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Research Policy 27 (1998) 823–833

research policy

The norms of entrepreneurial science: cognitive effects of the new university–industry linkages

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Abstract

Universities are currently undergoing a 'second revolution' these days, incorporating economic and social development as part of their mission. The first academic revolution made research an academic function in addition to teaching. Now the emerging entrepreneurial university integrates economic development as an additional function. The 'capitalisation of knowledge' takes many different forms that are discussed in this article.

Keywords: University–industry interaction; Capitalisation of knowledge; Technology transfer; Spin-off firms

1. Introduction

Entrepreneurial activities of scientists are by no means totally new phenomena. Such things occurred in 17th century German pharmaceutical science. Another famous example is Justus Liebig's fertiliser venture in the mid 19th century (Etzkowitz, 1983). However, these and other chemical spin-offs did not affect academic research sites. The formation of industrial consulting and scientific instrumentation firms by scientists also took place in the late nineteenth century at Harvard and MIT but were anomalies at the time (Shimshoni, 1970). During the past two decades, however, an increasing number of academic scientists have taken some or all of the steps necessary to start a firm by writing business plans, raising funds, leasing space, recruiting staff, etc. (Blumenthal et. al., 1986; Blumenthal, 1986a; Krimsky et al., 1991). Empirical studies which investigate these matters likely underestimate the extent of faculty involvement, especially in molecular biology. For example, although a survey identified half the faculty of the MIT biology department as having industrial ties in the late 1980s, an informant could identify only one of his colleagues as uninvolved. Although still only a minute proportion of the total US academic enterprise is directly involved, faculty inventing and commercialisation has had significant cognitive and organisational consequences.

A complex web of relationships has grown up among academics, university originated start-ups and larger firms. Often the same academic scientists are involved in both types of companies, managing a diversified portfolio of industrial interactions (Powell et al., 1996). Indeed, some early critics of such activities have become entrepreneurial scientists themselves. Nobelist Joshua Lederberg found the scientific issues and financial rewards too intriguing not to get involved. Another Nobelist, Arthur Kornberg, expressed bemused bewilderment in his autobiography 'The Golden Helix' that a highly focused academic scientist such as himself had become an

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PII: S0048-7333(98)00093-6

advocate of industry/academic intersection, finding it fruitful for both science and business. [1]

Remarkably, even those who leave academia retain ties. Having been turned down for tenure by Columbia University's Computer Science Department in the mid 1980s, David Shaw applied his computing skills to financial analysis and drew upon former colleagues and students for his firm's original talent pool. The D.E. Shaw & Co., a global investment bank, currently advertises to recruit, ''unusually talented and accomplished individuals with degrees in any area of the sciences or humanities... to a career they may never have considered before...'' (Advertisement in Political Science Quarterly, 1997). In the face of a tight academic job market, opportunities have opened up in firms based upon academic knowledge.

Until quite recently the commercialisation of academic research typically took place at a distance, by former students with or without the knowledge of their mentor. A striking comparison illustrating the change in this respect are sociologist Robert K. Merton and economist Robert C. Merton, father and son. In the early 1990s the New York chapter of the Public Opinion Research Association held a special meeting honouring Prof. Robert K. Merton, who was astonished to learn that a multimillion advertising and political industry had grown out of 'focus groups,' an interviewing technique that he had developed in the course of a 1940s study of interracial housing. In contrast, press reports of Prof. Robert C. Merton's 1997 Nobel Prize in economics, for a method to judge risks in options pricing, noted that he was a principal in a Greenwich Connecticut firm using these techniques in its business. The quite different stances of the Mertons to the pecuniary outcomes of their research exemplifies the generational change in attitude among academic scientists toward involvement in commercialisation.

