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Abstract

The recent U.S. experience with the various types of university-industry research relationships is reviewed: the reasons they have increased, the evidence on their performance, and the tensions that have emerged. I argue that the tradeoff between providing incentives for the production of new ideas and information and ensuring that spillovers from that research flow to others leads to different methods of organizing research efforts in different spheres depending on the relative importance of "appropriability" versus the benefits of full and costless knowledge diffusion and that problems may ensue when these spheres collide. The paper reviews the evidence that this is the case and then discusses the case of cumulative innovation, where the IP problem is particularly important.

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1. Introduction

In most modern economies, universities and public research laboratories are viewed as largely responsible for basic scientific and pre-commercial research, while industrial firms perform the bulk of the applied research and development that is necessary before introducing new products and processes to the marketplace. An important issue for both the participants in this process and for government policy makers is the functioning of the interface between these two activities. How well and how quickly do the results of scientific research transfer to industry and become contributors to the growth of the economy and the wellbeing of its members. Who finances the process and who captures its benefits? Does intellectual property protection on the results of university research impede or encourage the process? The answers to these questions affect the level and efficiency of the transfer process as a whole.

Partnering between university and industry has been widely viewed as one of the contributors to successful U.S. innovation and growth in the past two decades. In this paper, I review the U.S. experience with the various types of university-industry relationships, the reasons why they have grown during this period, and the tensions that have appeared, which are largely centered in the area of intellectual property. I also report on some survey evidence drawn from questionnaires sent to industry and university participants in research joint ventures, work that is joint with Albert Link and John Scott (Hall, Link, and Scott 2001, 2003).

In Hall (2004), I suggested that the tradeoff between providing incentives for the production of new ideas and information and ensuring that spillovers from that research flow to others is likely to lead to different methods of organizing research efforts in different spheres depending on the relative importance of "appropriability" versus the benefits of full and costless knowledge diffusion. In particular, as Paul David (David 1998; Dasgupta and David 1994; David 1992) has argued, the "open science" community has evolved a rather different approach to rewards for and spillovers from the production of information goods than that suggested by a conventional economic property rights analysis, one based on rapid publication and dissemination in order to achieve a prior claim as the inventor.[1]

Because this kind of system for securing rewards to investments in research is so different from that in which most industrial firms operate, it is not surprising that tensions arise in settings where the conventions of one world (private industry) come up against the conventions of another (public R&D and university science). Gambardella and Hall (2003, 2004) have modeled one of the sources of this tension, which is the instability of the open science regime when confronted with large returns to privatization. Consistent with Olson's insights on collective action (1971), one can show that the collective science enterprise has a tendency to breakdown when the rewards to privatization are great, the number of researchers becomes large, or the cultural norms of the free sharing of discoveries is weakened. Some examples given later in this paper suggest that increasing ties between universities and industry may sometimes increase the instability of the collective equilibrium, with negative consequences for the conduct of scientific research.

The paper first describes the university-industry research relationship as it now exists in the United States and then summarizes some research on the effectiveness of these collaborations. I

[1] Also see Arora, David, and Gambardella (1999) for empirical evidence on the "increasing returns" nature of the reward system in science, sometimes known as the "Matthew" effect.

review the evidence on the problems that have emerged in the intellectual property area, and discuss more thoroughly the case of cumulative innovation, where the IP problem is particularly salient. The paper concludes with some thoughts on policies to ensure the preservation of the "scientific commons."

2. *The growth of university-industry partnering in the U.S.*

For reasons partly related to the institutional origins of public universities in the United States, partnerships between both the agriculture and the manufacturing sectors and universities have a long history. As Mowery and Rosenberg (1989) point out, the increase in these partnering activities during the past ten or twenty years restores strong links that existed in the first half of the twentieth century. See Table 1, which shows that the share of university research coming from industry was actually higher in 1953 and 1960 than in 1970 or 1980, but as of 1990 had rebounded to the 1953 level. The table also makes it clear that industry funding is still a relatively small fraction of university research funding, about 6-7 percent of the total. The bulk of the funding for university research comes from the federal government.

