7 When factory meets faculty: university-industry co-operation in the US

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7.1 Background

In many countries research relationships between universities and industry have become more important. Contract research and consultancy services provided by universities have generated increasing revenues, more and more strategic research collaborations have been initiated, and universities have increased their efforts to patent their research findings and license them to private firms.

There is, however, controversy about the desirable level of university-industry co-operation. On the positive side, closer interaction is said to increase the transfer of knowledge between universities and private firms, and thus to enhance the social value of academic research. On the negative side, fears of secrecy in academic research and of a distortion of the research agenda toward applied research, from which the benefits may be privately appropriable, have been expressed.

In this chapter we discuss the pros and cons of university-industry interactions, and ask whether the incentives for both parties to collaborate lead to socially desirable outcomes. We try to assess whether the fears of secrecy and a distorted research agenda are justified. In doing so we look at the United States. The US have introduced government policies to foster the transfer of technology between universities and firms many years ago and are said to provide many examples of successful university-industry ventures. We focus on academic patenting and licensing and on collaborative research by universities and firms.

In Section 7.2 we first present some empirical evidence of the increase in university-industry interaction in the US. Subsequently we turn to the incentives of universities and firms to collaborate, and the possible role for government. Two main US policy measures to stimulate knowledge transfer from academe to industry are discussed in Section 7.3. In Section 7.4 we evaluate the costs and benefits of these policy measures.

7.2 University-industry ties and the role for government

7.2.1 The increasing importance of university-industry ties

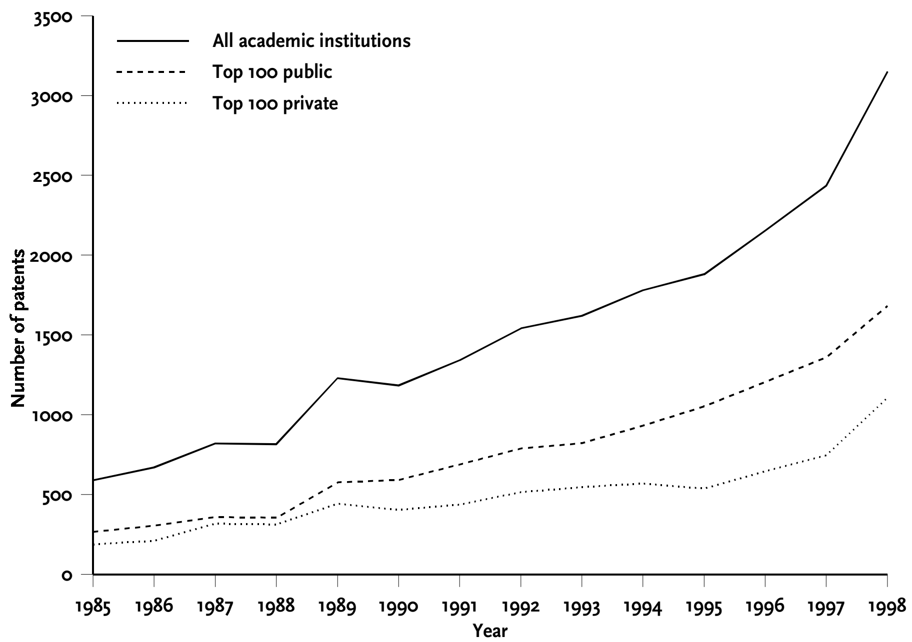
Interactions between universities and private firms have gained importance over the years, as is evidenced by a number of R&D-statistics.

The share of industry in the funding of research performed by universities, both basic and applied, has increased steadily (see Figure 7.1). From 1980 to 1990, a decade of rapid growth for total university research, industry's sponsorship increased from 4 percent to 7 percent of academic research expenditures. Since 1990 industry's share has remained around 7 percent.

Figure 7.1 Share of industry in US academic research expenditures

Source: NSB (2000).

Figure 7.2 US academic patenting 1985-1998



Source: NSB (2000).