This article analyses the cognitive effects of the new university/industry linkages on the way scientists view research, interpret the scientific role, and interact with colleagues, companies and universities. The growth of a commercial ethos within academia, and the emergence of conflict lines over this development, culminates in normative change in science. Traditionally, the most deeply held value of scientists is the extension of knowledge. To contribute to this is the highest striving of a scientist. The incorporation of 'extension of knowledge' into a compatible relationship with 'capitalisation of knowledge' is a profound normative change in science. It will be shown that the transition to entrepreneurial science is occurring as an interplay of cognitive opportunities, institutional rearrangements, and normative change, and that this in turn has cognitive effects on future research agendas. Certain cognitive changes in a growing number of disciplines and scientific fields open up possibilities to scientists to meet two goals simultaneously: the pursuit of truth and profit-making. Accordingly, the norms of science which traditionally condemn profit-making motives are beginning to change to allow for such a kind of entrepreneurship; and varying institutional structures are experimented with which fit to these new cognitive and normative patterns (Merton, 1973 [1942]; Etzkowitz, 1994).

2. Method and data

The article draws for data on more than 150 in-depth interviews conducted in several waves from the early 1980s. An initial study focused upon four disciplines (biology, computer science, electrical engineering, and physics) at two research universities.

This was followed up, in the mid 1980s, by a study of five disciplines (adding chemistry) at eight universities, including those with long standing and newly emerging industrial ties, with some geographical spread around the US. The study was replicated in the early 1990s. This paper primarily reports on longitudinal case studies of two public universities newly involved with industry: the University of Colorado, Boulder and the State University of New York at Stony Brook.

3. The transition from old to new forms of linkage

From an industrial perspective, relations with universities have traditionally been viewed primarily as

[1] Others, such as Jonathan King of MIT and Norton Zinder of Rockefeller University, remain steadfast in their opposition.

a source of human capital, future employees and, secondarily, as a source of knowledge useful to the firm. In this view what industry wants and needs from academic researchers is basic research knowledge; therefore, universities should focus on their traditional missions of research and education, their unique function. The hydraulic assumptions of knowledge flows include reservoirs, dams and gateways that facilitate and regulate the transmission of information between institutional spheres with distinctly different functions (e.g., academia: basic research; companies: product development). Thus, the academic and industrial spheres should each concentrate on their traditional functions and interact across distinct, strongly defended, boundaries.

This classic industrial perspective of academia is expressed in Europe by the industrial group (IRDAC) in the Research Directorate of the European Union and by the Industry–University–Government Roundtable in the U.S. These organisations primarily represent large multinational firms, whether of U.S. or European origin. Such firms represent the first sector in a typology of firm perspectives on relations with industry. Although this is changing, in such companies R&D was traditionally internalised within the firm, with a window on academic research obtained through consultation and participation in liaison programs. In a second group of companies, typically smaller and based on low and mid-level technologies, with little or no R&D capacity, relations with academia, if any, will also be informal through engaging an academic consultant to test materials or trouble shoot a specific problem. More intensive relationships occur with a third group of firms that have grown out of university research and are still closely connected to their original source. More recently, given the rapid pace of innovation in their industrial sector, some older firms have externalised some of their R&D and seek to import technologies or engage in joint R&D programs to develop them, thus creating a fourth group of firms that are becoming closer in their cognitive orientation to academic start-ups.

In these latter instances, traditional forms of academic–industry relations, such as consulting and liaison programs that encourage 'knowledge flows' from academia to industry become less important as an increasing number of companies look to external sources for R&D or are themselves based upon academic knowledge. As industrial sectors and universities move closer together, informal relationships and knowledge flows are increasingly overlaid by more intensive, formal institutional ties that arise from centres and firms. As companies externalise their R&D, they want more tangible inputs from external sources such as universities. As one close observer from the academic side of the equation put it, ''From the point of view of the company, they tend to want a lot of bang for the buck . . . [they] tend to not get involved in Affiliates programs precisely because they can't point to anything.'' The growth of centres and the formation of firms from academic research have had unintended consequences that have since become explicit goals: the creation of an industrial penumbra surrounding the university as well as a growing academic ethos among older firms that collaborate more closely with each other through joint academic links.

The older forms of university–industry connections involved payment for services rendered, whether it was received directly in the form of consultation fees or indirectly as endowment gifts. The new university–industry relationships involve the multiplication of resources through the university's and faculty members participation in capital formation projects such as real estate development and formation of firms. The capitalisation of knowledge, its transformation into equity capital by academics involving sectors of the university such as basic science departments heretofore relatively uninvolved with industry, and the university's emergence as a leading participant in the economic development of its region have shifted the direction of influence in relationships between business and the university from business to the university.