The shift in composition of university research funding shown in Table 1 has probably been driven by various policy responses to the productivity slowdown and loss of international market share for key industries such as autos and semiconductors during the late 1970s and early 1980s.[2] A number of policy measures designed to increase incentives for R&D more broadly and to increase cooperation both within industry and between industry and universities were introduced during the first half of the Reagan administration (1981-1984). These included an R&D tax credit

[2] See Poyago-Theotky, Beath, and Siegel 2002 for a fuller account.

with a specific provision for basic research conducted in industry,[3] relaxation of the antitrust rules for R&D joint ventures (1984), and the Bayh-Dole Act (1980), which allowed universities to retain the intellectual property rights on research results obtained using federal funds. The numbers presented above suggest that these measures might have had some impact on the share of university research funding that comes from industry or is generated within the university, where the latter funds may also have been obtained from industry via licensing of research results.

[Table 1 about here]

Currently, support of university research by industry in the U. S. takes a variety of institutional forms, ranging all the way from casual funding of individual researchers to large consortia of many firms supporting a permanent research facility. The main categories of support are the following:

1. Support of individual researchers via grants and consulting, often quite informal.
2. One time projects of varying lengths that involve a university as a partner, some government cost-shared, such as those funded by the Advanced Technology Program of the National Institute for Standards and Technology.
3. Large laboratories funded by industry consortia involving tens to hundreds of firms such as the Stanford Center for Integrated Systems.

[3] See Hall and Van Reenen 2000 for an overview of the effectiveness of this policy instrument around the world.

4. Quasi-permanent University-Industry Research Centers (UIRCs) and Engineering Research Centers, which are partially funded by the federal government (see Cohen, Florida, and Goe 1994 and Cohen et al 1998 for reviews of this kind of arrangement).

The implication of this variety is that no one data source provides information on university-industry partnering, so that it is hard to get a picture of the system as a whole.[4] Category 1 is largely unstudied and uncaptured, except to the extent that the funds flow through the university. Some of category 2 is collected in the form of data on subsidized ATP projects and other projects funded by the federal government, and the share of the R&D spent by universities is presumably included in the total industry funds for the university but there is no separate accounting on the industry side for the amount of funds devoted to joint ventures with universities, although an indication of the number of such ventures may be tracked via registration under the 1984 National Cooperative Research Act (NCRA).

A similar statement applies to category 3 spending, which is not separately tracked, except possibly by the individual research centers. The Cohen et al studies contain some data on the category 4 type of partnership (UIRC) that was obtained via survey, but these data have not been updated. Thus it is difficult to even form an impression of whether these kinds of partnerships have increased in aggregate, although many individual indicators suggest that they have and observers certainly believe it, to judge by the number of conferences and papers on the topic. As Table 1 showed, the share of university research funding that is paid for by private industry tripled in the United States between 1970 and 2000. This increase in share represents a tenfold

[4] Jankowski (1999) provides a recent overview of academic research funding trends, including some measures of coauthorship and co-patenting between university and industry researchers.

increase in real R&D dollars coming from industry in an environment where total university R&D increased about 3.5 times. Another indicator of increased university-industry interaction is that the number of Research Joint Ventures with at least one university member that were registered with the federal government as a consequence of the 1984 NCRA averaged 8 percent between 1984 and 1992, but 17 percent between 1992 and 1999, as shown in Figure 1, which is drawn from Hall, Link, and Scott (2000).

[Figure 1 about here]

What are the motivations of those participating in a university-industry partnership? In a survey of both the university and industry participants in approximately 400 research joint ventures, Lee (1996) found that industry participants ranked their reasons for participating in these alliances in the following order, ranked by their importance:

1. Access to new research
2. Development of new products
3. Maintaining a relationship with the university
4. Obtaining new patents
5. Solving technical problems

Improving products and recruiting students were viewed as less important than these other reasons.

