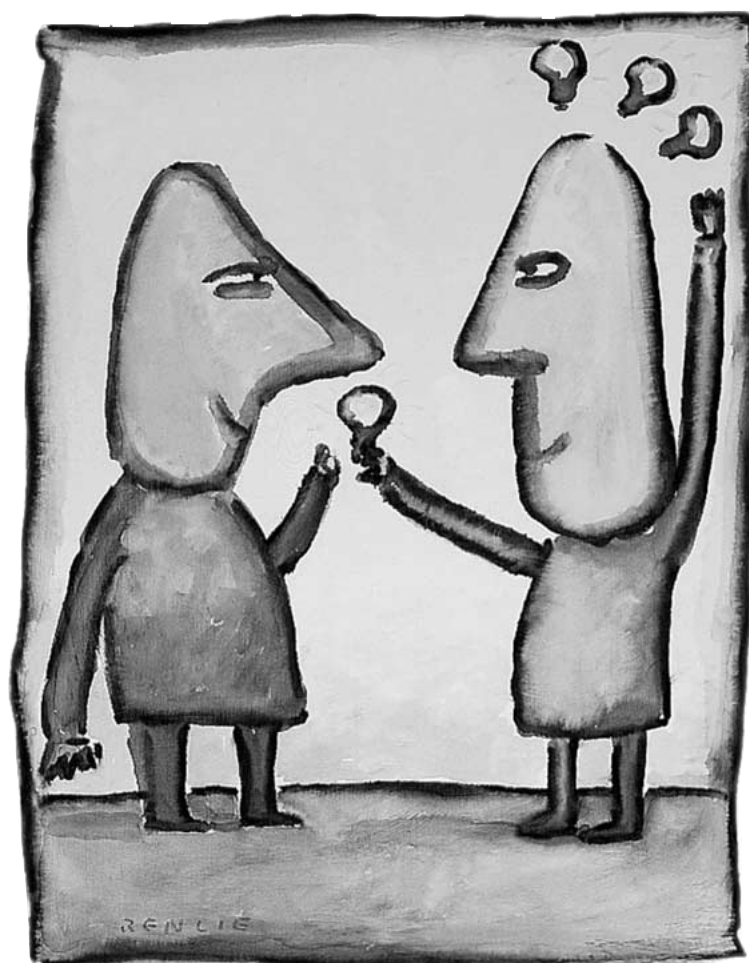


The Second Academic Revolution

and the Rise of Entrepreneurial Science

Henry Etzkowitz

Entrepreneurial scientists and entrepreneurial universities are reshaping the academic landscape by transforming knowledge into intellectual property. Faculty members and graduate students are learning to assess the commercial as well as the intellectual potential of their research. During the past two decades a broad range of universities, well beyond the Massachusetts Institute of Technology (M.I.T.), Stanford University, and a few other schools with traditional ties to industry, have undertaken to mine their research resources for profit. As their interest in making money from their research resources grows, universities compete in a new arena. When Columbia University announced a patent covering both U.S. and international rights to co-transformation (a genetic engineering technique invented by faculty member



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Richard Axel), the university's director of technology licensing exclaimed, "We captured both in one." The implicit comparison was to the Stanford Cohen-Boyer patents, the basis for genetic engineering, which had failed to gain such a high level of protection because the two researchers had already disclosed the techniques before their university could apply for patents in Europe and Japan.

Academic institutions participate in various ways in the capitalization of knowledge and its transmutation into factors of production. The University of Colorado and Columbia University accept equity in faculty formed firms. Washington University, St. Louis, and M.I.T. take the role of venture capitalist, and Harvard has participated in ventures through its corporation. A university licensing administrator outlined the new academic regime: "Instead of publishing it and giving it away, you license (it), publish (it), but don't give it away." For example, Rockefeller University announced the receipt of a \$20 million payment for a patent license for the "obesity gene" from Amgen, a biotechnology company, "with an agreement to pay many times that amount if the protein proves useful in treating fat people." As they seek intellectual property from their findings as well as publishable articles and an enhanced scientific reputation, academic scien-

tists become inventors, developers, and entrepreneurs.

Universities have become engines of regional economic development, developing new organizational mechanisms for this purpose as well as for the conservation, extension and dissemination of knowledge. Opportunities to translate research into industrial applications were always present, yet few academics took advantage of them. The few who did were a distinct and unusual minority. In early 19th century Germany, several instances have been noted of ill paid chemistry professors initiating commercial ventures, and supervising production processes, to supplement their incomes [9]. One entrepreneurial effort stands out from these mundane ventures, Liebig's mid-19th century use of chemical theory to develop an artificial fertilizer. Although unsuccessful, this venture represented a significant precursor of contemporary academic efforts to originate marketable products.