Universities have also given increased attention to commercial application of their research. Figure 7.2 indicates that the number of university patents has increased continuously ever since 1985. Henderson *et al.* (1998) provide more extensive information. They show that the increase already started in the early 1970s, and that the increase has been more rapid than the increase in the overall number of US patents. They also show that the number of patents per US-dollar of research expenditures (the propensity to patent) has increased for universities, while it has declined sharply for overall domestic R&D. Furthermore, patenting activity has become more widespread: the number of universities obtaining patents has increased from about 30 in 1965 and 111 in 1985 to 173 in 1998 (see also NSB, 2000). Despite this increase, the distribution of patents across universities remains highly concentrated. In 1991, for example, the top 20 universities receive about 70% of the total patent grants.

More detailed information about the patenting and licensing activities of universities is provided by the annual Survey of Research Universities conducted by the Association of University Technology Managers (AUTM), see Table 7.1. Through the 1990s all indicators related to patenting – like license disclosures, patent applications, granted patents, and license revenues – have shown an increase.[1] Another indication is that the number of technology transfer and licensing offices, set up by universities to organise the process from invention to license agreement, rose from 25 in 1980 to 200 in 1990.

Table 7.1 Patenting and licensing activities of universities

	1991	1993	1995	1997
Invention disclosures received	4,880	6,598	7,427	9,051
New patent applications filed	1,335	1,993	2,373	3,644
Total new patents received	n.a.	1,307	1,550	2,239
New licenses and options executed	1,079	1,737	2,142	2,707
Number of revenue-generating licenses, options	2,210	3,413	4,272	5,659
Gross royalties (million $)	130	242.3	299.1	482.9
Startup companies formed	n.a.	n.a.	169	258
Survey coverage				
Number of institutions responding	98	117	127	132
Percent of total academic R&D represented	65	75	78	82
Percent of federally funded academic R&D represented	79	85	85	90
Percent of academic patents represented	n.a.	80	82	91

Note: n.a. = not available.
Source: NSB (2000), Text table 6.11.

[1] This is partly due to the improved coverage of the survey, as is shown in the bottom rows of the table. Moreover, the data do not reveal whether the propensity to patent and license has increased through the years.

Citations to published research articles on the front page of patent applications also indicate an increased importance of science for innovation. Applications to the US Patent and Trademark Office include citations to all "prior art" – that is previous patents as well as the other sources of information, such as research journal articles, on which the application is based. These citations are not a perfect measure of knowledge spillovers, however: some references are added ex post, *e.g.* to prevent law suits. Both the absolute number of citations and the share of patents citing research articles have risen sharply. The intensity of research citations differs between industrial product fields, and is particularly high and growing in patents for "drugs and medicines" (NSB, 1998).

Another indication for the ties between universities and industry is the significance of university-based startups. Table 7.1 shows a sharp rise in the second half of the 1990s in university-based startups. This is confirmed by the 1996 AUTM-survey where universities reported a total number of just over 900 startups since 1980 (see Rahm *et al.*, 2000). University-startups are mostly located close to the originating university, frequently on a so-called research park that provides them with all kinds of services to facilitate the startup. Over the past decades many universities have designated an adjacent land area and established a research park (Rahm *et al.*, 2000).

The importance of university-industry collaborative research has been studied by Cohen *et al.* (1998). They find that there were approximately 1,056 university-industry R&D centers in the US in 1990. More than 500 university-industry centers have been established during the 1980s. These centers spent about $2.9 billion on R&D, which amounts to almost one-fifth of all US academic R&D expenditures on science and engineering. About half of the private expenditures on academic R&D went to university-industry R&D centers.

Bibliometric indicators also illustrate increased interaction of academic and private researchers. Co-authorship of journal articles by US industrial researchers with either academic or federal researchers increased steadily across all fields. The proportion of industry-produced articles that were co-authored with at least one US academic researcher increased from 21.6 percent in 1981 to 40.8 percent in 1995. Again, the largest increase has been in biomedical research (NSB, 1998).

Publication activity of industrial researchers has changed significantly at the level of research fields. The number of "industry publications" in the engineering and technology field dropped steeply during the 1980s, accompanied by declines in industrial publications in physics, chemistry and mathematics in the first half of the 1990s. In biotechnology and clinical medicine the trend was exactly the opposite.

7.2.2 Benefits and costs of university-industry interaction

Evidently, universities and firms only collaborate when it is in their mutual interest. What are the benefits and costs to universities and firms?

