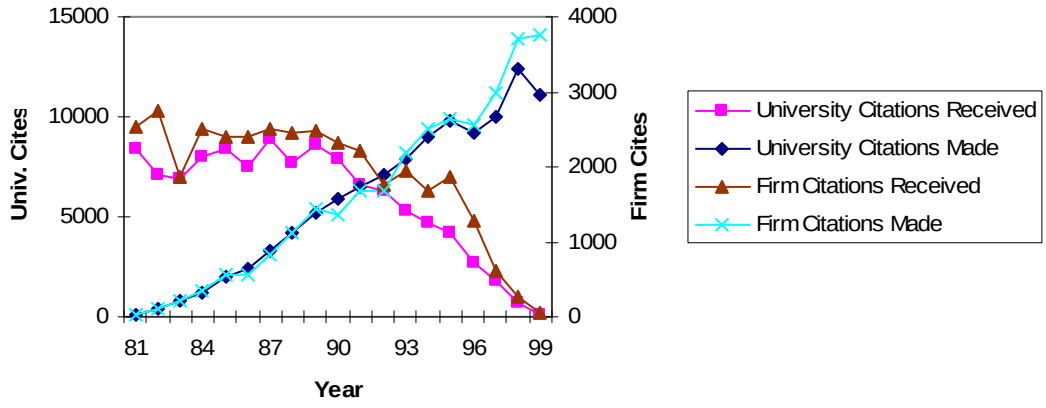



**Figure 5E--Citations Made and Received in Engineering**

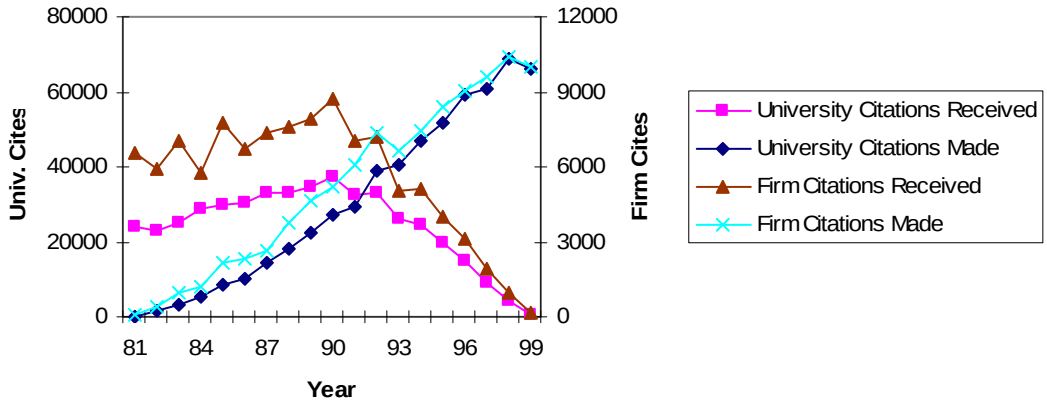
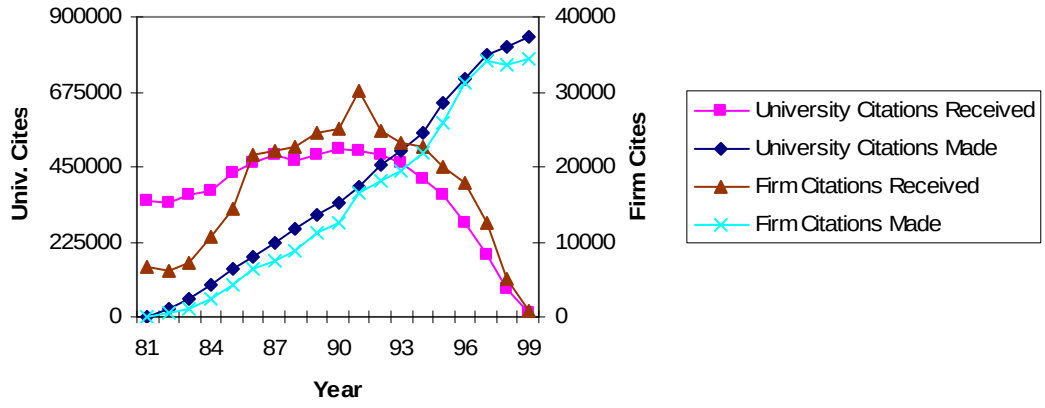



**Figure 5F--Citations Made and Received in Medicine**



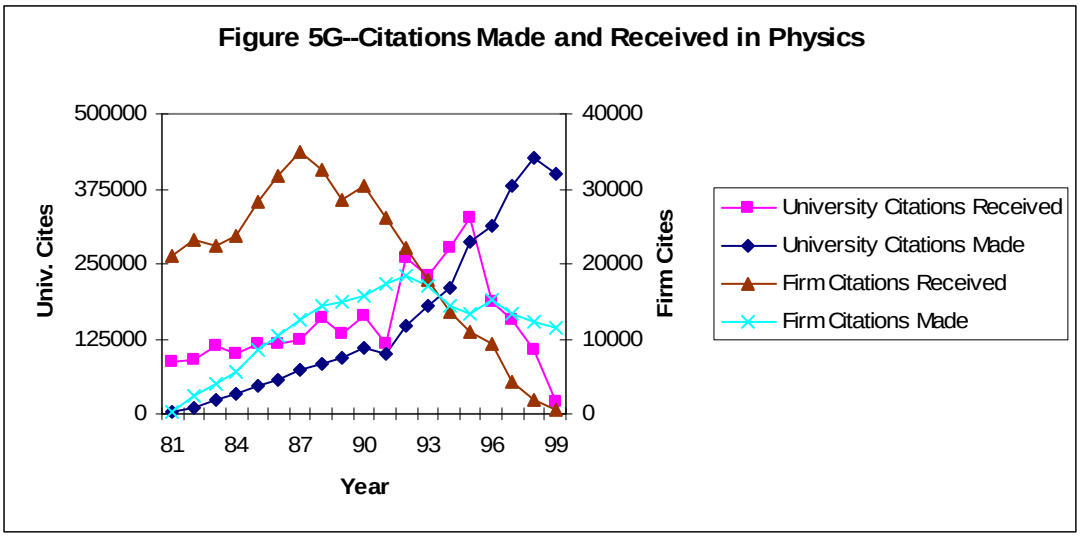


Figure 5G--Citations Made and Received in Physics
500000
375000
250000
125000
0
40000
30000
20000
10000
0
Univ. Cites
Firm Cites
81
84
87
90
93
96
99
Year
University Citations Received
University Citations Made
Firm Citations Received
Firm Citations Made

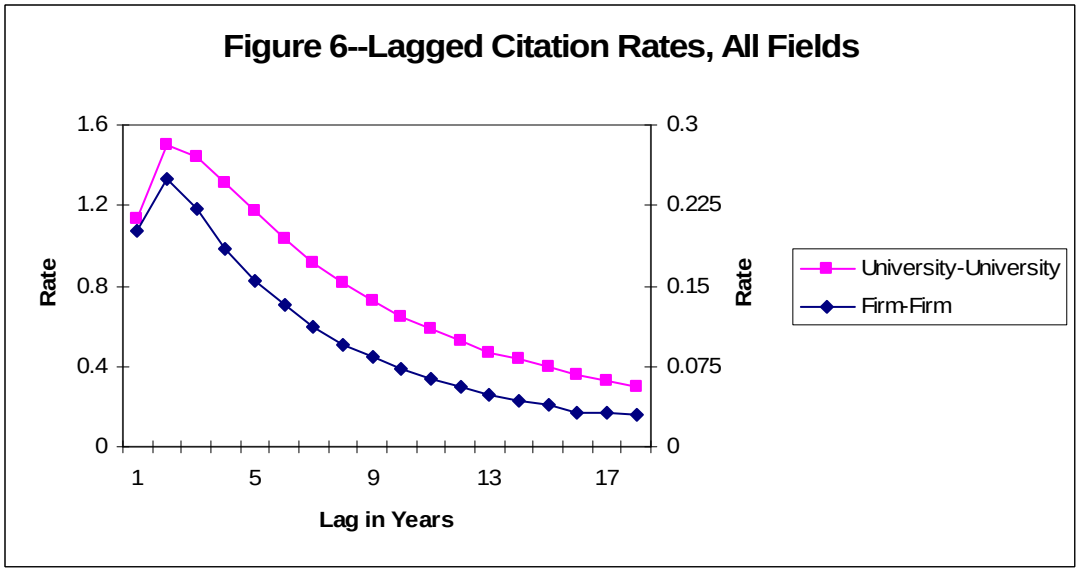


Figure 6--Lagged Citation Rates, All Fields
1.6
1.2
0.8
0.4
0
0.3
0.225
0.15
0.075
0
Rate
Rate
1
5
9
13
17
Lag in Years
University-University
Firm-Firm