The capitalization of knowledge represents a transformation of the role of the university in society comparable to the first academic revolution of the late 19th and early 20th century when research became an accepted academic task [13]. The thesis of this article is that a "second academic revolution" is underway as universities combine teaching and research with technology transfer and thus

play a more central role in the economy. I also argue that the university is undergoing a bi-evolution through a shift from an individual to an organizational perspective in each of its missions. As the university increasingly provides the basis for economic development through the generation of social and intellectual, as well as human capital, it becomes a core institution in society.

FIRST ACADEMIC REVOLUTION

An academic revolution would appear to be a contradiction in terms. As a medieval institution, going back more than 1000 years to its founding in Paris and Bologna, universities appear to change at a glacial pace. Originally conceived as institutions of cultural conservation, preservation, and transmission, they existed solely for that purpose for many centuries. The university has retained its original purpose even as it has expanded its purview to encompass new missions.

The continuity of the university resides in its history of development: each new task has evolved out of an effort to meet a previous goal. Research emerged, initially in philology and then in other disciplines, from a concerted effort to revive classical learning in the eighteenth century. New knowledge was inevitably created and a better understanding gained

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This article draws for data on various studies of university industry relations conducted in the United States by the author in 1984, 1988 and 1992, sponsored by the National Science Foundation. In-depth interviews with faculty members, graduate students administrators and archival research were conducted at eight universities, private and public, both those with long

standing and newly-emerging industrial links. The article also draws upon research on academic-industry relations in Sweden (1998) sponsored by Knowledge Competence Foundation (KK) and the Center for Business and Policy Studies (SNS) in Stockholm, as well as an incubator evaluation study sponsored by the State University of New York at Stony Brook (1995). The author also expresses appreciation for a Visiting Professorship at the Federal University of Rio de Janeiro (2000) supported by CNPq and IEL/CNI; (Instituto Euvaldo Lodi/Confederacao Nacional da Industria. Quotations, not otherwise identified, are from these investigations.

through the innovative methodological techniques invented to retrieve the meaning of Greek and Roman texts.

The seminar, an innovative advanced teaching method also arose out of the development of philological research. The cooperative examination of texts took place through presentations by advanced students and professors, with discussion of findings among them. This led to both levels of academics becoming inquirers into new knowledge. The seminar sup-

plemented lectures and enhanced the educational mission of universities even as it became a basic format for organizing research in the humanistic disciplines. As research became a distinctive activity at some universities in Europe, the experimental sciences were also incorporated into the university.

research, outlined by Johns Hopkins physicist Henry Rowland in the late 19th century. Early in his career Rowland had been a consultant to industry but when he took office and gave his inaugural address as President of the American Association for the Advancement of Science, he put this industrial career behind him in raising the banner of pure research.

Until the late 19th century in the U.S. no clear distinction was made between basic and applied research. The infusion of funds into academia from the great industrial fortunes created in the late 19th century was accompanied by fears that donors would attempt to influence the research agenda. The creation of an ideology of basic research was part of the effort to carve out a protected, yet financially secure, space for science. The practically oriented leaders of academic science in the mid-19th century, such as the Sillimans at Yale and Columbia's Chandler, well known as consulting chemists, were pushed aside by a younger generation devoted to pure science who became the academic exemplars. The distinction held until World War II when scientists who had grown up in the basic research culture found themselves immersed in war-related engineering projects, such as radar, which also led to the development of radio astronomy and the elucidation of theoretical issues in cosmology during the post-war period. The somewhat surprising emergence of theoretical issues during their war-time service, ostensibly devoted to practical issues, closed some of the gap between pure science and engineering for these researchers.

EVOLUTION WITHIN THE REVOLUTION

The gap between academic vision and available resources was true for virtually all U.S. academic institutions during the nineteenth century. The attempt to establish independent research institutes on the German model failed [16]. There were simply not enough funds available to realize the research ambitions of the increasing number of American scholars who returned from Europe with their Ph.D's. The organization of doctoral research was a creative response to these financial constraints. Research expanded beyond an individual effort when academics employed as teachers obtained small amounts of money to purchase research materials and to hire students to help carry out research. Since research funds did not come with academic positions as was typical in Germany, individual researchers were responsible for seeking their own sources of support.