On the other hand, university participants placed a high priority on two things: obtaining funds for research assistance, lab equipment, and their own research agenda; and obtaining insights into their own research by being able to field test theory and empirical research. They viewed acquiring practical knowledge useful for teaching, student internships and job placement, and obtaining patentable inventions and business opportunities as less important motivations for entering into research alliances with industry.

Thus although neither group rated obtaining patents very highly, the university partners thought they were even less important than the industry partners did. A simple interpretation of the results of this survey is that these transactions are driven by the supply and demand for upstream research results: the university partners are selling the output of their research in return for the funds to do it. The transaction is structured as an alliance rather than a simple sale for several reasons: the funds are needed up front before the research is done, there is some desire for risk-sharing and an ongoing relationship is preferred by industrial firms so that they can monitor the progress of the research in order to make full use of its output. Reason 3 given above also suggests that the firms value their ongoing relationship with the university, probably because it gives them an early look-in at discoveries that may not be anticipated.

When asked about the reasons for the increase in partnering, members of industrial firms cited the fact that universities have become more important as technical change moves closer to "science," in fields such as biotechnology and information technology. This is partly supported by the data on research joint ventures between industry and universities shown in Figure 2, which indicates that joint ventures in the computing and electronics/electrical areas are more likely to have a university as a partner. Industrial partners also mentioned the declines in direct industry spending on basic research following the wave of corporate restructuring in the 1980s, and the special basic research tax credit that was introduced in 1981 and strengthened in 1986. This incentive is currently a tax credit equal to 20% of the payments made to a "qualified" research organization (university or non-profit) by a taxpaying firms, which substantially reduces the cost of such R&D, especially in states like California where there is a state-level basic research credit also.

[Figure 2 about here]

Universities reported that their motivation for increased partnering with industry was primarily the changes in government levels of support. The real growth in federal R&D funding for universities was 16% between 1953 and 1968 and 1% between 1969 and 1983, followed by an upturn to 5% between 1984 and 2000, but with substantial declines in non-biomedical areas. As federal funding has declined, universities have used more of their own funds and more funds from industry. The interviewees reported that university administrators increasingly pressure faculty to engage in applied commercial research.

3. *Evaluating the Benefits*

Evaluating the benefits of increased university-industry partnering in the United States has centered on two areas, a broader one that looks at the many channels by which university research influences the productivity of industry R&D, and a more narrow focus on the effects of the Bayh-Dole Act on university research output.

Influence of university research on industry R&D

Earlier research on the impact of university research on industry was largely qualitative or based on case study evidence. Researchers emphasized the complementary nature of university research with respect to industrial R&D. For example, Rosenberg and Nelson (1994) argued that university research enhances and stimulates R&D in industry, while Pavitt (1998) describes such research as “augmenting the capacity of business to solve complex problems.” An early quantitative study was that by Griliches (1958), who evaluated the returns to investments by researchers in agricultural science in hybrid corn to society as a whole, including the firms to whom this technology was transferred, but who had to perform the necessary development to customize the seed for particular geographic areas. The effect of university and agricultural experimental stations in this case was to reduce the cost of innovation for the commercial seed companies.

Mansfield (1995,1996) surveyed 66 firms in a number of manufacturing industries and 200 academic researchers in 1993. He found that the pharmaceutical, information processing and metals industries considered academic research the most important and that the importance of this research for applied product and process development had increased between 1980 and 1993 in information processing, instruments, pharmaceuticals, and chemicals more broadly. All these sectors with the possible exception of chemicals are the most R&D-intensive today. Mansfield also found that geographical proximity was particularly important for absorbing the results of more applied research.

Similar findings in the present day pharmaceutical and biotechnology industries are reported by Henderson and Cockburn (1996) and Zucker, Darby, and Armstrong (2001). Henderson and Cockburn report that in the ten major pharmaceutical firms for which they collected data via interview and survey, access to university research enhances sales, R&D productivity, and patenting. Zucker et al find that collaborating (as evidenced by joint publishing) with "star" university scientists is very important for firm performance in the biotechnology area.