**Figure 7A--Lagged Citation Rates in Agriculture**

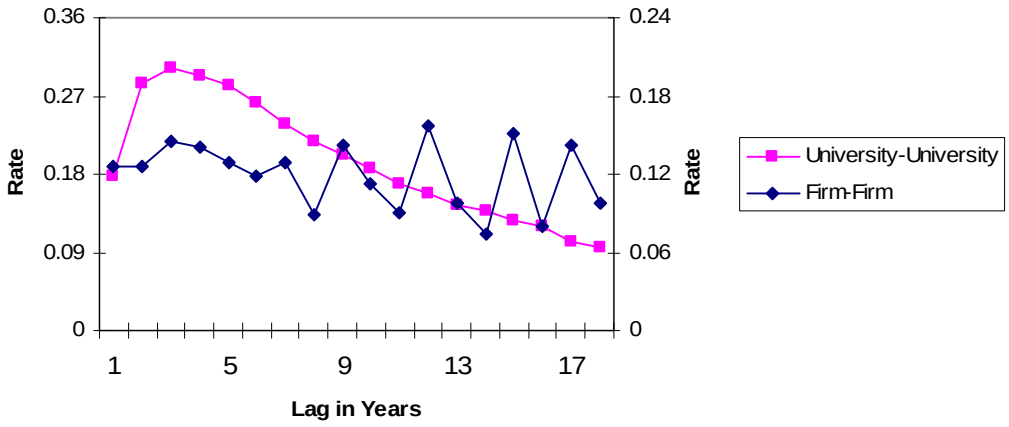



**Figure 7B--Lagged Citation Rates in Biology**

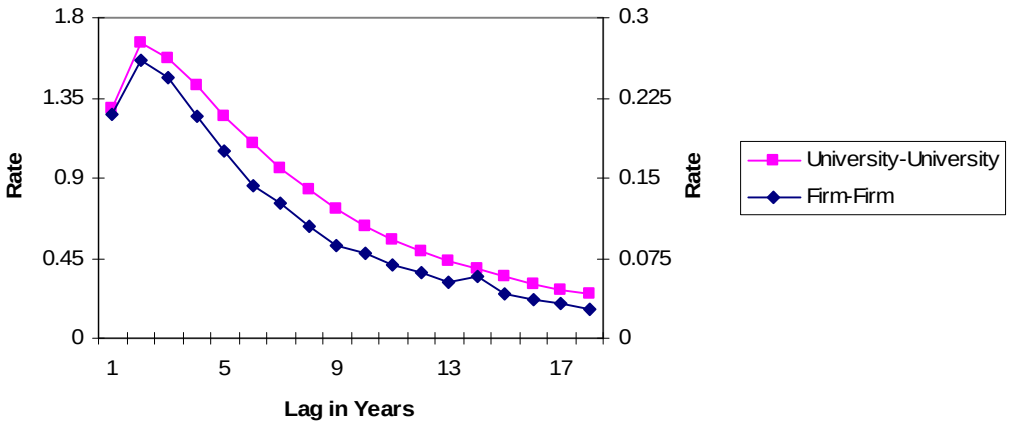
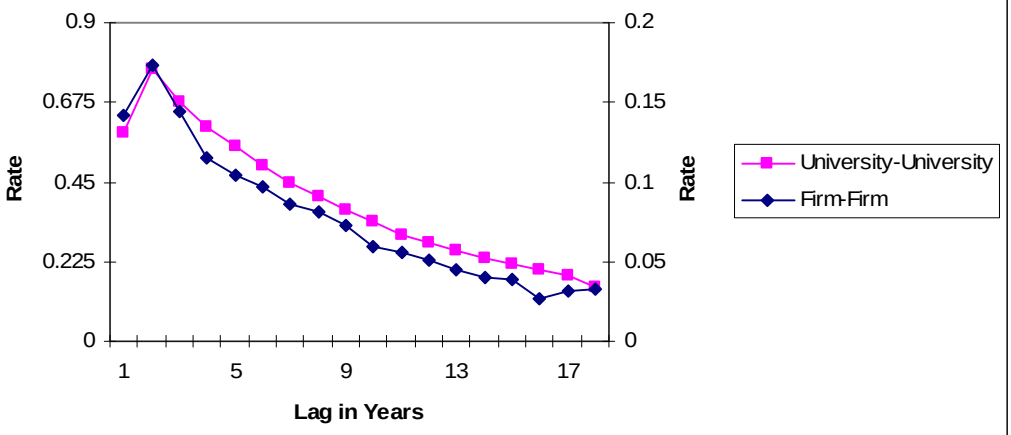



**Figure 7C--Lagged Citation Rates in Chemistry**



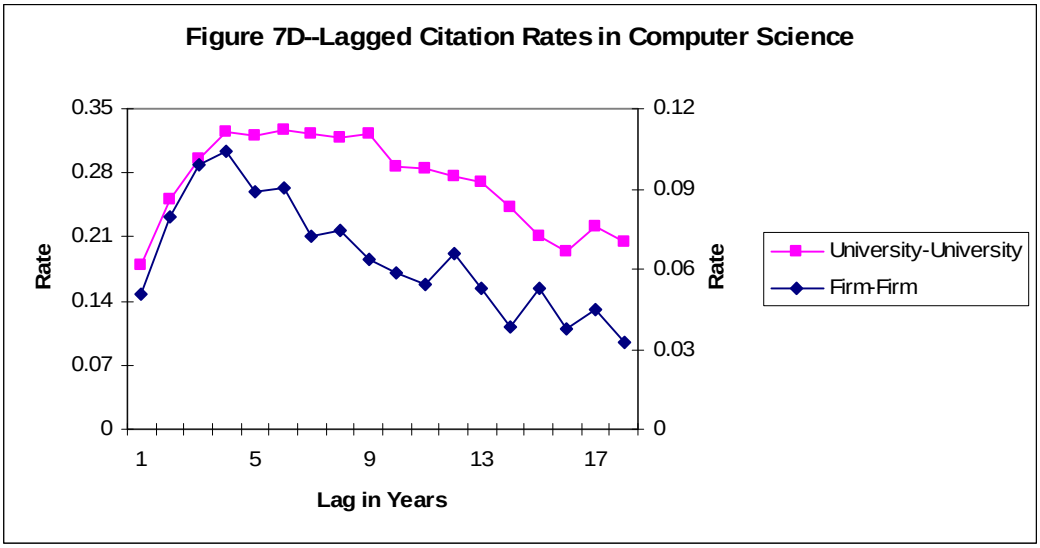


Figure 7D--Lagged Citation Rates in Computer Science
0.35
0.28
0.21
0.14
0.07
0
0.12
0.09
0.06
0.03
0
Rate
Rate
1
5
9
13
17
Lag in Years
University-University
Firm-Firm

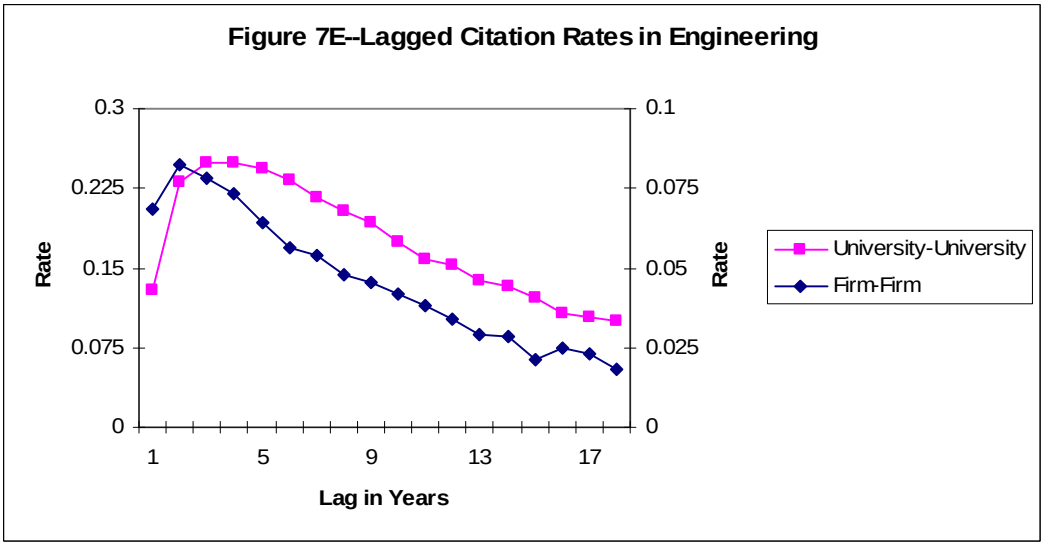


Figure 7E--Lagged Citation Rates in Engineering
0.3
0.225
0.15
0.075
0
0.1
0.075
0.05
0.025
0
Rate
Rate
1
5
9
13
17
Lag in Years
University-University
Firm-Firm

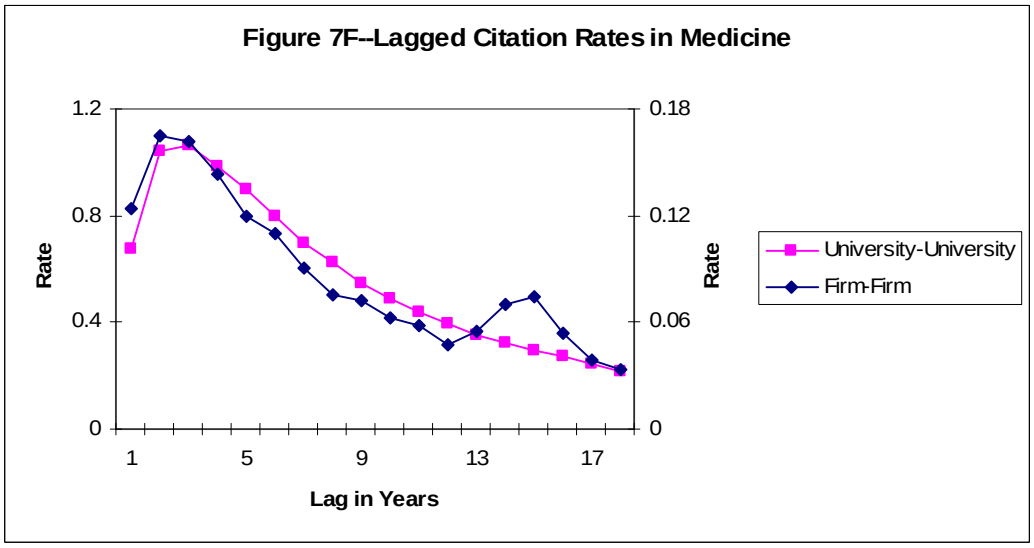


Figure 7F--Lagged Citation Rates in Medicine
1.2
0.8
0.4
0
0.18
0.12
0.06
0
Rate
Rate
1
5
9
13
17
Lag in Years
University-University
Firm-Firm