The professorial role took on an entrepreneurial cast and the research group became a firm-like entity, even before academics undertook to form firms. Built with foundation and industry funds early in the century, the U.S. academic research system was greatly expanded with federal funds during and after the World War II. It has brought with it an increased velocity of scientific activity and pressures to further increase funding in order to support existing research groups and form new ones.

Expansion currently takes place despite, or perhaps because of, stringency in research funding, in part due to greater competition from additional universities and regions seeking funds. An increasingly powerful constellation of forces, including but not limited to the academic research community, generates political support to maintain and even gain increases in government spending for scien-

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tific research. Encouraged by extensive financial support during the post-war era, academic science grew beyond the traditional professor-graduate student dyad still commonplace in the humanities and much of the social sciences. Research in the physical and then the biological sciences was increasingly carried out collaboratively by faculty members, graduate students, undergraduates, post-doctoral fellows, research associates, and technicians, sometimes supported by a research administrator and a secretary. An assistant professor may be responsible for three or four people, an associate perhaps seven, and a full professor, up to fifteen or twenty persons, or even more, in some research fields.

Despite the development of a highly organized research system, academic scientists are still typically called individual investigators. When visited in their laboratory; they were typically not at the research bench but in an office off to the side when in residence. In interviews, research group leaders typically said, "In many ways I am running a small business... It has been ten years since I actually performed an experiment. I spend my time going to scientific meetings to publicize the research...in meetings with the students, administering personnel and dealing with other problems..." Having many of the characteristics of a small business save for the profit motive, some of these research groups or "quasi firms" were but a short step from becoming an actual firm when opportunities arose [5]. Emanating from the research base created by the first revolution, economic development is becoming an academic mission, as well.

SECOND ACADEMIC REVOLUTION

The role of the university in society is currently undergoing a transformation comparable in

scale and scope to the first academic revolution of the late 19th and early 20th century when the university integrated research along with teaching into its academic mission [13]. As the first academic revolution spread to the sciences, a second revolution was set in motion: making findings from an academic laboratory into a marketable product. This requires a series of intermediate steps that follow from acquiring the intention to sell as well as publishing ones research. In these circumstances, organizations as well as individuals act as entrepreneurs.

Universities have acquired the capabilities to engage in business activities well beyond the traditional bursary functions such as collecting student fees and paying faculty salaries. Transcending its traditional industrial role of training persons for employment, the new entrepreneurial role of universities is based upon creating new knowledge-based firms, locally, as well as selling technology to the highest bidder among existing firms, nationally and internationally. A school's portfolio of industrial connections (industrial liaison programmes, technology transfer offices, incubator facilities, etc.) is becoming a defining institutional characteristic, much as research specialties and distinctive courses of study distinguished universities from one another in the past.

Academic science is being transformed into an economic as well as an intellectual endeavor. The industrial realignment of academia has broken down the separation between academic science and industry that most universities traditionally adhered to. Indeed, virtually all universities have adopted many of M.I.T.'s long-standing practices for relating to industry from the portfolio listed above. Some observers thought that M.I.T.'s growing research strength in the basic sciences would lead it to become more sim-

ilar to a liberal arts research university such as Harvard. The contrary has proved true as other universities, following Stanford's lead, have come to more closely resemble M.I.T.

In 1963, Clark Kerr, then Chancellor of the University of California, Berkeley, set forth a vision of the future of the university, extrapolated from the recent history of his campus. He called it the "multi-versity" to encompass a proliferation of activities. Conventional discipline-based departments were cross-cut by interdisciplinary research centers covering newly emerging fields such as materials science and foreign area studies, giving the university a matrix-like structure. Greatly expanded divisions of continuing education, offered credit and non-credit courses to the general public on an even wider variety of topics than could be found in the regular academic catalog.

Parallel to the trends that Kerr identified, and in part based upon them, another academic transformation was gathering force based upon the commercialization of academic research. For example, the Alumni Foundation of the University of Wisconsin marketed patents derived from academic research to industry and financed faculty research projects with the monies made [2]. These funds enabled Wisconsin to become a major research center in biology in the 1930s and 1940s.

Traditionally, academic-industry relations denoted the provision of research support from a firm to a campus based researcher. Such funding while often bound up with many fewer restrictions than government support and thus viewed favorably by academic research staff has represented a very small proportion of academic research support during the post-World-War-II period, even though it has recently increased from a low of 2% to 7%. The overall modest lev-

el of this flow, despite a steady increase in income earned from patents and a number of multi-million dollar research contracts, has led some observers to conclude that relations with industry are, and will continue to be, of minor import in comparison to universities ties to government. For example, Faulkner and Senker [8] argue that universities are ill advised to commit resources to the marketing of technology especially since companies prefer that academic institutions concentrate on making information freely available.