Adams, Chiang, and Starkey (2001) look more broadly at UIRCs in all industries and fund evidence that they do succeed in promoting technology transfer and increasing patenting rates at the associated industrial laboratories, especially if the UIRC in question was funded by NSF, which indicates that it is closer to a basic research area, as contrasted with targeted research such as that funded by the Department of Energy or Department of Defense. Unfortunately none of these studies, with the exception of the very early Griliches study, are able to give precise quantitative evidence on the contribution of academic research to productivity growth or other such measures.

The effects of Bayh-Dole

The Bayh-Dole act created a policy towards ownership of patents on the results of federally-funded research that was uniform across federal agencies, allowing universities to own the patents that resulted and removing some of the restrictions on licensing. These changes do seem to have promoted the transfer of research results from university to industry, but there is some debate about the ways in which it has changed the direction of university research. On the former point, Poyago-Theotoky et al (2002) report that the number of patents granted to U.S. universities has increased from 300 in 1980 to 3,661 in 1999. Membership in the Association of University Technology Managers (AUTM), an organization of licensing officers at U.S. universities, has increased from about 100 in 1979 to over 2000 in 1999. Licenses granted by these offices have increased almost twelve-fold since 1991 and annual licensing revenue has grown from $160 million to $862 million in 1999, about 2.7% of university R&D expenditures.

On the latter issue, whether the advent of Bayh-Dole has shifted university research towards applied areas or made it less productive, there is limited evidence. An early investigation by Henderson et al (1998) found that there had been a decline in the quality of university patents since Bayh-Dole, but subsequent work has modified this result. Using more recent data, Mowery and Ziedonis (2001, 2002) showed that this apparent decline is due to learning effects from the entry of universities unfamiliar with patenting and licensing into the activity. Universities such as Stanford, University of California, and Columbia that have always had technology transfer offices have not seen a decline in patent quality, but newer entrants at first patented inventions that were of somewhat lower quality.[5] Sampat, Mowery, and Ziedonis (2003) found that some of the apparent decline in quality is due to the fact that the citation rate to university patents has shifted intertemporally and that citations are now as high as ever, but are coming later in the life cycle of the technology.

Finally, we should not leave this topic without remarking that there is considerable heterogeneity across universities in their ability to elicit invention disclosures from their faculty. Interacting with the institution's technology transfer office takes time and may not have obvious benefits for a faculty member. There is some evidence that a significant number of inventions still go unreported and unpatented, although it is unlikely that this is true of "blockbuster" discoveries. See Jensen and Thursby (1998) for a discussion of the results of a survey of faculty and technology transfer officers, and Owen-Smith and Powell (2001) for a comparison of invention disclosure attitudes and behavior at two universities, one an elite private institution and the other a large public institution.

[5] See also Mowery, Nelson, Sampat, and Ziedonis (2001), who look in more detail at the experience of UC Berkeley, Stanford, and Columbia Universities.

4. *IP Issues on the Boundary*[6]

As university-industry relationships have increased, some tensions associated with differing attitudes towards intellectual property rights have become apparent. In this section of the paper I discuss some examples of these problems. The first is that of the university-industry research centers in the United States. Cohen, Florida, and Goe (1994) conducted a survey of 437 universities that covered more than 1000 University-Industry Research Centers (UIRCs) in 1991. One of the findings from their survey was that industrial participants were often able to restrict information flow and delay publication of the results of the academic research that they were supporting, suggesting a conflict between the university's desire for an open science regime and the needs of industry for secrecy and/or exclusivity. Whether we should be concerned about this deviation from the cultural norm of science depends somewhat on whether the research conducted in these centers was "additional" to that normally conducted by the university.

Hall, Link, and Scott (2000, 2001, 2003) surveyed 38 industry participants in projects funded by the Advanced Technology Program of the federal government, 13 of which had a university as a research partner.[7] The remaining 25 were asked why they did not have such a partner and 12 of

[6] The examples in this paper are largely drawn from the U.S. experience, with which I am more familiar and for which there have been a number of policy experiments and attendant studies in the recent past. See Cassier and Foray (2000) and Schmiemann and Durvy (2003) for discussions of this issue in Europe, and Collins and Wakoh (1999) for Japan.