First the benefits. Universities benefit from ties with industry for several reasons:

- Access to a source of complementary expertise and equipment;
- Access to a source of interesting new research problems;
- Channel through which to carry out the – legally assigned – objective of knowledge transfer to (regional) industry and the general public;
- Channel through which to provide students with experience in private research and to create a network for student job placement;
- Access to a source of income.

In other words, the ties add to fulfilling the academic tasks of education, research and knowledge transfer, and they generate income. The latter effect should not be considered to be a separate goal (universities are not profit maximisers). Clearly, increased importance of industry funds is likely to affect the incentives of universities towards research, as we will see further on.

The major reasons for firms to enter into collaborative agreements with universities are:

- Access to state-of-the-art knowledge and information, to university facilities, and to academic staff, and;
- Access to students as potential employees.

What about the costs? We distinguish three categories:

- Direct costs;
- Costs resulting from the different views of universities and firms on the dissemination of research results;
- Costs resulting from the different views of universities and firms on the research agenda.

First the direct costs. Evidently, universities and firms have to invest money, time and effort. Clear examples are the costs of setting up a technology transfer office to manage the patenting and licensing activities, and the overhead costs of cooperative research (like administrative costs).

Concerning the dissemination of knowledge, there exists a tension between the focus on open dissemination of knowledge at universities and the desire for secrecy by firms (Dasgupta and David, 1994). Secrecy – like delays in publication, partial dissemination of research results, or strict conditions on access to research material and technology by other researchers – helps firms to protect the commercial value of products and processes eventually resulting from the inventions.[2] This induces them to incur the costs of further applied research and development.[3]

Academic researchers are hesitant to accept requests to hold research results partly or temporarily secret. These practices would run counter to the age-old scientific norm of free disclosure; a norm which has contributed to research quality, to the dissemination of knowledge and to the prevention of wasteful duplicative research.[4] And even when academic researchers are not intrinsically motivated to hold on to this norm, they may be induced to do so out of fear that giving in to commercial ties and secrecy harms their long-term research productivity and academic career. This would be the case when other researchers refuse to co-operate with staff interacting with industry because of fear for commercial use of their research results, or in reaction to initial acts of secrecy by the researcher with the commercial ties.

The second tension concerns the research agenda. Profit oriented firms may be more interested in applied research, the benefits of which are relatively easy to appropriate, than in basic research. The primary focus of universities should be on basic research that is hard to appropriate privately (or on research for which private appropriation of the benefits is undesirable). When universities substitute short-term applied "industrial" research for basic research due to closer ties with industry, this might hamper long-term research productivity, diminish spillovers from academic research, and eventually even harm long-term national innovativeness.

Several factors may have strengthened the incentives of universities and firms to collaborate. The public demand for justification of public research expenditures, often stated in terms of relevance for industry, has increased. Furthermore, the stagnation in government funding for higher education has stimulated universities to search for private sources of income. This effect is strengthened by the rising costs of advanced research equipment in many fields. Other causal

[2] Note that the demand for secrecy by firms may be socially excessive for all firms together. However, given the behaviour of other firms it may be in each firm's short-term interest to ask for secrecy. Furthermore, restrictions on open dissemination of research results are less important to firms when collaboration with universities results to a large extent in tacit knowledge, which gives firms a competitive lead even when complementary codified knowledge is fully disclosed.

[3] A firm may also demand secrecy when research results are likely to have a negative effect on the market demand for the firm's product, and consequently on its profitability. An example of such behaviour is given by Schachman (2000). He reports on clinical trials for a drug, financed by the firm selling the drug, which revealed that the drug was causing toxic effects rather than benefiting the patients. The quest for secrecy induced the firm to threaten the university with litigation and elimination of financial support.

[4] Note that although secrecy hurts spillovers from research in the first instance, their exists a partial counter-mechanism. Secrecy increases the marginal benefits from more applied research performed by firms, which also exhibits some externalities (although to a lesser extent than basic research). Hence, R&D expenditures and research spillovers are increased further down the road. The magnitude of this effect is not likely to be very large.

factors that have been mentioned in the literature (but are not evident and have not been substantiated precisely) is that firms rely more and more on public research due to the rising complexity of technology, intensified competition on the product market, and the shorter product cycles and hence shorter time horizons for private R&D. Furthermore, the distinction between basic research and applied research is relatively vague in new technology fields like ICT, biotechnology and new materials. Finally, governments increasingly encourage universities and firms to increase the knowledge transfer between academe and commerce.