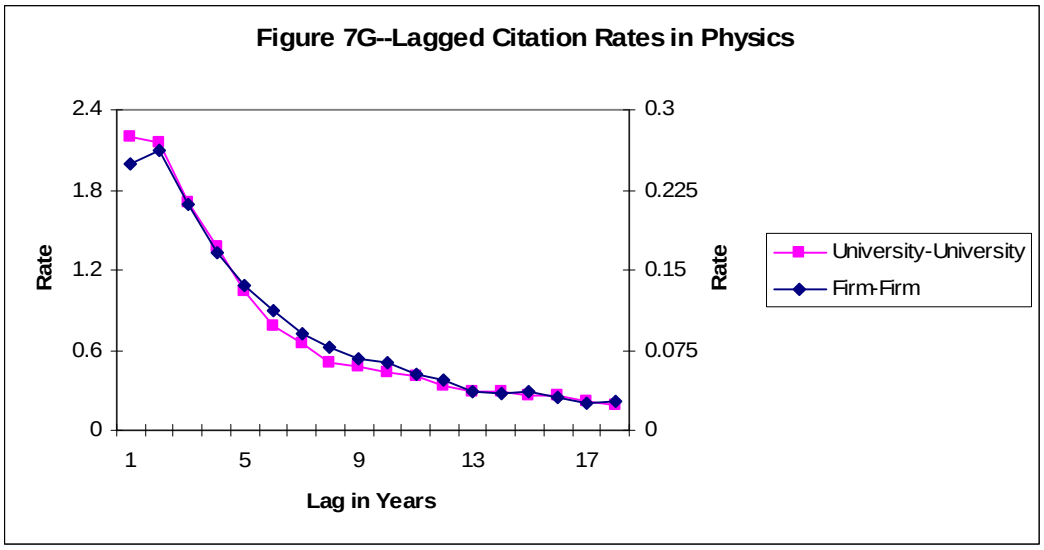


Figure 7G--Lagged Citation Rates in Physics
2.4
1.8
1.2
0.6
0
Rate
0.3
0.225
0.15
0.075
0
Rate
1
5
9
13
17
Lag in Years
University-University
Firm-Firm

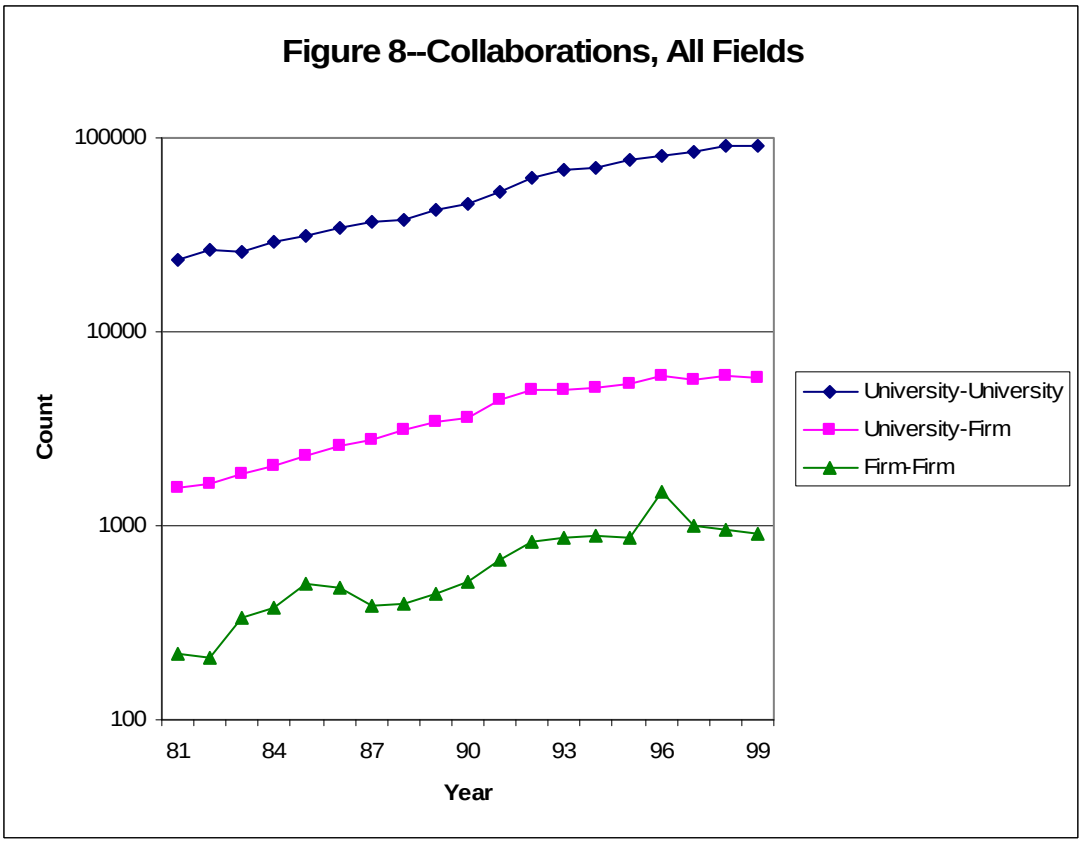


Figure 8--Collaborations, All Fields
100000
10000
1000
100
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

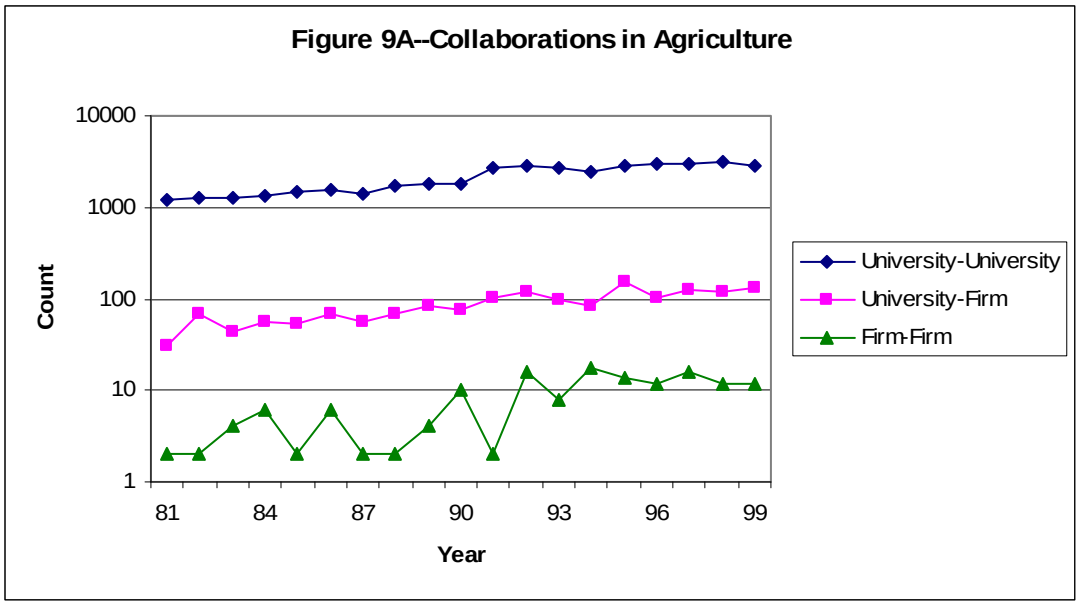


Figure 9A--Collaborations in Agriculture
10000
1000
100
10
1
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

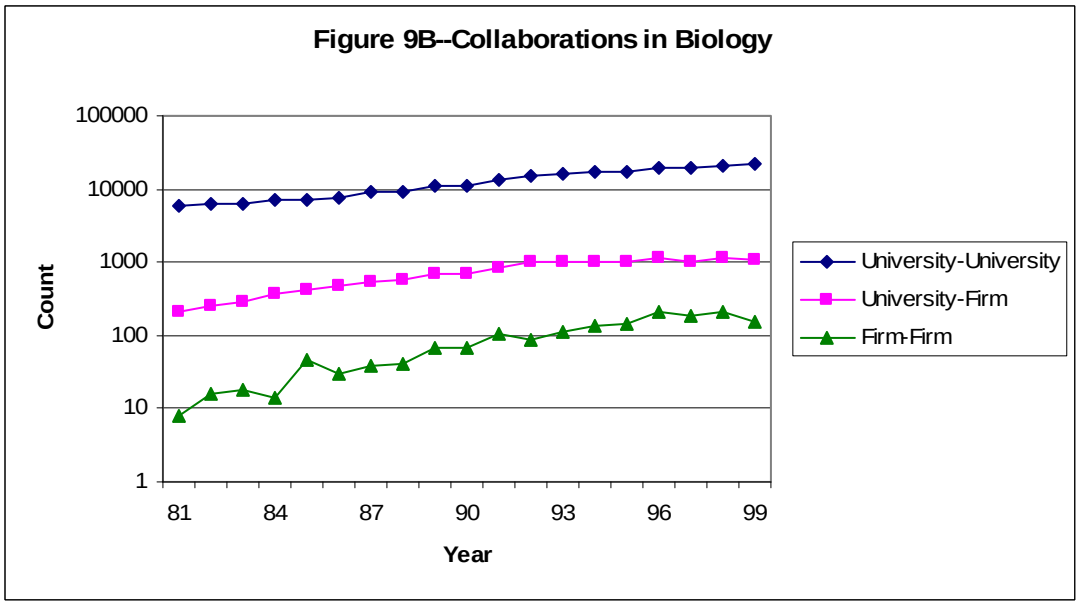


Figure 9B--Collaborations in Biology
100000
10000
1000
100
10
1
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