[7] A selected list of such projects in shown in Table 2.

these (approximately half) reported that IP issues were an insurmountable barrier to partnering. Comments by these firms included the following:

> "believe we own the IP developed for us under sponsored research. This view is often not shared by potential university partners."

> "many universities want to publish results prior to IP protection, and sometimes will not grant exclusivity."

[Table 2 about here]

A third example concerns the effects of the Bayh-Dole Act of 1980. Argyres and Liebeskind (1998) found that university efforts to commercialize biotechnology innovations following the Bayh-Dole Act of 1980 were impeded by the academic institution's traditional commitment to the "intellectual commons" and absence of secrecy, suggesting that there are barriers also on the other side of the transaction. Mowery and Ziedonis (2001, 2002) report that the majority of technology licenses granted by UC Berkeley and Stanford are exclusive, which suggests that where successful transfer takes place, the traditional norms of the university have been somewhat subordinated to the desire to license discoveries.

In general, the conclusion from research on university-industry partnerships in the United States and the effects of changes in IP protection during the past 15-20 years is that "harvesting" of patents from inventions has increased greatly in the university, but with relatively little effect on actual research (this is similar to the trends in industry, see Hall and Ziedonis 2001 and Ziedonis and Hall 2001). At the same time, the growth in partnerships with industry has led to increased tension over IP rights and the ability to publish freely. However, it is likely that the current trends in patenting (especially in software and genomics) and in database protection are probably more threatening to the university research environment than the effects of 1980s policy changes in joint venturing and university patenting (Nelson 2003). The next section discusses the general problem of incentives for cumulative innovation, which is particularly important in these fields.

5. Cumulative Innovation

Cumulative innovation is a major challenge both for the economic theory of "the allocation of resources to invention," to use Arrow's (1962) expression, and for the structure of intellectual property rights. Recent trends in biotechnology (gene sequencing) and information technology (the internet) have brought to the forefront a set of issues that were first brought to the attention of economists by Scotchmer (See Scotchmer 1996 for a survey of this work). These issues have to do with the problem of rewarding multiple inventors in a setting with cumulative innovation. That is, is it possible to provide optimal incentives for innovation simultaneously to the producer of a first generation product and a second generation product that builds on it? The answer in general is no. At least two problems arise:

The first invention creates an externality for the second inventor and therefore may be worth developing even if the expected cost exceeds its value as a stand-alone product. However, broad patent rights for the first inventor to ensure innovation do not leave enough profit for the second inventor. One solution to this problem is "internalizing the externality" via licensing. Scotchmer (1996) shows the following:

> *Ex post licensing agreements*, entered into after the cost of first innovation is sunk can increase the profits available for the two innovators, but cannot not achieve the first best, because it is impossible to give the total surplus to each party separately using this (or any other) mechanism, and this is what would be required.

> *Ex ante cooperative R&D investment (RJVs)*, entered into before the R&D cost sunk generally will achieve a more efficient outcome (in terms of total welfare), but it is very difficult to identify potential partners *ex ante* in practice.[8]

Where the first invention is the pure outcome of scientific research, that is, where the value is only the information, it cannot be sold without revealing it, which makes a sale moot unless extremely strong IP protection is in place. In this case Anton and Yao (1998) show that a signaling equilibrium exists with partial disclosure of the idea, which essentially means that the inventor will receive a "lemons" discount for his innovation. This discount, which can be large, will clearly reduce the provision of ideas unless non-financial motivations come to the fore (such as researcher priority).