There are two dynamics at work in these activities: one is an extension of university research into development, the other is an insertion into the university of industrial research goals, work practices and development models. These activities may initially take place as isolated and separate initiatives. At a later time, they may fold back upon each other in spiral fashion and become integrated into each other, for example, a centre that sets up an incubator facility or a department that establishes its own liaison office. The emergence of trends to commercialise academic research is both an outcome of the development of internal capacities to administer research services and a shift in the motivation of faculty and administrators.

4. The capitalisation of knowledge

Max Weber, in his classic essay ‘Science as a Vocation’ (1946) argued that scholars would lose control of their means of production as the scale of scientific instrumentation increased. Indeed, the separation of investigators from their research tools has occurred in many laboratories as academic scientists can more often be found in their offices than at the laboratory bench. Although these researchers have given up direct control of their instrumentation to students and technicians, they have retained control over the direction of its use. The dependence of scientists on large scale research tools that they do not own themselves has grown greater than in Weber’s time but the outcome is reversed: researchers ability to capitalise knowledge has superseded the proletarianization of scientists.

Moreover, computerisation and miniaturisation of components is currently reducing the scale of scientific instrumentation. The recent closing of several NSF supercomputer centres is an example of the decreasing need for centralisation of research tools in a few centres. Combined with the reproduction of scientists outpacing replacement, more universities are able to mount credible research programs in a proliferation of niche areas. New topics have arisen from interdisciplinary syntheses, local economic needs and the intersection between the two, such as the application of biotechnology or electronics to traditional production processes.

As research decentralises to a broader range of universities, including some that were not heretofore known for their research strengths, competition among universities for funds increases. Since research funding is not growing as fast as the number of researchers seeking support, the impetus among investigators to seek support from a broader range of sources, including industrial firms, has thus grown apace. The intersection of industry and academia is also driven by the transformation of technology and science from two largely separate enterprises, with notable exceptional instances of crossover, into two increasingly integrated and closely related activities. As technological innovation becomes more closely tied to research and vice versa, both organisationally and cognitively, boundaries that were once sacrosanct are disregarded.

Cognitive changes are a crucial precondition of these developments. As long as the traditional disjuncture between theory and invention is accepted, the emergence of entrepreneurial science is an anomaly, even a deviance from the shared normative role model of scientific behavior. Entrepreneurial scientists’ research is typically at the frontiers of science and leads to theoretical and methodological advance as well as invention of devices. These activities involve sectors of the university, such as basic science departments, that heretofore, in principle, limited their involvement with industry. One explanation for the emergence of entrepreneurial science is that academic scientists, such as the founders of biotechnology firms in the late 1970s and early 1980s, suddenly awakened to the financial opportunities emanating from their research. Implicit in this explanation is the notion that there were recent scientific advances in molecular biology, polymers, materials science that could be quickly developed as sources of profit. It may seem as if this cognitive condition exists only in a small number of research fields and scientific disciplines. But recent developments suggest that such a cognitive shape appears in more and more scientific fields. For instance, linguistics, for a long time a purely curiosity-oriented basic research field, suddenly became part of the emerging transdisciplinary area of cognitive sciences which has strong links to computer and software industry.