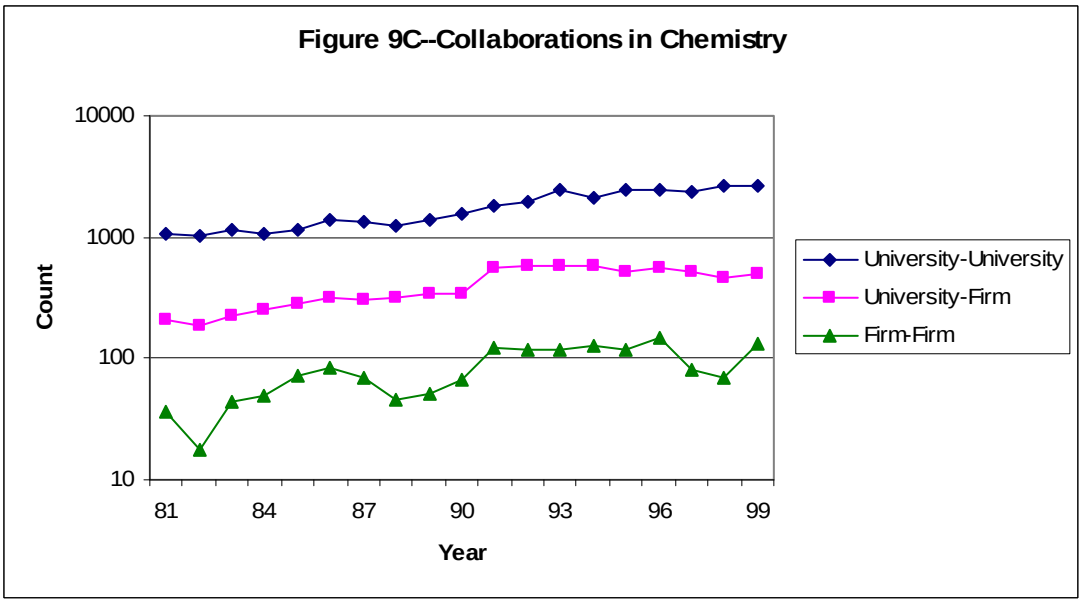


Figure 9C--Collaborations in Chemistry
10000
1000
100
10
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

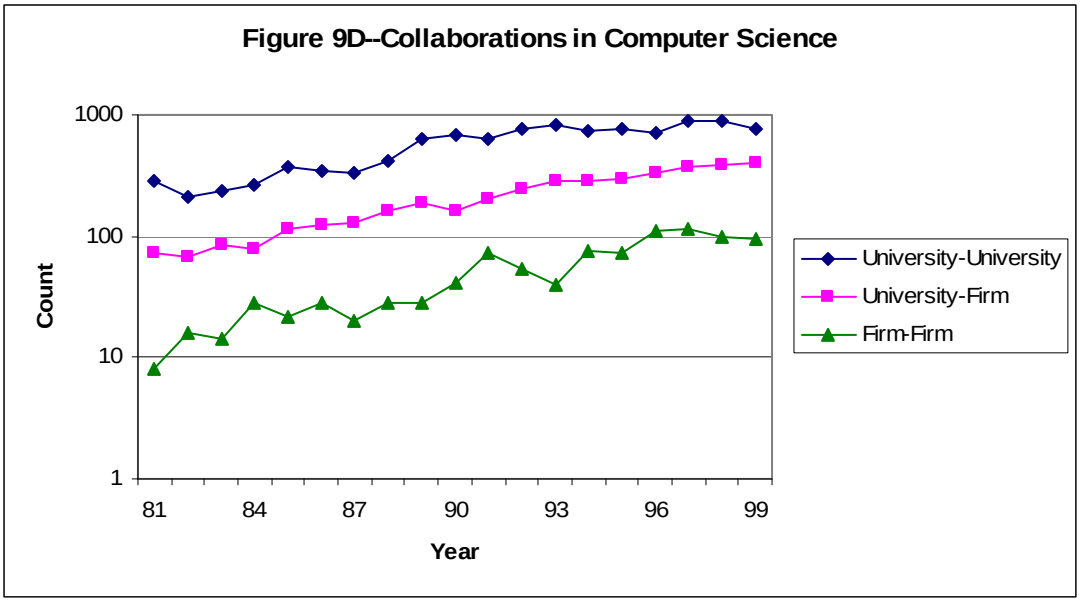


Figure 9D--Collaborations in Computer Science
1000
100
10
1
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

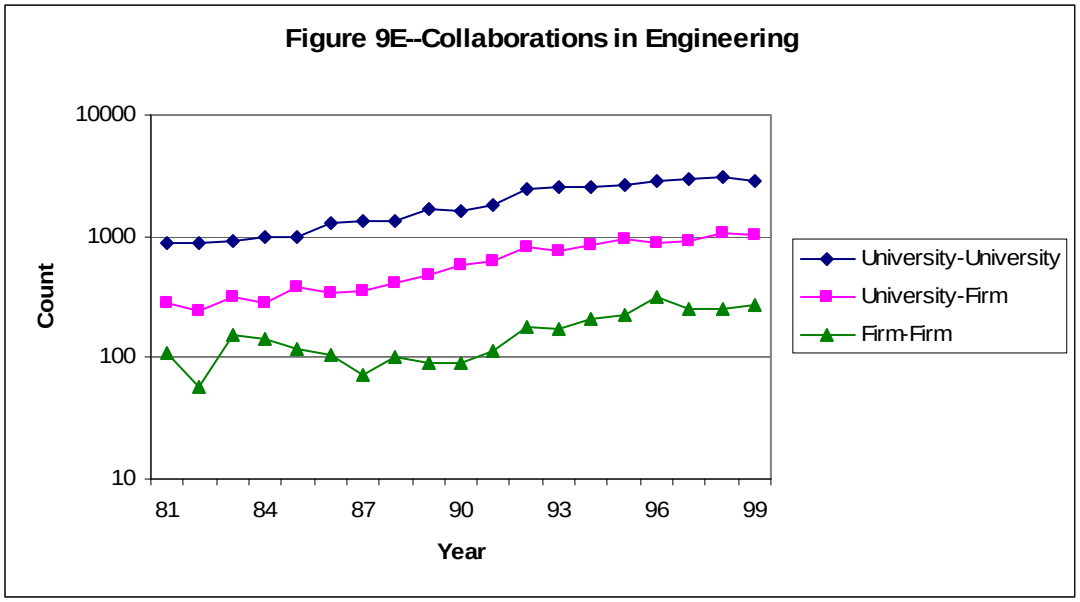


Figure 9E--Collaborations in Engineering
10000
1000
100
10
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

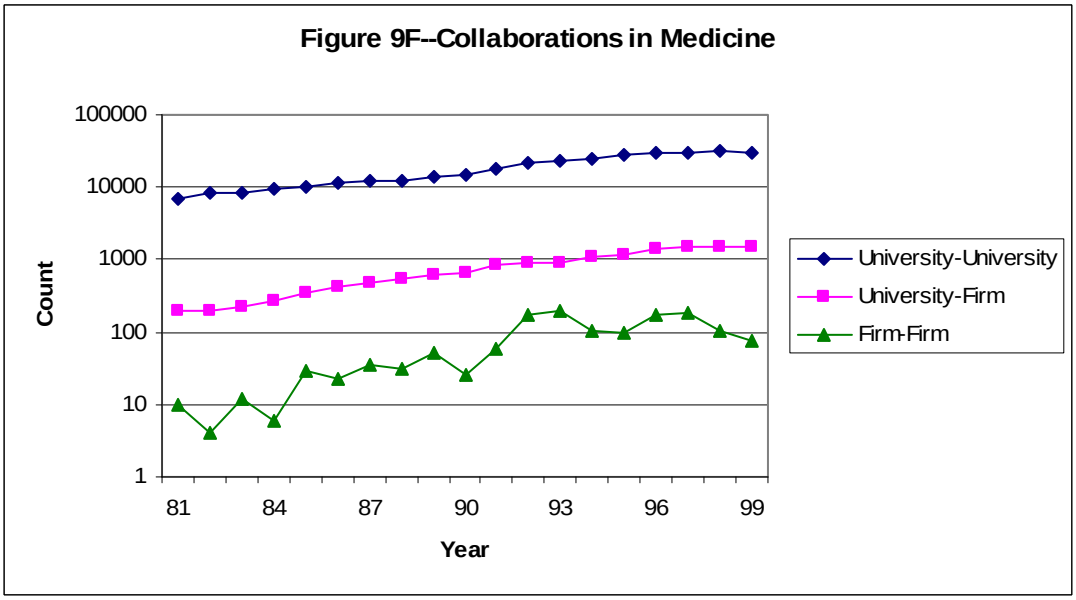


Figure 9F--Collaborations in Medicine
100000
10000
1000
100
10
1
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

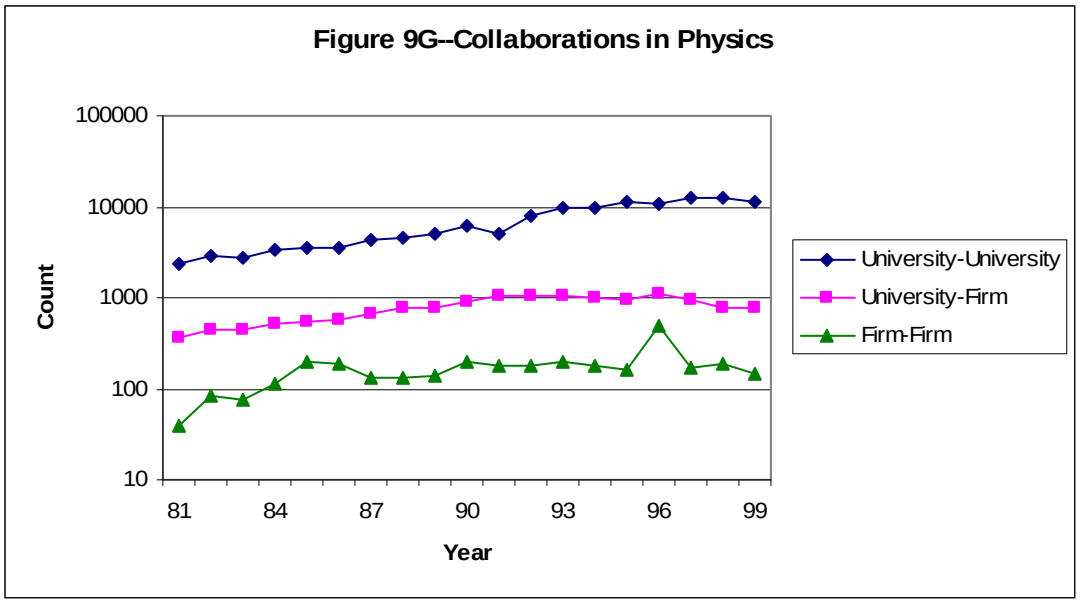


Figure 9G--Collaborations in Physics
100000
10000
1000
100
10
Count
81
84
87
90
93
96
99
Year
University-University
University-Firm
Firm-Firm

**Table 1**
**Files of the NBER-Rensselaer Scientific Papers Database**

| File Name | Number of Observations | Function |
|---|---|---|
| UNIVERSITIES | 110 | Defines the set of Top 110 U.S. Universities and whether or not they belong to a multi-campus system |
| UNIVERSITY_SYSTEMS | 142 | Defines the set of branch campuses for universities that are multi-campus systems |
| UNIVERSITY_DESCRIPTION | 143,119 | Describes papers and citations received by university, Thomson-Reuters ISI 88 science field, and year [a] |
| FIRMS | 200 | Defines the set of Top 200 U.S. R&D-performing firms |
| FIRM_DESCRIPTION | 36,689 | Describes papers and citations received by firm, ISI 88 science field, and year |
| FIELDS | 88 | Defines Thomson-Reuters ISI 88 science fields and provides a cross-walk to NSF 12 main fields and NSF 20 fields [a] |
| CITATION_PAIRS | 21,386,007 | Describes science citations and numbers of citing and cited papers, by institution, Thomson-Reuters 88 science field, and year [a] |
| COLLABORATION_PAIRS | 797,348 | Describes science collaborations and numbers of collaborating and collaborated papers, by institution, Thomson-Reuters 88 science field, and year [a] |

Notes: Thomson-Reuters was formerly known as the Institute for Scientific Information (ISI), hence the use of the acronym ISI to refer to the 88 relatively detailed fields used in the data.