7.2.3 What role for government?

Various policy documents consider the transfer of knowledge and technology from academe to commerce to be insufficient. Why might this be the case? We discuss three candidate explanations: the incentive structure, uncertainty, and lack of transparency.

First, most university inventions are little more than a "proof of concept", and require substantial further research to generate new products and processes (see Jensen and Thursby, 1998). Since part of the knowledge is tacit, *i.e.* in the heads of researchers, further research based on the invention requires active involvement of the inventor. To elicit the effort of academic researchers, they should have a stake in the commercial success of further research. The current academic reward system may not leave enough room for such incentive contracts, and patenting policy may play a useful role.

Second, the expected value of collaboration may be highly uncertain. This may induce risk-averse parties to turn down opportunities that are socially valuable. Governments may correct for this by subsidising university-industry collaboration (possibly with reimbursement of the subsidy in case of commercial success, although this will be hard to implement).

Third, the "knowledge transfer market" may suffer from a lack of transparency: firms do not know where to find knowledge, and universities do not know where their knowledge might be valuable. This problem need not apply to large firms, which have their own research capacity and access to the scientific network. But it may be a problem to smaller firms. And private parties may not have enough incentives to gather and bring together supply of and demand for knowledge. Patent policy may enhance transparency by providing a data-base of academic research findings that have the potential to result in profitable products after some further research and development. Subsidies to collaborative research may make it more worthwhile to search for research partners.

Eventually, policy instruments to stimulate knowledge transfer should only be implemented when the social benefits outweigh the costs. Hence, the positive effect of stronger collaboration between universities and industry on the use of public knowledge should outweigh the possible negative effects on the research agenda and on secrecy. And incentives from patenting rules on public research should not distort the attention of universities from their primary mission of open and basic research that would have been insufficiently performed by private firms due to the limited possibilities for appropriability.[5] Furthermore, the instruments that are implemented should be effective in bringing about more collaboration. This may not be the case for the following reasons: (1) subsidies may co-finance collaborations that would have taken place anyway; (2) subsidies to formal collaborations may drive out equally or more efficient informal contacts; and (3) governments may be tempted to use R&D policies for subsidising national firms, and policy competition may render the national policies ineffective. The next section will discuss the main policies implemented in the US for stimulating university-industry collaboration.

7.3 University-industry collaboration in the US

The higher education landscape in the US is very diverse. Universities and colleges (about 3,500 in total) vary in size, ownership, endowment and character (see also Chapter 4). The generally accepted classification by the Carnegie Foundation distinguishes some 10 types of higher education institutes, including 6 types of universities, ranging from research universities (offering a full range of undergraduate and graduate programs and giving a high priority to research) to Master's colleges. The universities that are engaged in research collaboration with the private sector belong (mostly) to the group of research universities.

The US have a long tradition of university links with industry. This tradition started with the land-grant colleges. In 1862 every state was offered a sizeable piece of federal land for the purpose of establishing colleges dedicated to agriculture and mechanics (the Morrill Act). Other policy initiatives to improve agriculture by linking university researchers with farmers followed: a national bureau for assistance to farmers, federal support for agricultural experiment stations based at land-grant colleges (1887), and federal funding of state co-operative extension services (1914). After WWII science policy was characterised by an intimate linkage of universities with the defence sector, and a broad political consensus that the country would reap large social benefits from university research. Federal funding of academic research was not disputed. The productivity slowdown during the 1970s prompted many policy analysts to emphasise the need to enlarge the benefits of academic research for the competitiveness of domestic firms. This desire resulted in a number of policy initiatives during the 1980s and 1990s, listed in Table 7.2.[6]

[5] Notice that another justification for patenting is to prevent private ownership of research findings. An example is the Cohen-Boyer patent covering the fundamental techniques of gene splicing. Private ownership of this patent might have resulted in exclusive licensing involving very large royalties, thereby impeding important new avenues of research.

[6] US technology transfer policy has not been limited to universities. Many policy initiatives in the same period address the federal laboratories. See the sources mentioned in Table 7.1 for details.