Traditional industrial relations with academia were often accompanied by the payment of small amounts of funds, typically to individual professors. Most of these funds flowed through consulting relationships with faculty members who provided advice (on campus to visitors from the company and at the industrial lab), conducted tests of materials and products in their laboratories, and occasionally carried out small research projects for a company.

Based upon the consulting model, some universities like M.I.T. and Cal Tech established liaison programs to link up firms with professors. In its most developed format, a liaison program staff member would keep up with the technical interests of a group of companies who paid a fee to a member of the program and then received suggestions of faculty members to contact. The older forms of university-industry connections such as consultation practices and industrial liaison offices provide a means of access to traditional university activities of research and education. They involved payment for services rendered, whether it was received directly in the form of consultation fees or indirectly as endowment gifts.

The founding of firms by professors, whether directly or indirectly based upon their academic research, represents a new stage in the development of academic-industry relations. The objective is

to multiply the value of intellectual property derived from academic research through the stock market, either directly through the formation of a new firm or indirectly through a stream of royalty income from an existing firm. The new focus of relations with industry builds upon the development of scientific research capabilities and the creation of a series of boundary spanning mechanisms, including technology transfer offices and spin-off firms. Incubator facilities provide a home and support services for new firms while research parks are designed to link successful firms to academic resources, in a format designed to be compatible with academic goals. Whether this goal can be achieved is a matter of considerable academic soul-searching and debate.

CONTROVERSIES OVER RELATIONS TO INDUSTRY

Academic-industry relations have become a Rorschach test of academic values as well as a vehicle for transfer of technology. They expose assumptions about the purpose of higher learning and the legitimacy of an economic role for the university. One axis of opposing views about the utility and propriety of academic-industry ties concerns whether it is possible for the university to contribute significantly to the economy — the practical question. The value issue posed is whether such participation will detract from the traditional educational and research missions of the university — the value dimension. There is concern that attention to economic issues will cost the university its independence. Some of these same fears were expressed by academics opposed to federal research support in the 1930s. Critics of academic-industry relations believe that the university is at risk of losing its independent identity and special purpose by engaging in such activities.

Controversies have erupted

such as the one at Harvard in 1980 when the administration proposed that the university participate financially in a firm based on the research of one of its faculty members. The ensuing debate rapidly escalated into a struggle over the goals of the university, the purpose of science, and the professional ethics of scientists. According to one observer, "What has drawn Harvard into this quagmire is the heady expectations of a genetic Eldorado". In the face of widespread faculty opposition, Derek Bok, the President of Harvard University, withdrew the university from the plan to invest in a joint university/faculty initiated biotechnology firm. Instead, he issued a statement eschewing such projects in the name of protecting the disinterested stance of the university while reserving the right to capture the economic worth of university research through other means. In 1988, a joint venture involving the Harvard Corporation, an administrative entity, and the university's medical school was announced. Although the *New York Times* questioned whether traditional academic values were being abandoned, there were no reports of on campus opposition as there had been eight years before.

Academic-industry relations provide a litmus test of a university's goals. Just as a litmus test partially turns color indicating degree of acidity, conflicts over relations with industry signal the stage of transition that a university is in, shifting from a feudal to a capitalist mode of production. How much has changed during the past two decades and how much hasn't? In the early 1980s, the *New Scientist* reported that a London University professor proudly refused to assert an economic interest in the results of his research. Along with the announcement from Edinburgh that Dolly Parton's namesake was a cloned sheep, was the mention that the academic institution where

the research was conducted had helped found the biotechnology firm that had part funded the research. Capitalized on the London stock exchange, the present firm was the result of a merger with a U.S. company, founded by faculty at Johns Hopkins University and Virginia Polytechnic Institute, with support from their state science agencies. The *New York Times* also reported interviews with scientists at the University of Wisconsin who asserted that the NSF would never have funded the Edinburgh research, it simply wasn't basic enough!

Universities try to balance their academic and business roles in the increasingly brief interval between discovery and utilization of research findings. Once academic research is redefined from a free to a marketable good and treated as intellectual property, the traditional forms of dissemination, such as publication of articles in academic journals and presentation of papers at conferences, continue but under a new set of conditions. "Limited secrecy" becomes the watchword as publication is delayed to allow time for patenting. If universities take a strong stand for openness and do not want the time span for delay to be long, companies will usually agree. Nor, once a university has a technology transfer office ready to act quickly is there any need to take a long period of time to file an intention to patent. Having a paper published in a major journal can be advantageous to a company seeking funds to support product development or an appreciation in the price of its stock. Forces within the academic technology transfer process militate for and against the freedom of scientific information as the university creates a business from its research activities.