However, opportunities for commercial utilisation of scientific research were often available to scientists in the past, such as the Curies, Marie and Pierre, and Pasteur, who did not believe in crossing the boundary between science and business themselves, even though they evinced a strong interest in the practical implications of their findings. What is new in the present situation is that many academic scientists no longer believe in the necessity of an isolated ‘ivory tower’ to the working out of the logic of scientific discovery. Heretofore, in the hiatus between scientific discovery and application, industry was expected to have its scientists and engineers pursue applied research and product development. The model of separate spheres and technology transfer across strongly defined boundaries is still commonplace. However, academic scientists are often eager and willing to marry the two activities, nominally carrying out one in their academic laboratory and the other in a firm to which they maintain a close relationship. A typical initial reaction of a molecular biologist to the possibility of doing science for financial gain as well as the production of knowledge was, ''I never realised I had a trade,'' later followed by, ''I can do good science and make money''. In this final phase of normative change, a significant number of persons share similar experiences and arrive at a common conclusion. This conversion experience suggests the transmutation of ambivalence—the opposition between two principles, one primary, the other secondary—into consonance and the reformation of ideological elements into a consistent identity. Entrepreneurship is made compatible with the conduct of basic research through a legitimating theme that integrates the two activities into a complementary relationship. For example, scientists often say that monies made from commercialising their research will be applied to furthering their basic research interests.

Thus, technology transfer is a two-way flow from university to industry and vice versa, with different degrees and forms of academic involvement: (1) the product originates in the university but its development is undertaken by an existing firm, (2) the commercial product originates outside of the university, with academic knowledge utilised to improve the product, or (3) the university is the source of the commercial product and the academic inventor becomes directly involved in its commercialisation through establishment of a new company.

In recent years, a non-linear recursive interaction between theory and practice, academia and industry, individual and group research has become an alternative academic mode. A significant number of faculty members have adopted multiple objectives, ''...to not only run a successful company... and start a centre here ((at the university)) that would become internationally recognised'' but to retain their traditional role as 'individual investigator,' directing a research group. An ideal-typical entrepreneurial scientist held that the ''...interaction of constantly going back and forth from the field, to the university lab, to the industrial lab, has to happen all the time.'' These relationships involve different levels of commitment (financial and otherwise) by industrial sponsors, including the involvement of industrial sponsors in problem selection and research collaboration. Conversely, the level of commitment required of a university and its faculty in the commercialisation of research varies in intensity according to the mechanism selected (Matkin, 1990).

Recognition of a congruence between basic research and invention vitiates the ideological separation of these spheres of activity. Until quite recently most academic scientists assumed that the advancement of knowledge was synonymous with theoretical innovation. Recent examples of research in which theoretical advances have occurred in tandem with the invention of devices or innovation in methodology in transistors/semiconductors, superconductivity and genetic engineering have called into question the assumption of a one-way flow of knowledge from basic to applied research to industrial innovation (Gibbons et al., 1994). The acceptance of dualisms such as patents vs. publication and basic vs. applied research goals were the surface expressions of a theory of knowledge based on an underlying dichotomy that placed scientific advance, i.e., development of theory, in opposition to technological advance. In an apparently growing number of scientific fields, this dualism is no longer a valid picture of what happens.

5. Cognitive effects of entrepreneurialism on academic culture

A scientist, by choice of vocation, would heretofore have been assumed to have put aside all thoughts of business-like activity to live a monk-like existence as a searcher for truths about nature. The fictionalised 'Arrowsmith' character in the Sinclair Lewis novel of the same name exemplified the scientific researcher as an un-worldly, but determined, individual. Attired in a white lab coat to protect their street clothing from chemical spills, the uniform of the scientist also signified a certain purity of motives, an abstraction from material concerns and a bemused tendency toward absentmindedness in daily life brought on by exclusivity of attention to science. Researchers were expected to totally concentrate their lives on running experiments in their laboratories and writing up and publishing their results. They were believed to find rewards for their discoveries not in pecuniary advantage but in recognition from their scientific peers through citation in the literature, election to a national academy and the ultimate accolade of the Nobel prize.

The term entrepreneurial scientist formerly referred solely to a teacher who attempted to secure funds from external agencies in order to pursue research within the university (Vollmer, 1962). It was a label especially applied to those teachers who devoted considerable effort to making applications to granting agencies, whether successfully or unsuccessfully. It was often an ambivalent appellation. While successful applicants were admired for their ability to attract the attention of outside agencies and amass funds, they were viewed by some colleagues as less than pure academics for engaging in activities removed from actual scholarship. Nevertheless, the negative attributes of the term have diminished over the years. This is especially true in the sciences, where the ability to obtain funding to support a laboratory and its personnel has virtually become a prerequisite for doing science. Indeed, successfully writing the proposals to fund ones own laboratory has become the litmus test of having advanced along the rite of passage from apprentice to attain the status of a full-fledged scientist. In many departments it is a de-facto, and in some an openly recognised, requirement for a permanent appointment to tenure.