The insights of Scotchmer and Anton and Yao suggest the difficulty of contract design for optimal cumulative innovation in a setting where each innovation builds on the last, and where subsequent innovators are many, geographically diffuse, and hard to identify. This description characterizes the production of research tools and of both software and databases in the scientific research community. Thus far, the problems potentially created by the patenting of research tools for genomic research seem to have been minor, at least according to the survey conducted by Walsh, Arora, and Cohen (2003) in 2001. These authors found that there was some evidence of delays associated with negotiating access to patented research tools, and areas

[8] See Headley (1995) for an interesting discussion of the political/legal history of the idea of extending *droit de suite* to cover scientific inventions during the earlier part of the twentieth century. This idea essentially foundered on a reluctance to impose compulsory licensing on inventors into the far future and the consequences such a move might have for the publication the results of scientific research.

in which patents over targets limit access or where research has been redirected to areas with more intellectual property (IP) freedom. However, most respondents reported that there were no cases in which valuable research projects were stopped because of IP problems relating to research inputs. Firms and universities have developed "working solutions" such as licensing, inventing around, infringing (often informally invoking a research exemption), developing and using publicly available research tools, and challenging patents.

With respect to software and databases, the difficulties center on the need for complementary investments to make these research products useful both within and without academia (Gambardella and Hall 2004). Historically academically-produced software in particular has both survived as a public and freely-available good and been privatized simultaneously. The origins of database and software packages in common use in academia are often "lost in the mists of time."[9] See Maurer (1999) for some examples. In other cases, they are public and non-protected, but have been developed and augmented by private researchers or research firms. Nevertheless, until recently, almost all of the university-based development of such products has been public

[9] One widely diffused statistical package for the social sciences with which the author is familiar was originally developed by a set of graduate students in their spare time in the 1960s. The approximately 50,000 lines of code now contained in the package probably include at most 100 lines of the original code, but the basic design of the syntax has changed little over the years and its origins are clear. Some of the earlier development was financed on research grants, but most of the value added in the past twenty years has been financed by sales of the product. In spite of this, the package retains a strong link to the academic community and is typically sold to them at a substantial discount from the commercial price. This type of situation is very common in the scientific software world, where the primary product being sold back to the academic community from the private sector is service and support rather than programming code. Were the algorithms in the code protected by strong patents, it is likely that these packages would command much higher prices than they do now.

domain (as in the case of Linux, which is based originally on a university-developed UNIX system).

The implication of the previous discussion of incentives when innovation is cumulative is that it pays to be extremely careful when considering the creation of new forms of property rights for these goods. An admirable desire to ensure the creation of the "first" version may inhibit the production of any recombinations or enhancements, in addition to restricting access for a set of users that may well be the most productive of potential users: new entrants, whether new researchers or new firms.

6. Concluding Thoughts

This paper has reviewed recent developments in industry-university research cooperation in the United States and the evidence on their impact on university research. Although there are hints that some university research may have become more applied in response to Bayh-Dole, most of the evidence suggests relatively little actual change in its direction, but does find substantially increased patenting and licensing activity. It is not yet clear whether this has increased the rate of technology transfer overall, although there are suggestive indications in fields like biotechnology.

The central problem with these trends highlighted in the paper is the tension between the two worlds of commercial innovation and scientific research with respect to the twin goals of appropriating and diffusing knowledge. Recent developments in the protection of intellectual property in the United States., together with the increasing closeness of public and university research to commercialization in several major research areas have heightened this tension, causing concern in the academic community and elsewhere that in the race to ensure that there are incentives to create new forms of information such as databases and software, and new research tools for genomic research, we may have inhibited their diffusion back to the research enterprise for which they are essential tools.

Of course, from an economic theoretical perspective, the policy question and remedy are relatively simple and not new: if society benefits from researchers having access to some forms of information or research output at low cost, and there exists private sector willingness to pay for that information, then subsidies to researchers so that they can acquire the information would be socially beneficial, and at the same time, would leave the incentives to produce the information intact. Because private sector firms would still be charged the “market” price, these subsidies would not have to be as large as they would need to be if the government funded the entire activity.

In the real world, this simple economic solution confronts a number of difficulties. First, government granting agencies such as the National Science Foundation usually exhibit considerable reluctance to finance the acquisition of easily reproducible software and/or databases at prices above marginal cost. In practice, there seems to be a bias towards funding the creation of new databases rather than simply purchasing them on the open market. This is especially true when some of the inputs to the database where themselves produced under government grants. Second, the transactions costs of this kind of solution can be substantial. In the software case, consider the difficulties faced by participant(s) in a small computer science research project with little administrative overhead that might have to license various pieces of software from a series of organizations in order to pursue its research agenda.