**Table 2—Contents of File UNIVERSITIES**

| Variable Name | Label | Format |
|---|---|---|
| STANDALONE | 1 if stand alone campus, 0 if part of a multi-campus system | Numeric |
| UNIVID | Modified Federal FICE Code [a] | Character |
| UNIVNAME | University Name | Character |

Notes: Here and in the following tables the FICE Code refers to the Federal Interagency Committee on Education Code that identifies a university.

**Table 3—Contents of File UNIVERSITY_SYSTEMS**

| Variable Name | Label | Format |
|---|---|---|
| BRANCH | Name of Branch Campus | Character |
| UNIVID | Modified Federal FICE Code | Character |
| UNIVNAME | University Name | Character |

**Table 4—Contents of File UNIVERSITY_DESCRIPTION**

| Variable Name | Label | Format |
|---|---|---|
| CITSFIRM | Total Forward Citations from Firms | Numeric |
| CITSFIRM5 | Forward Citations from Firms, Five Years | Numeric |
| CITSUNIV | Total Forward Citations from Other Universities | Numeric |
| CITSUNIV5 | Forward Citations from Other Universities, Five Years | Numeric |
| FRCITSFIRM | Fractional CITSFIRM | Numeric |
| FRCITSFIRM5 | Fractional CITSFIRM5 | Numeric |
| FRCITSUNIV | Fractional CITSUNIV | Numeric |
| FRCITSUNIV5 | Fractional CITSUNIV5 | Numeric |
| FRPAPERS | Fractional PAPERS of a Firm | Numeric |
| ISI88 | Thomson-Reuters ISI 88 Field Code | Character |
| PAPERS | Number of Papers | Numeric |
| UNIVID | Modified Federal FICE Code | Character |
| YEAR | Year | Character |

**Table 5—Contents of File FIRMS**

| Variable Name | Label | Format |
|---|---|---|
| FIRMID | 1998 Ticker Symbol of a Firm | Character |
| FIRMNAME | Firm Name | Character |
| SIC4 | 4 Digit 1987 SIC Code | Numeric |

**Table 6—Contents of File FIRM_DESCRIPTION**

| Variable Name | Label | Format |
|---|---|---|
| CITSFIRM | Total Forward Citations from Other Firms | Numeric |
| CITSFIRM5 | Forward Citations from Other Firms, Five Years | Numeric |
| CITSUNIV | Total Forward Citations from Universities | Numeric |
| CITSUNIV5 | Forward Citations from Universities, Five Years | Numeric |
| FIRMID | 1998 Ticker Symbol of Firm | Character |
| FRCITSFIRM | Fractional CITSFIRM | Numeric |
| FRCITSFIRM5 | Fractional CITSFIRM5 | Numeric |
| FRCITSUNIV | Fractional CITSUNIV | Numeric |
| FRCITSUNIV5 | Fractional CITSUNIV5 | Numeric |
| FRPAPERS | Fractional PAPERS of a Firm | Numeric |
| ISI88 | Thomson-Reuters ISI 88 Field Code | Character |
| PAPERS | Number of Papers | Numeric |
| YEAR | Year | Character |

**Table 7—Contents of File FIELDS**

| Variable Name | Label | Format |
|---|---|---|
| ISI88_DESCRIPTION | Thomson-Reuters ISI 88 Field Description | Character |
| NSF12 | NSF-CASPAR 12 Field Code | Character |
| NSF20 | NSF-CASPAR 20 Field Code | Character |
| NSF12_DESCRIPTION | NSF-CASPAR 12 Field Description | Character |
| NSF20_DESCRIPTION | NSF-CASPAR 20 Field Description | Character |
| ISI88 | Thomson-Reuters ISI 88 Field Code | Character |

**Table 8—Contents of File CITATION_PAIRS**

| Variable Name | Label | Format |
|---|---|---|
| CITATIONS | Number of Citations from Citing to Cited | Numeric |
| CTG_CTD | Citing and Cited Type, UNV or FRM | Character |
| INSTCTD | Cited UNIVID or FIRMID | Character |
| INSTCTG | Citing UNIVID or FIRMID | Character |
| ISI88CTD | Cited Thomson-Reuters ISI 88 Field Code | Character |
| ISI88CTG | Citing Thomson-Reuters ISI 88 Field Code | Character |
| PAPERSCTD | Potentially Cited Number of Papers | Numeric |
| PAPERSCTG | Potentially Citing Number of Papers | Numeric |
| YEARCTD | Cited Year of Publication | Character |
| YEARCTG | Citing Year of Publication | Character |

**Table 9—Contents of File COLLABORATION_PAIRS**

| Variable Name | Label | Format |
|---|---|---|
| CLBG_CLBD | Collaborating and Collaborated Type, UNV or FRM | Character |
| COLLABORATIONS | Number of Collaborations | Numeric |
| INSTCLBD | Collaborated UNIVID or FIRMID | Character |
| INSTCLBG | Collaborating UNIVID or FIRMID | Character |
| ISI88 | Thomson-Reuters ISI 88 Field Code | Character |
| PAPERSCLBD | Potentially Collaborated Number of Papers | Numeric |
| PAPERSCLBG | Potentially Collaborating Number of Papers | Numeric |
| YEAR | Year of Publication | Character |

**Table 10**
**Distribution of Fractional and Whole Papers, 1981-1999**
**Universities and Firms**
**(Column Percentages in Parentheses)**

| NSF 12 Main Science Field | Top 110 Universities | | Top 200 R&D Firms | |
|---|---|---|---|---|
| | Fractional Papers | Whole Papers | Fractional Papers | Whole Papers |
| Agriculture | 180,427 (7.5%) | 199,045 (7.0%) | 4,927 (2.4%) | 5,720 (2.4%) |
| Astronomy | 35,534 (1.5%) | 47,593 (1.7%) | 777 (0.4%) | 1,128 (0.5%) |
| Biology | 609,732 (25.4%) | 717,213 (25.3%) | 35,506 (17.6%) | 42,053 (17.7%) |
| Chemistry | 190,108 (7.9%) | 208,604 (7.4%) | 34,682 (17.2%) | 38,820 (16.3%) |
| Computer Science | 26,647 (1.1%) | 32,821 (1.2%) | 10,258 (5.1%) | 12,367 (5.2%) |
| Earth Sciences | 72,541 (3.0%) | 88,306 (3.1%) | 2,799 (1.4%) | 3,616 (1.5%) |
| Economics and Business | 43,767 (1.8%) | 53,292 (1.9%) | 485 (0.2%) | 642 (0.3%) |
| Engineering | 167,191 (7.0%) | 188,100 (6.6%) | 43,883 (21.7%) | 50,356 (21.1%) |
| Mathematics and Statistics | 59,739 (2.5%) | 70,730 (2.5%) | 1,994 (1.0%) | 2,574 (1.1%) |
| Medicine | 686,459 (28.6%) | 821,534 (29.0%) | 23,039 (11.4%) | 29,200 (12.3%) |
| Physics | 212,414 (8.8%) | 267,697 (9.4%) | 42,791 (21.2%) | 50,588 (21.2%) |
| Psychology | 117,695 (4.9%) | 141,765 (5.0%) | 932 (0.5%) | 1,213 (0.5%) |
| All Fields | 2,402,255 (100%) | 2,836,700 (100%) | 202,069 (100%) | 238,277 (100%) |

# Appendix:
# Universities, Firms, and Fields

**Table A1**
**The Top 110 U.S. Universities**

| University Name | Modified Federal FICE Code | Observation |
|---|---|---|
| ARIZONA STATE UNIV | 1081 | 1 |
| UNIV ARIZONA | 1083 | 2 |
| CALTECH | 1131 | 3 |
| UNIV TEXAS HOUSTON HLTH SCI CTR | 11618 | 4 |
| STANFORD UNIV | 1305 | 5 |
| UNIV CALIF BERKELEY | 1312 | 6 |
| UNIV CALIF DAVIS | 1313 | 7 |
| UNIV CALIF IRVINE | 1314 | 8 |
| UNIV CALIF LOS ANGELES | 1315 | 9 |
| UNIV CALIF RIVERSIDE | 1316 | 10 |
| UNIV CALIF SAN DIEGO | 1317 | 11 |
| UNIV CALIF SAN FRANCISCO | 1319 | 12 |
| UNIV CALIF SANTA BARBARA | 1320 | 13 |
| UNIV CALIF SANTA CRUZ | 1321 | 14 |
| UNIV SO CALIF | 1328 | 15 |
| COLORADO STATE UNIV | 1350 | 16 |
| YALE UNIV | 1426 | 17 |
| UNIV DELAWARE | 1431 | 18 |
| GEORGETOWN UNIV | 1445 | 19 |
| FLORIDA STATE UNIV | 1489 | 20 |
| UNIV FLORIDA | 1535 | 21 |
| UNIV MIAMI | 1536 | 22 |
| EMORY UNIV | 1564 | 23 |
| UNIV GEORGIA | 1598 | 24 |
| UNIV HAWAII | 1610 | 25 |
| LOYOLA UNIV | 1710 | 26 |
| NORTHWESTERN UNIV | 1739 | 27 |
| UNIV CHICAGO | 1774 | 28 |
| UNIV ILLINOIS URBANA | 1775 | 29 |
| UNIV ILLINOIS CHICAGO | 1776 | 30 |
| IOWA STATE UNIV | 1869 | 31 |
| UNIV IOWA | 1892 | 32 |
| TULANE UNIV | 2029 | 33 |
| JOHNS HOPKINS UNIV | 2077 | 34 |
| UNIV MARYLAND COLLEGE PARK | 2103 | 35 |