A relatively small number of scientists, but some of the most successful researchers, who are also the intellectual leaders of their fields, operate at relatively high levels of funding. Professor Z. is described by colleagues as a ‘real entrepreneur,’ a man who ‘has raised a fortune.’ Professor Z. himself reports having raised about one million dollars in research funds during the 1983–1984 academic year, over half of it from corporate sources which is an unusually high proportion for an academic scientist. Prof. Z. said, ‘‘There are two ways of getting money from industry that I know of. One is where they’re just interested in your research, and they’ll give you money to support the basic research they’re interested in return for ... access to the lab, access to your students, and pre-prints of the work they’re supporting before it gets published... It’s not required but that’s what they like. But the biggest money comes from industry in return for collaborative research. It’s like a contract... the work is generally publishable but not until they’ve gotten protection.’’ Through these arrangements, he can obtain funding to keep his thirty-member laboratory operating. He said, ‘‘I wouldn’t let any industrial person come to the laboratory to spend a year training or something like that without a substantial investment in our laboratory by the corporation.’’ At the same time he could provide support for the university as a whole, including US$300,000 in overhead payments from companies. Despite this level of funding, Professor Z. found his current arrangements less than fully satisfactory and expressed an interest in trying new models in which he would participate in commercialising intellectual property rights rather than passing them on to corporations in exchange for research funds.

Professor Z. exemplifies the transition from a kind of entrepreneurial habitus which was always connected with academic research to the new entrepreneurialism which recently has begun to spread. To put it in a nutshell, the new entrepreneurialism is the old one plus the profit motive. Seeking for funds has always been an important activity in the American research system which demands a lot of entrepreneurial energy and phantasy. Therefore, as soon as traditional academic ambitions for the pursuit of the truth could be combined with profit seeking, the door was open for the new entrepreneurialism.

6. The entrepreneurial scientist

The closing gap between research and utilisation of the fruits of research encourages faculty to look at their research results from a dual perspective: (1) a traditional research perspective in which publishable contributions to the literature are entered into the ‘cycle of credibility’ (Latour and Woolgar, 1979) and (2) an entrepreneurial perspective in which results are scanned for their commercial as well as their intellectual potential. A public research university that we studied experienced a dramatic change from a single to a dual mode of research salience. A faculty member who lived through the change described the process, ''When I first came here the thought of a professor trying to make money was anathema, . . . really bad form. That changed when biotech happened.'' Several examples of firm-formation encouraged by overtures from venture capitalists led other faculty, at least in disciplines with similar opportunities, to conclude that, ''gosh these biochemists get to do this company thing, that's kind of neat, maybe its not so bad after all.'' Once a university has established an entrepreneurial tradition, and a number of successful companies, fellow faculty members can offer material, in addition to moral, support to their colleagues who are trying to establish a company of their own.

Faculty who have started their own firms also become advisors to those newly embarking on a venture. An aspiring faculty entrepreneur recalled that a departmental colleague who had formed a firm, ''gave me a lot of advice . . . he was the role model.'' The availability of such role models makes it more likely that other faculty members will form a firm out of their research results, when the opportunity appears. A previous strata of university originated firms and professors who have made money from founding their own firms creates a potential cadre of 'angels' that prospective academic firm founders can look to in raising funds to start their firms. Early faculty firm founders at MIT were known on campus for their willingness to supply capital to help younger colleagues.