The two most influential, industry-university cooperative research centers and the Bayh-Dole Act, will be described more extensively in the remainder of this section.

Table 7.2 Principal US federal policy legislation toward university-industry technology transfer

1975	Industry-University Cooperative Research Centers program of the National Science Foundation: partial funding by the NSF of university research programs enlisting industrial firms as participants in collaborative research activities.
1980	Bayh-Dole University and Small Business Patent Act: permits universities, small companies and non-profit organisations to obtain the property rights to innovations resulting from federally-funded research. In 1984 certain restrictions regarding the kinds of inventions and the right to assign property rights to other parties were removed.
1981	The Economic Recovery Tax Act: extends the industrial R&D tax breaks to company-financed academic research.
1984	National Cooperative Research Act: establishes the "rule of reason" standard for determining anti-trust prosecution for collaborative R&D efforts of firms, universities and federal laboratories. This means that collaborations are not automatically forbidden, but only if there is an "unreasonable" restraint of competition.

Sources: Bozeman (2000), NSB (2000), Rahm *et al.* (2000), Cohen *et al.* (1998), Henderson *et al.* (1998).

The Bayh-Dole Act represented an important change in patent policy. Prior to passage of the Bayh-Dole Act, it was the policy of government agencies to take title to all inventions that were made in whole or part through the expenditure of federal funds. The agencies, however, were unsuccessful in transferring the technology represented by those inventions to the public. The bureaucratic red tape that accompanied any attempt at innovation, cumbersome procedures that differed between the agencies, impeded companies to license directly from the government. As a consequence, government agencies obtained and held patents on many inventions, but the technology represented by most of those inventions and patents was never transferred to the public.

The Bayh-Dole Act gives universities and other non-profit organisations the first option to retain title to inventions made under federally-funded research programs. It requires universities to set up technology licensing offices, and researchers are required to report research findings that are thought to be eligible for patent grants to these offices. Universities are allowed to profit from the patent rights directly, or assign the rights to others through licenses (including exclusive licenses). Universities distribute the licensing revenues between the technology transfer offices, the university, and the individual inventor. All in all, Bayh-Dole was intended to facilitate industrial application of university research, and it endorsed the principle that exclusive licensing of publicly funded technology was sometimes necessary to achieve this goal.

Industry-University Cooperative Research Centers (IUCRCs) are small academic centers designed to foster research that is of strategic importance to industry. The purpose of the

IUCRCs is to strengthen the relationship between industry and academic institutions, especially the colleges of engineering. At the federal level, the NSF has stimulated such centers since the late 1970s through a special program. Furthermore, IUCRCs have also been stimulated by state governments. Within the NSF-program, universities and industry have to make joint proposals for a IUCRC. The NSF provides seed money, 50 percent of total funding, and after 10 years the centers are expected to be self-financing.

IUCRCs have to satisfy a number of requirements. We highlight several interesting ones. Centers have to obtain a minimum amount of cash from membership fees annually, coming from a minimum of six center-members to encourage a more generic research program. In general these members are industrial firms, but this need not be the case. The membership fees may differ between the different members, but at least three members have to contribute a minimum fee level or more. Membership categories with lower fees have been introduced to encourage smaller firms to become a member as well. Finally, involvement and education of graduate students is emphasised.

From the IUCRC-experience other co-operative NSF programs evolved. Among these are the Engineering Research Centers (ERC) Program initiated in 1985, and the Science and Technology Centers (STC) Program established in 1987.

ERCs[7] are university-industry partnerships in the engineering disciplines. They were designed to create long-term collaborations between universities and industry, to create new industry-relevant knowledge at the intersections of the traditional disciplines, and to improve undergraduate and graduate engineering education through practical experience in ERCs. Each new center receives support for at most 11 years, with a phasedown in years nine and ten. The 5-year agreements are renewed on the basis of a formal review. The central idea is that firms become member of a center (or more centers). Such center-membership usually involves payment of a fixed annual fee that is pooled with cash from other members and sponsors for support of the center's research and research-related activities. Centers set their own membership rates and often have associate memberships for small firms that cannot afford the cost of full membership, or for larger firms that are not yet ready to make a commitment for full membership.