**Table A1**
**The Top 110 U.S. Universities**

| University Name | Modified Federal FICE Code | Observation |
|---|---|---|
| UNIV MARYLAND BALTIMORE | 2104 | 36 |
| BOSTON UNIV | 2130 | 37 |
| BRANDEIS UNIV | 2133 | 38 |
| HARVARD UNIV | 2155 | 39 |
| MIT | 2178 | 40 |
| TUFTS UNIV | 2219 | 41 |
| WOODS HOLE OCEANOG INST | 2230 | 42 |
| MICHIGAN STATE UNIV | 2290 | 43 |
| WAYNE STATE UNIV | 2329 | 44 |
| WASHINGTON UNIV | 2520 | 45 |
| DARTMOUTH COLL | 2573 | 46 |
| UNIV NEW HAMPSHIRE | 2589 | 47 |
| PRINCETON UNIV | 2627 | 48 |
| UNIV NEW MEXICO | 2663 | 49 |
| NEW YORK UNIV | 2785 | 50 |
| ROCKEFELLER UNIV | 2807 | 51 |
| UNIV ROCHESTER | 2894 | 52 |
| YESHIVA UNIV | 2903 | 53 |
| UNIV ALASKA | 29094 | 54 |
| DUKE UNIV | 2920 | 55 |
| N CAROLINA STATE UNIV | 2972 | 56 |
| UNIV N CAROLINA CHAPEL HILL | 2974 | 57 |
| WAKE FOREST UNIV | 2978 | 58 |
| CASE WESTERN RESERVE UNIV | 3024 | 59 |
| OREGON STATE UNIV | 3210 | 60 |
| UNIV OREGON | 3223 | 61 |
| CARNEGIE MELLON UNIV | 3242 | 62 |
| LEHIGH UNIV | 3289 | 63 |
| UNIV PENN | 3378 | 64 |
| BROWN UNIV | 3401 | 65 |
| VANDERBILT UNIV | 3535 | 66 |
| RICE UNIV | 3604 | 67 |
| UNIV TEXAS AUSTIN | 3658 | 68 |
| UNIV TEXAS SAN ANTONIO HLTH SCI CTR | 3659 | 69 |
| UNIV TEXAS SOUTHWESTERN MED CTR DALLAS | 3660 | 70 |
| UNIV UTAH | 3675 | 71 |
| UTAH STATE UNIV | 3677 | 72 |
| UNIV VERMONT | 3696 | 73 |
| VIRGINIA COMMONWEALTH UNIV | 3735 | 74 |
| VIRGINIA POLYTECH INST | 3754 | 75 |
| UNIV WASHINGTON | 3798 | 76 |

**Table A1**
**The Top 110 U.S. Universities**

| University Name | Modified Federal FICE Code | Observation |
|---|---|---|
| WASHINGTON STATE UNIV | 3800 | 77 |
| W VIRGINIA UNIV | 3827 | 78 |
| UNIV WISCONSIN MADISON | 3895 | 79 |
| OREGON HLTH SCI UNIV | 4882 | 80 |
| BAYLOR COLL MED | 4949 | 81 |
| NEW MEXICO STATE UNIV | 8773 | 82 |
| UNIV CINCINNATI | 8805 | 83 |
| SUNY STONY BROOK | 9555 | 84 |
| UNIV ALABAMA | X1051 | 85 |
| UNIV MISSOURI | X2515 | 86 |
| CUNY | X2686 | 87 |
| TEXAS A&M UNIV | X3632 | 88 |
| UNIV VIRGINIA | X3745 | 89 |
| COLUMBIA UNIV | X7963 | 90 |
| UNIV NEBRASKA | X8025 | 91 |
| UNIV TENNESSEE | X8051 | 92 |
| UNIV COLORADO | X8717 | 93 |
| UNIV CONNECTICUT | X8718 | 94 |
| GEORGIA INST TECHNOL | X8723 | 95 |
| INDIANA UNIV | X8731 | 96 |
| PURDUE UNIV | X8732 | 97 |
| UNIV KENTUCKY | X8744 | 98 |
| LOUISIANA STATE UNIV | X8745 | 99 |
| UNIV MASSACHUSETTS | X8755 | 100 |
| UNIV MINNESOTA | X8761 | 101 |
| RUTGERS STATE UNIV | X8771 | 102 |
| CORNELL UNIV | X8779 | 103 |
| SYRACUSE UNIV | X8789 | 104 |
| OHIO STATE UNIV | X8802 | 105 |
| PENN STATE UNIV | X8813 | 106 |
| UNIV PITTSBURGH | X8815 | 107 |
| UNIV KANSAS | X9001 | 108 |
| UNIV MICHIGAN | X9091 | 109 |
| SUNY BUFFALO | X9554 | 110 |

**Table A2**
**The Top 200 U.S. R&D Firms in 1998**

| Firm Name | Firmid [a] | Observation |
|---|---|---|
| ALCOA INC | AA | 1 |
| APPLE COMPUTER INC | AAPL | 2 |
| ABBOTT LABORATORIES | ABT | 3 |
| ADOBE SYSTEMS INC | ADBE | 4 |
| ADC TELECOMMUNICATIONS INC | ADCT | 5 |
| ANALOG DEVICES | ADI | 6 |
| ADAPTEC INC | ADPT | 7 |
| AUTODESK INC | ADSK | 8 |
| ALLERGAN INC | AGN | 9 |
| AMERICAN HOME PRODUCTS CORP | AHP | 10 |
| ALLIEDSIGNAL INC | ALD | 11 |
| APPLIED MATERIALS INC | AMAT | 12 |
| ADVANCED MICRO DEVICES | AMD | 13 |
| AMGEN INC | AMGN | 14 |
| AMP INC | AMP | 15 |
| AMERICA ONLINE INC | AOL | 16 |
| AIR PRODUCTS & CHEMICA LS INC | APD | 17 |
| APPLIED MAGNETICS CORP | APM | 18 |
| AMERN STANDARD CO INC | ASD | 19 |
| ASCEND COMMUNICATIONS INC | ASND | 20 |
| ATMEL CORP | ATML | 21 |
| AUTOMATIC DATA PROCESSING | AUD | 22 |
| AVID TECHNOLOGY INC | AVID | 23 |
| BOEING CO | BA | 24 |
| BAXTER INTERNATIONAL INC | BAX | 25 |
| BRUNSWICK CORP | BC | 26 |
| BARD (C.R.) INC | BCR | 27 |
| BLACK & DECKER CORP | BDK | 28 |
| BECTON DICKINSON & CO | BDX | 29 |
| BEA SYSTEMS INC | BEAS | 30 |
| BECKMAN COULTER INC | BEC | 31 |
| BELL COMMUNICATIONS RESEARCH INC [b] | BELLC | 32 |
| BIOGEN INC | BGEN | 33 |
| BAKER-HUGHES INC | BHI | 34 |
| BMC SOFTWARE INC | BMCS | 35 |
| BRISTOL MYERS SQUIBB | BMY | 36 |
| BAUSCH & LOMB INC | BOL | 37 |
| BOSTON SCIENTIFIC CORP | BSX | 38 |
| COMPUTER ASSOCIATES INTL INC | CA | 39 |
| CATERPILLAR INC | CAT | 40 |

**Table A2**
**The Top 200 U.S. R&D Firms in 1998**

| Firm Name | Firmid [a] | Observation |
|---|---|---|
| CADENCE DESIGN SYS INC | CDN | 41 |
| CERIDIAN CORP | CEN | 42 |
| CHIRON CORP | CHIR | 43 |
| CHEVRON CORP | CHV | 44 |
| COLGATE-PALMOLIVE CO | CL | 45 |
| COMVERSE TECHNOLOGY INC | CMVT | 46 |
| CENTOCOR INC | CNTO | 47 |
| COMPAQ COMPUTER CORP | CPQ | 48 |
| CIRRUS LOGIC INC | CRUS | 49 |
| CABLETRON SYSTEMS | CS | 50 |
| CISCO SYSTEMS INC | CSCO | 51 |
| CUMMINS ENGINE | CUM | 52 |
| CONVERGYS CORP | CVG | 53 |
| CYPRESS SEMICONDUCTOR CORP | CY | 54 |
| DANA CORP | DCN | 55 |
| DU PONT (E I) DE NEMOU RS | DD | 56 |
| DETROIT DIESEL CORP | DDC | 57 |
| DEERE & CO | DE | 58 |
| DELL COMPUTER CORP | DELL | 59 |
| DEXTER CORP | DEX | 60 |
| DATA GENERAL CORP | DGN | 61 |
| DANAHER CORP | DHR | 62 |
| GENENTECH INC | DNA | 63 |
| DOVER CORP | DOV | 64 |
| DOW CHEMICAL | DOW | 65 |
| DELPHI AUTOMOTIVE SYS CORP | DPH | 66 |
| EASTMAN KODAK CO | EK | 67 |
| EMC CORP/MA | EMC | 68 |
| EASTMAN CHEMICAL CO | EMN | 69 |
| EMERSON ELECTRIC CO | EMR | 70 |
| ELECTRONIC ARTS INC | ERTS | 71 |
| EATON CORP | ETN | 72 |
| FORD MOTOR CO | F | 73 |
| FMC CORP | FMC | 74 |
| FEDERAL-MOGUL CORP | FMO | 75 |
| GILLETTE CO | G | 76 |
| GENERAL DYNAMICS CORP | GD | 77 |
| GENERAL ELECTRIC CO | GE | 78 |
| GENZYME GENERAL | GENZ | 79 |
| CORNING INC | GLW | 80 |
| GENERAL MOTORS CORP | GM | 81 |