A final consideration is that imposing administrative and pecuniary costs on researchers who wish to use others’ research tools as inputs, even if reimbursement is theoretically possible, tends to discriminate against new and young scientists without grants and also against “outsiders” with radical ideas who cannot get past a peer review. It is hard to quantify this idea, but there are repeated historical examples which suggest that the unpredictability of the sources of new ideas means that they are best encouraged when the costs of entry into the research or innovation endeavor are kept as low as is practicable.

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Table 1

R&D Performance in Universities and Federally Funded R&D Centers

Funding for University R&D	*1953*	*1960*	*1970*	*1980*	*1990*	*2000*
% Federal government*	69.3%	76.9%	76.7%	75.9%	69.8%	64.6%
% Industry	5.2%	3.7%	2.1%	3.0%	5.5%	6.2%
% Self-funded	9.2%	6.1%	8.2%	10.4%	14.9%	16.6%
% Other (non-profit; state&local)	16.6%	13.3%	13.0%	10.6%	9.8%	12.6%
Total (millions of 1996$)	2,104	4,912	10,826	15,468	25,306	34,398

* Including FFRDCs administered by universities.

Table 2

Selected ATP Projects

Engineering Design with Injection-Molded Thermoplastics
Ultra-High Density Magnetic Recording Heads
Enhanced Molecular Dynamics Simulation Technology for Biotechnology Applications
Computer-Integrated Revision Total Hip Replacement Surgery
Film Technologies to Replace Paint on Aircraft
Low-Cost Advanced Composite Process for Light Transit Vehicle Manufacturing
Low Cost Manufacturing and Design/Sensor Technologies for Seismic Upgrade of Bridge Columns
Automated Care Plans and Practice Guidelines
Development of Rapid DNA Medical Diagnostics
Integrated Microfabricated DNA Analysis Device for Diagnosis of Complex Genetic Disorders
Diagnostic Laser Desorption Mass Spectrometry Detection of Multiplex Electrophore Tagged DNA
Automated DNA Amplification and Fragment Size Analysis

Figure 1
Research Joint Ventures in the U. S. Federal Register

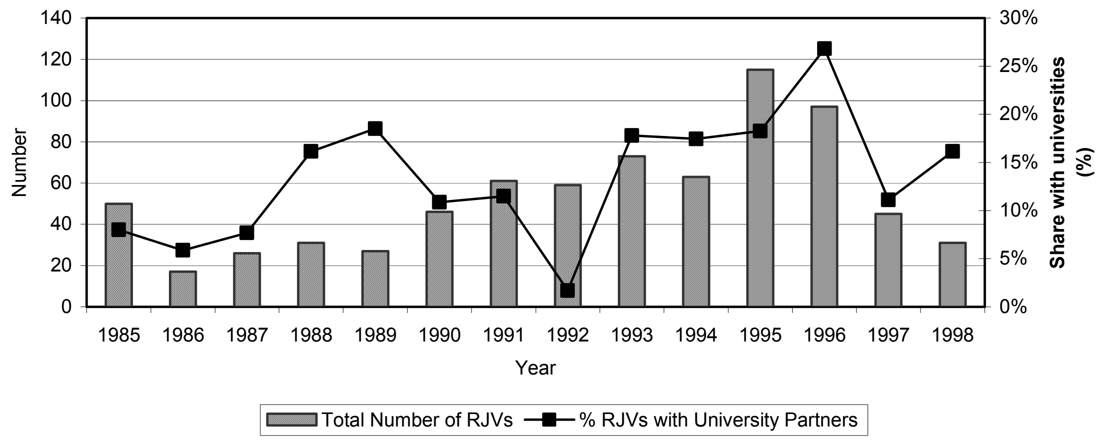

Figure 2
Participation of Public Organizations in Industry RJVs: United States 1985-2000