STCs are similar to ERCs. The main difference is that the STC-program concerns open competition among research fields, whereas the ERC-program entails a competition restricted to the engineering directorate of the NSF. Hence the STC-program has a somewhat stronger focus on multi-disciplinary research. There have been three rounds to establish STCs to date: in 1989 (11 centers), in 1991 (14 centers) and in 1999 (5 new STCs). Currently 17 centers still receive NSF support, and a fourth competition is taking place.

[7] The subsequent information is extracted from NSF (1997).

7.4 Evaluation of American linkage policies

In this section we discuss whether the US knowledge transfer policies have been effective in raising knowledge transfer and the social value of public research. We also look for evidence of distortions in the research agenda or increases in secrecy.

A first indication of the overall effect on the research agenda can be taken from aggregate statistics. These do not support a shift in the research agenda. The shares of basic research, applied research, and development in total university research have been relatively stable over the past fifteen years. Ever since the 1980s the share of basic research hovers between 65 and 70%.

7.4.1 Academic patenting

What have been the effects of the Bayh-Dole Act? As shown in Section 7.1, university patenting has increased steadily over the past three decades, and more rapidly than overall US patenting. Between 1991 and 1996 license revenues have grown by 23% per year on average. However, this has not (yet) made license agreements an important source of income for universities. In 1996, the gross earnings from licenses were on average only 1.5% of total research expenditures. Moreover, the income from license agreements differed strongly between universities, ranging from 0% to 17.5%. For about half of the universities, license income was less than 0.5% of total research expenditures (Rahm *et al.*, 2000).[8]

How much of the increase in patenting activity can be attributed to Bayh-Dole? Circumstantial evidence, like the number of universities establishing technology transfer and licensing offices directly after the passage of the Bayh-Dole Act[9], suggests an important role of the act. But it is hard, if not impossible, to disentangle the effect of Bayh-Dole from the effect of alternative explanations:

- An increase in industry funding of academic research (see Figure 7.1);
- Important advances in some research fields (particularly the rapid advances in biotechnology starting in the 1970s, well before Bayh-Dole);
- The establishment (in 1982) of the Court of Appeals for the Federal Circuit as the court of final appeal for patent cases;
- Judicial decisions in favour of strong patent protection (Mowery and Ziedonis (2000) report such a decision with regard to a broad biotechnology patent).

Since the increase in university patenting has begun before the implementation of Bayh-Dole, this act is surely not the only causal factor. The growth in university patents has indeed accelerated in the late 1980s, hence after Bayh-Dole, but this is also the case for overall US

[8] These figures do not take account of the costs of patenting and licensing, like legal fees, costs of technology transfer personnel and administrative overhead.

[9] AUTM Licensing Survey (reported in Cohen *et al.* (1998)) and Henderson *et al.* (1998).

patenting. The changes in patenting of Stanford University and the University of California (UC), two universities that were actively patenting before 1984, were to a large extent linked to advances in biomedical research, which were primarily a consequence of the rapid growth of federal funding in biomedical research, notably under the auspices of the National Institutes of Health, and especially the War on Cancer program of the early 1970s (Mowery and Ziedonis, 2000). For the entire US, patents in the life sciences and biotechnology in 1998 account for 41 percent of the academic patents, up from 13 percent in 1980 (NSB, 2000). Despite these caveats, most researchers agree that the Bayh-Dole Act has been an important determinant of the sharp rise in academic patents.

The aim of the Bayh-Dole Act has been to increase the transfer of technology from universities to industry without distorting the commitment toward basic research and openness too much. Has it been successful in this respect? First, increases in patents cannot be translated directly into increases in technology transfer. This is shown by the relationship between granted patents and license agreements and income. For the University of California and Stanford University the ratio of license agreements over patents has increased, but the share of licenses yielding no royalties has increased as well and the average license income per patent has declined (Mowery and Ziedonis, 2000). Similar results of a decline in the license agreements and revenues per patent are obtained by Thursby and Thursby (2000) for a wider sample of universities. However, this only means that these marginal patenting and licensing activities are less profitable, not that they are not profitable at all.

Has Bayh-Dole changed the composition of research? The economic literature has not provided a satisfactory answer to this question. Some indication is given by two patent quality measures (introduced in Henderson *et al.*, 1998):

- "Importance": the number of times other patents cite the patent within five years after the patent has been granted. This is a useful proxy for spillovers;
- "Generality": the extent to which citations come from patents in different patent classes.