**Table A2**
**The Top 200 U.S. R&D Firms in 1998**

| Firm Name | Firmid [a] | Observation |
|---|---|---|
| GOODRICH (B F) CO | GR | 82 |
| GOODYEAR TIRE & RUBBER CO | GT | 83 |
| GTE CORP | GTE | 84 |
| HALLIBURTON CO | HAL | 85 |
| HASBRO INC | HAS | 86 |
| HONEYWELL INC | HON | 87 |
| HERCULES INC | HPC | 88 |
| HARRIS CORP | HRS | 89 |
| HEWLETT-PACKARD CO | HWP | 90 |
| INTL BUSINESS MACHINES CORP | IBM | 91 |
| ICOS CORPORATION | ICOS | 92 |
| INTEGRATED DEVICE TECH INC | IDTI | 93 |
| INTL FLAVORS & FRAGRANCES | IFF | 94 |
| INFORMIX CORP | IFMX | 95 |
| ITT INDUSTRIES INC | IIN | 96 |
| IMATION CORP | IMN | 97 |
| IMMUNEX CORP | IMNX | 98 |
| INTERGRAPH CORP | INGR | 99 |
| INTEL CORP | INTC | 100 |
| INTUIT INC | INTU | 101 |
| IOMEGA CORP | IOM | 102 |
| INTL PAPER CO | IP | 103 |
| INGERSOLL-RAND CO | IR | 104 |
| I2 TECHNOLOGIES INC | ITWO | 105 |
| JOHNSON CONTROLS INC | JCI | 106 |
| EDWARDS J D & CO | JDEC | 107 |
| JDS UNIPHASE CORP | JDSU | 108 |
| JOHNSON & JOHNSON | JNJ | 109 |
| KELLOGG CO | K | 110 |
| KLA-TENCOR CORP | KLAC | 111 |
| KIMBERLY-CLARK CORP | KMB | 112 |
| LYCOS INC | LCOS | 113 |
| LEAR CORP | LEA | 114 |
| LITTON INDUSTRIES INC | LIT | 115 |
| LILLY (ELI) & CO | LLY | 116 |
| LOCKHEED MARTIN CORP | LMT | 117 |
| LAM RESEARCH CORP | LRCX | 118 |
| LSI LOGIC CORP | LSI | 119 |
| LUCENT TECHNOLOGIES INC | LU | 120 |
| LEXMARK INTL GRP INC | LXK | 121 |
| LUBRIZOL CORP | LZ | 122 |

**Table A2**
**The Top 200 U.S. R&D Firms in 1998**

| Firm Name | Firmid [a] | Observation |
|---|---|---|
| MATTEL INC | MAT | 123 |
| MCKESSON HBOC INC | MCK | 124 |
| MEDTRONIC INC | MDT | 125 |
| MENTOR GRAPHICS CORP | MENT | 126 |
| MALLINCKRODT INC | MKG | 127 |
| MINNESOTA MINING & MFG CO | MMM | 128 |
| PHILIP MORRIS COS INC | MO | 129 |
| MOBIL CORP | MOB | 130 |
| MOLEX INC | MOLX | 131 |
| MOTOROLA INC | MOT | 132 |
| MERCK & CO | MRK | 133 |
| MICROSOFT CORP | MSFT | 134 |
| MONSANTO CO | MTC | 135 |
| MICRON TECHNOLOGY INC | MU | 136 |
| MYLAN LABORATORIES | MYL | 137 |
| NAVISTAR INTERNATIONL | NAV | 138 |
| NCR CORP | NCR | 139 |
| NABISCO GROUP HLDGS CORP | NGH | 140 |
| NORTHROP GRUMMAN CORP | NOC | 141 |
| NOVELL INC | NOVL | 142 |
| NETSCAPE COMMUNICATIONS CORP | NSCP | 143 |
| NATIONAL SEMICONDUCTOR CORP | NSM | 144 |
| NOVELLUS SYSTEMS INC | NVLS | 145 |
| PITNEY BOWES INC | PBI | 146 |
| PACCAR INC | PCAR | 147 |
| PFIZER INC | PFE | 148 |
| PROCTER & GAMBLE CO | PG | 149 |
| PIONEER HI-BRED INTERNATIONL | PHB | 150 |
| PARAMETRIC TECHNOLOGY CORP | PMTC | 151 |
| PHARMACIA & UPJOHN INC | PNU | 152 |
| PPG INDUSTRIES INC | PPG | 153 |
| POLAROID CORP | PRD | 154 |
| PEOPLESOFT INC | PSFT | 155 |
| QUALCOMM INC | QCOM | 156 |
| QWEST COMMUNICATION IN TL INC | QWST | 157 |
| RALSTON PURINA CO | RAL | 158 |
| READ-RITE CORP | RDRT | 159 |
| ROHM & HAAS CO | ROH | 160 |
| ROCKWELL INTL CORP | ROK | 161 |
| RAYTHEON CO -CL B | RTN.B | 162 |
| SUNGARD DATA SYSTEMS I NC | SDS | 163 |

**Table A2**
**The Top 200 U.S. R&D Firms in 1998**

| Firm Name | Firmid [a] | Observation |
|---|---|---|
| SEAGATE TECHNOLOGY | SEG | 164 |
| SCIENTIFIC-ATLANTA INC | SFA | 165 |
| SILICON GRAPHICS INC | SGI | 166 |
| SCHERING-PLOUGH | SGP | 167 |
| SHELL OIL CO | SHELL | 168 |
| S3 INCORPORATED | SIII | 169 |
| SHARED MEDICAL SYSTEMS CORP | SMS | 170 |
| SYNOPSYS INC | SNPS | 171 |
| SUNDSTRAND CORP | SNS | 172 |
| SEQUENT COMPUTER SYSTEMS INC | SQNT | 173 |
| ST JUDE MEDICAL INC | STJ | 174 |
| STORAGE TECHNOLOGY CP | STK | 175 |
| SUN MICROSYSTEMS INC | SUNW | 176 |
| SYBASE INC | SYBS | 177 |
| STRYKER CORP | SYK | 178 |
| SYMANTEC CORP | SYMC | 179 |
| AT&T CORP | T | 180 |
| TERADYNE INC | TER | 181 |
| TELLABS INC | TLAB | 182 |
| THERMO ELECTRON CORP | TMO | 183 |
| TRW INC | TRW | 184 |
| TEXACO INC | TX | 185 |
| TEXAS INSTRUMENTS INC | TXN | 186 |
| TEXTRON INC | TXT | 187 |
| UNIGRAPHICS SOLUTIONS INC | UGS | 188 |
| UNISYS CORP | UIS | 189 |
| UNION CARBIDE CORP | UK | 190 |
| UNITED TECHNOLOGIES CO RP | UTX | 191 |
| VARIAN MEDICAL SYTEMS INC | VAR | 192 |
| VLSI TECHNOLOGY INC | VLSI | 193 |
| WORLD ACCESS INC | WAXS | 194 |
| WESTERN DIGITAL CORP | WDC | 195 |
| WHIRLPOOL CORP | WHR | 196 |
| WARNER-LAMBERT CO | WLA | 197 |
| XILINX INC | XLNX | 198 |
| EXXON CORP | XON | 199 |
| XEROX CORP | XRX | 200 |

Notes: [a,b] Firmid is the 1998 ticker symbol of the firm, except for BELL COMMUNICATIONS RESEARCH INC, which is assigned the artificial ticker BELLC.

**Table A.3**
**Treatment of AT&T and General Motors**
**Families of Companies**

| Name of Family or Firm | FIRMID | Spinoff Date | Treatment of Papers and Citations |
|---|---|---|---|
| **AT&T Family** | | | |
| AT&T CORP | T | N.A. | Separate in all years |
| BELL COMMUNICATIONS RESEARCH INC | BELLC | 1984 | " |
| LUCENT TECHNOLOGIES INC | LU | 1996 | " |
| **General Motors Family** | | | |
| GENERAL MOTORS CORP | GM | N.A. | Separate in all years |
| DELPHI AUTOMOTIVE SYS CORP | DPH | 1998 | " |

Notes: [a,b] Firmid is the 1998 ticker symbol of the firm, except for BELL COMMUNICATIONS RESEARCH INC, which is assigned the artificial ticker BELLC.