The success of the strategy to create a penumbra of companies surrounding the university has given rise to an industrial pull upon faculty members. For example, a faculty member reported that: ''The relationship with Collaborative [a biotechnology firm that grew out of the Stony Brook incubator] is ongoing daily. We are always talking about what project we are going to do next. What the priority is, who is involved, there are probably six projects, a dozen staff members and maybe close to a dozen people scattered around three or four different departments on campus that are doing things with them.'' Geographical proximity makes a difference in encouraging appropriate interaction. Such intensive interaction sheds new light on the question of industrial influence on faculty research direction. Thus, the '' . . . issue of investigator initiation is much more complicated because I am bringing my investigator initiated technology to their company initiated product. It is a partnership in which each partner brings his own special thing. That is the only reason they are talking. Do your thing on our stuff.'' This is still an intermediate case. Full integration of research and entrepreneurship occurs wherever scientists found their own firms to continue pursuing a particular kind of research from basic issues to concrete products for the market. Previous conflicts based on an assumption of a dividing line between the academic and industrial sides of a relationship are superseded as divisions disappear. A more integrated model of academic–industry relations is emerging along with a diversified network of transfer institutions.

Potential products are often produced as a normal part of the research process, especially as software becomes commonplace in collecting and analysing data. As a faculty member commented in the mid-1980s, ''In universities we tend to be very good at producing software, [we] produce it incidentally. So there is a natural affiliation there. My guess is a lot of what you are going to see in university–industry interaction is going to be in the software area.'' In the 1990s this phenomenon has spread well beyond the research process, with software produced in academia outside of the laboratory, and start-ups emerging from curriculum development and other academic activities.

In an era when results are often embodied in software, sharing research results takes on a dimension of complexity well beyond reproducing and mailing a pre-print or reprint of an article. Software must be debugged, maintained, enhanced, translated to different platforms to be useful. These activities require organisational and financial resources well beyond the capacity of an academic lab and its traditional research supporters, especially if the demand is great and the software complex. As one of the researchers described the dilemma of success, ''We had an NSF grant that supported [our research] and many people wanted us to convert our programs to run on other machines. We couldn't get support (on our grant) to do that and our programs were very popular. We were sending them out to every place that had machines available that could run them.''

The demand grew beyond the ability of the academic laboratory to meet it. Firm formation, in this instance, was driven by the norms of academic collegiality, mandating sharing of research results. When the federal research funding system was not able or willing to expand the capabilities of a laboratory to meet the demand for the software that its research support had helped create, the researchers reluctantly turned to the private sector. They decided that, ''Since we couldn't get support, we thought perhaps the commercial area was the best way to get the technology that we developed here at Stanford out into the commercial domain.'' The researchers also tried and failed to find an existing company to develop and market the software. As one of the researchers described their efforts, ''We initially looked for companies that might license it from us, ...none were really prompted to maintain or develop the software further.'' Failure to identify an existing firm to market a product is a traditional impetus to inventors, who strongly believe in their innovation, to form a firm themselves to bring it to market.

Chemists involved with molecular modelling, previously a highly theoretical topic, have also had to face the exigencies of software distribution as their research tools increasingly became embodied in software. Since the interest in the software is not only from academic labs but from companies who can afford to pay large sums, the possibility opens up of building a company around a program or group of programs and marketing them to industry at commercial rates while distributing to academia at a nominal cost. Academic firm founders thus learn to balance academic and commercial values. In one instance, as members of the Board, the academics were able to influence the firm to find a way to make a research tool available to the academic community at modest cost. An academic described the initial reaction to the idea, ''The rest of the board were venture capitalists, you can imagine how they felt! They required we make a profit.'' On the other hand, ''It was only because we were very academically oriented and we said, look, it doesn't matter if this company doesn't grow very strongly at first. We want to grow slow and do it right and provide the facilities to academics.'' The outcome was a compromise between the two sides, meeting academic and business objectives at the same time, through the support of a government research agency to partially subsidise academic access to the firm's product.

A biotech incubator company at Stony Brook kept one eye on academia, the other on industry. The cognitive focus in this firm is on developing techniques that could be useful in research in academic labs and in larger companies. An academic lab might also develop techniques but their orientation would be more focused on the discoveries that might result from the techniques rather than the techniques themselves. Nevertheless, other biotechnology firms operate in a dual mode interested both in marketing techniques but also in using them for discovery within the firm. The incubator company also operated in a dual research and production mode. One of its scientists said, ''So we have this kind of constant production operation which is going on and takes a little of our time, and the rest of it is research. And everybody basically does some of both.''