University patents tended to be both more important and more general than industrial patents in the 1970s, but the difference had disappeared since the mid 1980s. This change does not apply to all universities: the importance and generality of Stanford and UC patents has not declined relative to industrial patents, and the importance may even have increased (Mowery and Ziedonis, 2000). At universities where the change does apply, it may reflect both a change in the composition of research underlying the patents, and a change in the propensity to patent (and thus a trend toward patenting inventions of lower quality). The relative importance of these alternatives is still an open question. All in all, these analyses do not yield conclusions about the research agenda.

Zucker and Darby (1998) suggest that closer ties to industry do not necessarily deter basic research by the academic researchers: commercial activities of top-researchers may increase their scientific productivity. They find evidence of this mechanism for top-researchers in the field of biotechnology. Top-researchers at universities who perform research and write articles with researchers from firms in their region produce significantly more articles in these periods. Furthermore, the number of citations to these papers, a measure of quality, does not decline, and even increases significantly for scientists who are affiliated with a firm (which they have frequently started themselves). According to Zucker and Darby (1998), this positive effect on research productivity should be attributed to the habit of scientists to partly use the revenues from commercial ties to advance their scientific career. Another mechanism through which industry scientists stimulate academic research productivity is by providing a different perspective on a problem and suggesting refinements of experiments (Siegel *et al.*, 1999). It is not yet clear whether these findings are specific for the biotechnology field, where basic and applied research are hard to separate, or whether they apply more generally. Ongoing work of Zucker and Darby on similar studies for semiconductors and interactive media may reveal to what extent their conclusions generalise to other fields of research.

The effect of patenting activity of universities on secrecy has not been studied empirically. There does, however, exist a lot of “anecdotal evidence”. The effect is likely to depend on the design of the license agreements and the rules for sharing the revenues. For instance, universities and academic staff are more likely to give in to acts of secrecy when they accept equity shares in start-ups as opposed to cash payments for patents and licenses.

7.4.2 Co-operative research centers

We now turn from patenting policy to the programs for collaborative research between universities and firms (and frequently also government laboratories), especially the NSF-programs.

There have been several official evaluations of the NSF-programs, which have been rather favourable to continuation. NSF (1997) has reviewed the effects of the ERC program of the NSF. The major input of the evaluation study has been a survey among the employees of firms participating in the program that were most closely involved with the centers. Overall, the 355 respondents were positive about the effects of center membership, although the outcomes differed between centers. Outcomes improved with the length of center membership and with the active involvement of industry researchers, articulating the importance of tacit knowledge. Interestingly, the share of industry representatives reporting to have little or no influence on the research agenda is 31%, compared to 16% in 1988.

The evaluation of the STC-program in 1996 is also positive (Fitzsimmons *et al.*, 1996), and even provides some quantitative evidence. Bibliometric data reveal that the STC-program as a whole has compiled a creditable publication record. STC-articles were cited 1.69 times as often as the average US academic paper for the same journals for the same years. STC-papers achieved especially high relative citation rates in physics, biomedical research, and engineering and technology, with the average citation rates of center papers exceeding the norms in these fields by factors of almost 1.8. Analysis of the centers' 1989-1995 papers revealed that as a group the centers are publishing in journals with a somewhat higher impact than the average journal. STC-papers in mathematics and chemistry have unusually high representation of industrial organisations in their authorship, and STC-papers overall have relatively high industrial representation among citing organisations.

The first (and very recent) econometric analysis of the effects of IUCRCs is Adams *et al.* (2000b). They find that UICRC laboratories are 2.5 times larger than private laboratories that do not participate in a UICRC, and are more science-oriented. This suggests that small firms are less likely to benefit from UICRCs. They also find that IUCRC-membership is positively related with private laboratory patenting, and with private R&D expenditures. Their analysis does not allow firm conclusions, however. First, the effects are rather small. Second, the effects are not always statistically significant. And finally, more effort needs to be put in identifying to what extent IUCRCs actually cause an increase in industry-university technology transfer. The effects that are found may also result from the fact that private labs that perform more R&D and produce more patents are also more likely to participate in IUCRCs.