**Table A4**
**Mapping Between ISI88 Fields and NSF12 and NSF20 Fields**

| ISI88 | ISI88 Field Description | NSF12 | NSF12 Field Description | NSF20 | NSF20 Field Description |
|---|---|---|---|---|---|
| A_A | AGRICULTURE/AGRONOMY | AGRI | Agriculture | AGRI | Agriculture |
| AN | ANIMAL & PLANT SCIENCES | AGRI | Agriculture | AGRI | Agriculture |
| AQU | AQUATIC SCIENCES | AGRI | Agriculture | AGRI | Agriculture |
| AS | ANIMAL SCIENCES | AGRI | Agriculture | AGRI | Agriculture |
| CMA | AGRICULTURAL CHEMISTRY | AGRI | Agriculture | AGRI | Agriculture |
| ENT | ENTOMOLOGY/PEST CONTROL | AGRI | Agriculture | AGRI | Agriculture |
| F | FOOD SCIENCE/NUTRITION | AGRI | Agriculture | AGRI | Agriculture |
| PL | PLANT SCIENCES | AGRI | Agriculture | AGRI | Agriculture |
| VET | VETERINARY MEDICINE/ANIMAL HEALTH | AGRI | Agriculture | AGRI | Agriculture |
| SP | SPACE SCIENCE | ASTR | Astronomy | ASTR | Astronomy |
| BEH | NEUROSCIENCES & BEHAVIOR | BIOL | Biology | BIOL | Biology |
| BIL | BIOCHEMISTRY & BIOPHYSICS | BIOL | Biology | BIOL | Biology |
| BIO | BIOLOGY | BIOL | Biology | BIOL | Biology |
| BTC | BIOTECHNOLOGY & APPLIED MICROBIOLOGY | BIOL | Biology | BIOL | Biology |
| CEL | CELL & DEVELOPMENTAL BIOLOGY | BIOL | Biology | BIOL | Biology |
| CGX | ONCOGENESIS & CANCER RESEARCH | BIOL | Biology | BIOL | Biology |
| ENV | ENVIRONMENT/ECOLOGY | BIOL | Biology | BIOL | Biology |
| EXP | EXPERIMENTAL BIOLOGY | BIOL | Biology | BIOL | Biology |
| IMM | IMMUNOLOGY | BIOL | Biology | BIOL | Biology |
| MBG | MOLECULAR BIOLOGY & GENETICS | BIOL | Biology | BIOL | Biology |
| MCB | MICROBIOLOGY | BIOL | Biology | BIOL | Biology |
| PHM | PHARMACOLOGY & TOXICOLOGY | BIOL | Biology | BIOL | Biology |
| PSL | PHYSIOLOGY | BIOL | Biology | BIOL | Biology |

**Table A4**
**Mapping Between ISI88 Fields and NSF12 and NSF20 Fields**

| ISI88 | ISI88 Field Description | NSF12 | NSF12 Field Description | NSF20 | NSF20 Field Description |
|---|---|---|---|---|---|
| CML | CHEMISTRY & ANALYSIS | CHEM | Chemistry | CHEM | Chemistry |
| CMP | CHEMISTRY | CHEM | Chemistry | CHEM | Chemistry |
| INC | INORGANIC & NUCLEAR CHEMISTRY | CHEM | Chemistry | CHEM | Chemistry |
| ORG | ORGANIC CHEMISTRY/POLYMER SCIENCE | CHEM | Chemistry | CHEM | Chemistry |
| PHC | PHYSICAL CHEMISTRY/CHEMICAL PHYSICS | CHEM | Chemistry | CHEM | Chemistry |
| SIA | SPECTROSCOPY/INSTRUMENTATION/ANALYTICAL SCIENCES | CHEM | Chemistry | CHEM | Chemistry |
| CSE | COMPUTER SCIENCE & ENGINEERING | COMP | Computer Science | COMP | Computer Science |
| IST | INFORMATION TECHNOLOGY & COMMUNICATIONS SYSTEMS | COMP | Computer Science | COMP | Computer Science |
| ECO | ECONOMICS | ECON | Economics | ECON | Economics |
| MTH | MATHEMATICS | MATH | Mathematics and Statistics | MATH | Mathematics and Statistics |
| XY | STATISTICS | MATH | Mathematics and Statistics | MATH | Mathematics and Statistics |
| AIC | ANESTHESIA & INTENSIVE CARE | MEDI | Medicine | MEDI | Medicine |
| CAR | CARDIOVASCULAR & RESPIRATORY SYSTEMS | MEDI | Medicine | MEDI | Medicine |
| CVS | CARDIOVASCULAR & HEMATOLOGY RESEARCH | MEDI | Medicine | MEDI | Medicine |
| DEN | DENTISTRY/ORAL SURGERY & MEDICINE | MEDI | Medicine | MEDI | Medicine |
| DER | DERMATOLOGY | MEDI | Medicine | MEDI | Medicine |
| DGX | "MEDICAL RESEARCH, DIAGNOSIS & TREATMENT" | MEDI | Medicine | MEDI | Medicine |
| END | "ENDOCRINOLOGY, NUTRITION & METABOLISM" | MEDI | Medicine | MEDI | Medicine |
| GAS | GASTROENTEROLOGY AND HEPATOLOGY | MEDI | Medicine | MEDI | Medicine |

**Table A4**
**Mapping Between ISI88 Fields and NSF12 and NSF20 Fields**

| ISI88 | ISI88 Field Description | NSF12 | NSF12 Field Description | NSF20 | NSF20 Field Description |
|---|---|---|---|---|---|
| GNC | GENERAL & INTERNAL MEDICINE | MEDI | Medicine | MEDI | Medicine |
| HEM | HEMATOLOGY | MEDI | Medicine | MEDI | Medicine |
| HLT | HEALTH CARE SCIENCES & SERVICES | MEDI | Medicine | MEDI | Medicine |
| INF | CLINICAL IMMUNOLOGY & INFECTIOUS DISEASE | MEDI | Medicine | MEDI | Medicine |
| MED | RESEARCH/LABORATORY MEDICINE & MEDICAL TECHNOLOGY | MEDI | Medicine | MEDI | Medicine |
| MGN | MEDICAL RESEARCH, GENERAL TOPICS | MEDI | Medicine | MEDI | Medicine |
| MUL | MULTIDISCIPLINARY | MEDI | Medicine | MEDI | Medicine |
| NEU | NEUROLOGY | MEDI | Medicine | MEDI | Medicine |
| NUT | ENDOCRINOLOGY, METABOLISM & NUTRITION | MEDI | Medicine | MEDI | Medicine |
| OGS | MEDICAL RESEARCH, ORGANS & SYSTEMS | MEDI | Medicine | MEDI | Medicine |
| ONC | ONCOLOGY | MEDI | Medicine | MEDI | Medicine |
| OPH | OPHTHALMOLOGY | MEDI | Medicine | MEDI | Medicine |
| ORT | ORTHOPEDICS, REHABILITATION & SPORTS MEDICINE | MEDI | Medicine | MEDI | Medicine |
| OTO | OTOLARYNGOLOGY | MEDI | Medicine | MEDI | Medicine |
| PED | PEDIATRICS | MEDI | Medicine | MEDI | Medicine |
| PMC | PHARMACOLOGY/TOXICOLOGY | MEDI | Medicine | MEDI | Medicine |
| PSY | CLINICAL PSYCHOLOGY & PSYCHIATRY | MEDI | Medicine | MEDI | Medicine |
| RAD | RADIOLOGY, NUCLEAR MEDICINE & IMAGING | MEDI | Medicine | MEDI | Medicine |
| REP | REPRODUCTIVE MEDICINE | MEDI | Medicine | MEDI | Medicine |
| RHU | RHEUMATOLOGY | MEDI | Medicine | MEDI | Medicine |
| SOC | ENVIRONMENTAL MEDICINE & PUBLIC HEALTH | MEDI | Medicine | MEDI | Medicine |

**Table A4**
**Mapping Between ISI88 Fields and NSF12 and NSF20 Fields**

| ISI88 | ISI88 Field Description | NSF12 | NSF12 Field Description | NSF20 | NSF20 Field Description |
|---|---|---|---|---|---|
| SUR | SURGERY | MEDI | Medicine | MEDI | Medicine |
| URO | UROLOGY & NEPHROLOGY | MEDI | Medicine | MEDI | Medicine |
| APP | APPLIED PHYSICS/CONDENSED MATTER/MATERIALS SCIENCE | PHYS | Physics | PHYS | Physics |
| O_A | OPTICS & ACOUSTICS | PHYS | Physics | PHYS | Physics |
| PHS | PHYSICS | PHYS | Physics | PHYS | Physics |
| PSI | PSYCHIATRY | PSYC | Psychology | PSYC | Psychology |
| PSO | PSYCHOLOGY | PSYC | Psychology | PSYC | Psychology |
| AER | AEROSPACE ENGINEERING | TENG | Total Engineering | AERE | Aerospace Engineering |
| ARA | AI, ROBOTICS & AUTOMATIC CONTROL | TENG | Total Engineering | INDE | Industrial Engineering |
| CIV | CIVIL ENGINEERING | TENG | Total Engineering | CIVE | Civil Engineering |
| CME | CHEMICAL ENGINEERING | TENG | Total Engineering | CHEE | Chemical Engineering |
| EEE | ENVIRONMENTAL ENGINEERING & ENERGY | TENG | Total Engineering | OENG | Other Engineering |
| EL | ELECTRICAL & ELECTRONICS ENGINEERING | TENG | Total Engineering | ELEE | Electrical Engineering |
| EMA | ENGINEERING MATHEMATICS | TENG | Total Engineering | OENG | Other Engineering |
| GNE | ENGINEERING MANAGEMENT/GENERAL | TENG | Total Engineering | INDE | Industrial Engineering |
| GPM | GEOLOGICAL, PETROLEUM & MINING ENGINEERING | TENG | Total Engineering | OENG | Other Engineering |
| I_M | INSTRUMENTATION & MEASUREMENT | TENG | Total Engineering | INDE | Industrial Engineering |
| IG | BIOMEDICAL ENGINEERING | TENG | Total Engineering | OENG | Other Engineering |
| IJ | INDUSTRIAL ENGINEERING | TENG | Total Engineering | INDE | Industrial Engineering |
| MEC | MECHANICAL ENGINEERING | TENG | Total Engineering | MECE | Mechanical Engineering |
| MET | METALLURGY | TENG | Total Engineering | MATE | Materials Science |

**Table A4**
**Mapping Between ISI88 Fields and NSF12 and NSF20 Fields**

| ISI88 | ISI88 Field Description | NSF12 | NSF12 Field Description | NSF20 | NSF20 Field Description |
|---|---|---|---|---|---|
| MTR | MATERIALS SCIENCE & ENGINEERING | TENG | Total Engineering | MATE | Materials Science |
| NCL | NUCLEAR ENGINEERING | TENG | Total Engineering | OENG | Other Engineering |
| EAR | EARTH SCIENCES | TGEO | Total Earth Sciences | EART | Earth Science |
| SI | OCEANOGRAPHY | TGEO | Total Earth Sciences | OCEA | Oceanography |

Notes: ISI88 is a set of 88 detailed fields developed by Thomson-Reuters (formerly, the Institute for Scientific Information) for the assignment of scientific journals to disciplines. NSF12 is a set of 12 main fields used by the National Science Foundation to assign research expenditures, graduate students, and other survey data to universities and sciences. NSF20 is a slightly more detailed breakdown of fields that considers engineering and earth science sub-fields separately.