7. A typology of interaction with industry

The university, and an increasing number of its faculty, have learned how to pursue basic research in tandem with the capitalisation of knowledge. Support for faculty involvement in technology transfer varied widely from active encouragement to active discouragement. In an expression of the traditional view a faculty member reported that his chair ''...regarded the [company name] money as bad money, dirty money. He was an NIH (National Institute of Health) man all the way.'' Nevertheless, there has been a change of attitude among many faculty members in the sciences toward industrial funding; a shift away from the old view of industrial money as unacceptable. Three styles of participation in technology transfer have emerged among the Stony Brook faculty, reflecting increasing degrees of industrial involvement. These approaches can be characterised as (1) hands off, leave the matter entirely to the transfer office; (2) knowledgeable participant, aware of the potential commercial value of research and willing to play a significant role in arranging its transfer to industry; and (3) seamless web, integration of campus research group and research program of a firm. Of course, many faculty fit in the fourth cell of 'no interest' or non-involvement. These researchers are often referred to under the rubric of the federal agency that is their primary source of support as in, 'She is an NIH person.'

The approach of leaving it up to the technology transfer office to find a developer and marketer for a discovery precisely met the needs of many faculty members, then and now, who strictly delimit their role in putting their technology into use. A faculty member delineated this perspective on division of labour in technology transfer: ''It would depend on the transfer office expertise and their advice. I am not looking to become a business person. I really am interested in seeing if this could be brought into the market. I think it could have an impact on people's lives. It is an attractive idea.'' This attitude does not necessarily preclude a start-up firm, but it does exclude the possibility that the faculty member will be the entrepreneur.

A stance of moderate involvement is becoming more commonplace, with scientists becoming knowledgeable and comfortable operating in a business milieu while retaining their primary interest and identity as an academic scientist. A faculty member exemplifying this approach expressed the view that: ''In science you kind of sit down and you share ideas... There tends to be a very open and very detailed exchange. The business thing when you sit down with somebody, the details are usually done later and you have to be very careful about what you say with regard to details because that is what business is about: keeping your arms around your details so that you can sell them to somebody else, otherwise there is no point.'' Faculty are learning to calibrate their interaction to both scientific and business needs, giving out enough information to interest business persons in their research but not so much so that a business transaction to acquire the knowledge becomes superfluous. Another researcher said, ''I am thinking about what turns me on, in terms of scientific interest and the money is something if I can figure out how to get it then it is important but it is certainly not the most important thing to me.'' The primary objective is still scientific; business objectives are strictly secondary.

Many companies, both large established and start-ups, want a closer, more involved relationship with the academic scientists that they work with. Such a collaborative approach makes the old model of licensing intellectual property into an initial first step in setting the ground rules as to how the relationship should be structured and any profits divided. But once the contract is signed a much higher degree of involvement is expected of both parties. As one faculty member described the changed situation: ''More and more the company's attitude is we want you with your unique expertise to contribute, not to the development of an as yet uninvented product, but to the definition of this product which we as a company may need...'' In this model the professor becomes involved in helping set the strategic research direction of the company rather than merely handing over a technology, developed as a by-product of academic research, that happens to coincide with a corporate need.

Relations with industry have become further complicated as companies see the university as a potential competitor through its role in the creation of new firms. Although some academics and industrialists wish the university to return to its traditional role of training students and publishing research findings, many states and local governments fund centres and programs to encourage academic institutions to generate new economic activity from the campus. Indeed, venture capitalists advise prospective academic founders of companies that the best way to launch their firm is to remain on campus and work with students to develop the early stages of their technology. Although many academics would prefer to return to an era when federal support was sufficient to meet the needs of their research enterprise, few see this as a realistic possibility. The conflicts are no longer about whether the university should pursue knowledge for profit, but over the shape that organisational innovations to accommodate industry connections will take (Etzkowitz et al., 1998).