Evidence of the effect of the co-operative research centers on the academic research agenda is also scarce. Cohen *et al.* (1994) find that most university-industry engineering centers tended to focus on relatively short-term research problems and issues faced by industry, at the cost of productivity in terms of academic papers. Together with the increase in the number of centers this might indicate a shift in the overall research agenda. On the other hand, Fitzsimmons *et al.* (1996) find that STC-papers tend to be published in journals oriented more toward basic than applied research. There is no evidence that STC-research is tilted toward the applied end of the spectrum compared to the average papers in the centers' respective fields. Clearly, the picture is diffuse. And maybe more important, a causal effect of participation in co-operative research centers on the research agenda can not really be concluded from these data. The finding of Cohen *et al.* (1994) might also be explained by the fact that universities that have always been more focussed on applied research now undertake this research in the context of co-operative research centers.

Recent evidence of restrictions on the disclosure of research results is more pervasive. In reaction to mounting anecdotal evidence of secrecy, Blumenthal *et al.* (1997) mailed a survey in 1994-95 to 3,394 life-science faculty in the 50 universities that received the most funding from the National Institutes of Health in 1993. The responses by 2,167 US life-science researchers indicate that withholding of research results and publication delays were significantly associated with participation in academic-industry research relationships and engagement in the commercialisation of research. On the other hand the responses indicate that practices of secrecy were not (yet) widespread, although underreporting may have taken place.

The review of collaborative research by Cohen *et al.* (1998) provides some indications for secrecy at research centers. Cohen *et al.* have asked respondents at IUCRCs about the policies regarding restrictions placed on publication and informal communication, and about the prevalence of restrictions on sharing information with internal and external peers and the public in general (see Table 7.3). The responses indicate that secrecy occurs, and is more likely at centers that consider contributing to industry's productivity as part of their mission.

Table 7.3 Research disclosure at US university-industry research centers

	% of all centers	% of centers committed to industry	% of centers not committed to industry
Information can be deleted from publication	34.8	44.7	22.2
Publication can be delayed	52.5	58.7	47.3
Both restrictions are possible	31.1	39.9	19.7
Ever restricted in sharing information with faculty within the university	21.3	27.0	14.0
Ever restricted in sharing information with faculty at other universities	28.6	35.6	17.8
Ever restricted in sharing information with the general public	41.5	48.9	30.6

Source: adapted from Cohen *et al.* (1998).

The figures might indicate that an increase in the share of researchers and institutes that collaborate with industry will lead to decreasing public dissemination of research results. But it might also simply indicate that currently those researchers and institutes that are more willing to forgo open disclosure are also more likely to enter into collaborations with industry. Increasing the level of university-industry collaboration might then only be possible by inducing researchers that are less inclined to give in to requests of secrecy to collaborate with private firms. In this case, the larger number of collaborations may increasingly concern more basic research and less secrecy. We have not seen any data providing insight in the development of open disclosure versus secrecy through time, however, which makes it hard to infer a causal relation with US policies.

It is important to note that the figures do not give a complete picture of the importance of secrecy. The first three rows in the table concern the policy of research centers, and not the actual incidence of restrictions. The last three lines show whether communication restrictions have ever been imposed, and not how frequently. Both these caveats suggest that the figures overestimate the problem of secrecy. On the other hand, faculty participation in firms and university spin-offs is not considered in the surveys, which probably causes the figures to underestimate the extent of secrecy and delay accepted by faculty.

Concluding, the US policies toward academic patenting and toward cooperative research centers seem to have been effective in increasing the knowledge transfer from academe to commerce and the commercial application of academic research findings. Satisfying empirical analyses are hard to find, however (especially concerning the research centers). Consequently, it has been difficult to be precise about the effectiveness of these policies. For instance, the introduction of Bayh-Dole was followed by a number of other changes working in favour of knowledge transfer. This may have resulted in an overestimation of the effects of Bayh-Dole. That Bayh-Dole has had an effect is beyond doubt, however.

What about the drawbacks? Distortion of the research agenda and, especially, the incidence of secrecy, have featured prominently in recent discussions about US transfer policies. Are these concerns supported by empirical evidence? One conclusion is that there do not exist satisfying empirical analyses on these issues as well. The increase in secrecy seems to be supported empirically, but the evidence is still weak and the extent of the problem does not become clear.