An interesting further development of academy–industry relations is the concept of 'discovery exchange' at the University of Colorado, Boulder, invented by a departmental chairperson and a venture capitalist. The Discovery Exchange plan drew out the logical implications of university technology transfer efforts and carried them to a new height. The idea was to generate significant income by raising venture capital funds to commercialise a much larger proportion of academic research than even the most entrepreneurial university to date. The Discovery Exchange was based on the premise that only a small portion of university research is patented despite universities having the right and the obligation by law to seek commercialisation possibilities as a condition of accepting federal research funds. Given their financial constraints university technology transfer offices ''...seek patents on only the 'ost promising' ideas, as judged by industry contacts, expert consultants, and, in some cases, by a company's expressed willingness to license a new invention once the office patents it'' (Gold, 1990). Only the immediately available obvious candidates for commercialisation were patented.

In contrast, the Discovery Exchange plan envisioned an aggressive and expensive strategy. Patents would be taken out on a wide range of potentially useful research results, irrespective of current estimates of their commercial value, on the premise that a significant number of these patents would accrue value that could not be entirely foreseen in advance in the interim before their lapse. To draw upon the research capacity of academic staff more effectively than traditional means of encouraging faculty to bring potential commercialisable research to the attention of a university office, the Discovery Exchange proposed to have one of its staff sit in on the meetings of research groups to help identify potentially commercialisable knowledge. The Discovery Exchange proposal stated that, ''Providing that the directors of a laboratory give their consent, the churner will participate in laboratory research meetings, follow on-going experiments, and join in the intellectual life of the laboratories.'' (Gold and Butcher, 1989: 14). Based upon the assumption that not all academic staff were aware of potential uses for their research the 'churners' would join the research group to monitor for useful results. They would, ''... attend the lab meetings of the faculty member... prepared to recognise the commercial potential of discoveries'' (Gold and Butcher, 1989: 20). It was also planned to hire sufficient legal staff to allow the filing of ten times a many applications as a typical university patent office and six times as much as the most active.

The implantation of the Discovery Exchange would make technology transfer an integral part of the everyday operation of the university. The cognitive effects are manifest among both supporters and detractors. In interviews, both proponents and opponents of the Discovery Exchange professed their faith in the 'meandering stream' of basic research. Although the Discovery Exchange representative was intended as a non-obtrusive participant in the research group, the introduction of such a presence was argued as having the potential to influence research direction. An opponent said, ''They used a wonderful and I think a totally self-defeating agricultural metaphor. They were going to put these cultivators in peoples laboratories, churners they were called, interestingly enough. In a perfect business approach to it faculty were going to be invited to be churners so some of us could make some money out of this thing because we would be intermediaries between the Discovery Exchange and a particular laboratory. So somebody has a lab and one of us, either another scientist in that field or someone else who has a larger perspective would go to those meetings, sit around and help to steer the choices in a direction that would have more payoff, potential payoff, for patentable ideas for industrially relevant kinds of works. These churners would be participating in the scholarly process and then they would harvest this stuff'' (Jessor, 1990). As a consequence of such criticism, the churners, attorneys and venture capital arm of the Exchange were replaced by a more modest effort that would nevertheless promote the formation of companies from faculty research and allow the university to maintain an equity interest in these firms. Although the leading proponent of the Exchange was sceptical of this more modest effort (''The university plan is worse than nothing''; Gold, 1993), but in principle it represented a considerable expansion of the university's technology transfer efforts (Harpel, 1993).

8. Conclusion: the industrial penumbra of the university

Controversies such as the one about the Discovery Exchange show that it is still a long way to a full-blown establishment of entrepreneurial science. Universities are undergoing a 'second revolution' these days, incorporating economic and social development as part of their mission (Etzkowitz, in press).

The first academic revolution, taking off in the late nineteenth century in the U.S., made research an academic function in addition to the traditional task of teaching (Jencks and Riesman, 1968). This revolution is by no means finished. But in the most advanced segments of the worldwide university system, a 'second revolution' takes off. The entrepreneurial university integrates economic development into the university as an academic function along with teaching and research. It is this 'capitalisation of knowledge' that is the heart of a new mission for the university, linking universities to users of knowledge more tightly and establishing the university as an economic actor in its own right.

9. Unlinked References

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