ALTERNATIVE EXPLANATIONS OF ENTREPRENEURIAL SCIENCE

Entrepreneurial science is sometimes said to be the result of

a convergence between basic and applied research that creates commercial opportunities from basic research. As a closer relationship has emerged between basic research and industrial development the time gap between the two processes has shortened, resulting in several new syntheses. Heretofore, there was a long term relationship in which basic understanding of physical phenomena later resulted in practical devices utilizing earlier discoveries. For example, Marconi's patent application of 1896 for a long range radio transmitter was "...the technological embodiment of Maxwell's theory of the electromagnetic field, stated thirty years earlier" [1]. Thus, a major scientific advance in the understanding of a physical phenomenon was translated into a working device.

Persons with different professional outlooks and goals, discovery and theoretical advance versus commercial and military use, carried out each phase. More recently these processes have been collapsed into each other, sometimes with the same individuals involved in each phase. For example, the first successful insertion of foreign DNA in a host microorganism in 1973 was quickly followed from 1976 by the founding of small entrepreneurial firms to make industrial applications of this new genetic technique in the production of new drugs and chemicals [15].

Although insufficient as a full explanation of entrepreneurial science, recognition of a congruence between basic research and invention reduces the ideological separation of these spheres of activity. Another explanation of entrepreneurial science is that scientists suddenly awakened to the opportunities attendant upon the application of recent scientific discoveries. Implicit in this explanation is the notion that there were scientific discoveries in the past twenty

years, e.g., biotechnology, computers, unique in that they could be quickly developed as sources of profit. This explanation is deficient in its assumption that previous scientific research did not have direct commercial potential.

Such possibilities have always existed, but few basic scientists took advantage of them [1].

Opportunities for commercial utilization of scientific research were often available to scientists, whose norms did not permit them to violate the boundary between science and business. 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 long hiatus between scientific discovery and application, industry was expected to have its industrial scientists' pursue research and development, an activity presumed to be too mundane for university scientists. Now, academic scientists and engineers are often eager and willing to direct, or participate in, developmental research programs leading to commercial application.

CAUSES OF ENTREPRENEURIAL SCIENCE

The transformation of academic science has a series of proximate and long term causes. While short term causes vary in different countries and academic systems, the common long-term factors driving the emergence of entrepreneurial science have to do with the increasing significance of science to economic development, on the one hand, and changes in internal structure of scientific research itself.

In the U.S., short-term causes include shifts in funding patterns for academic research and policy changes regarding the ownership of intellectual property. The Bayh Dole Act of 1980 offered universi-

ties the opportunity to gain income from licensing intellectual property rights, making receipt of federal grant funds conditional on universities making an effort to put research results to use. Universities responded by changing their patent rules to assume ownership rights to this research. University offices and administrative procedures were established to patent and market research results.

As leading universities went into the intellectual property business, others followed. In a relatively short time, virtually all universities with a significant research capacity developed the capability to identify and market intellectual property. A new academic role of university technology transfer officer was invented and the people who filled it: lawyers, industrial scientists, social scientists, and business people soon created a profession with its own organization, The Association of University Technology Managers (AUTM).

Individual scientist's business activities have been encouraged by university technology transfer offices who have alerted faculty members of the potential financial worth of their discoveries. In Prof. Mark Ptashne's case, a memorandum from such an office at Harvard led him to notify the office of some recent discoveries; in the case of the founders of Synergen at the University of Colorado Boulder, a personal acquaintance with a venture capitalist initiated the discussions that led to the formation of the company. In another instance, a renewal of ties with college friends who had pursue careers in business was the catalyst to the initiation of a firm.

The founding of companies by academic scientists, formerly a phenomenon associated with a relatively few universities, has become more widespread in recent years. Sometimes the entrepreneurial culture in which firm formation has been encouraged is

spread by scientists who have left universities where this culture had long taken root; other times it is an example gleaned from afar, through the media and informal conversations in departmental corridors and at scientific meetings. This phenomenon has its roots in the invention of the laboratory and the transition of research from an individualized master-apprentice relationship to a more highly organized activity.

RISE OF ENTREPRENEURIAL SCIENCE: A BI-EVOLUTION

There is a parallel bi-evolution of the university, increasing its functions and expanding its roles. A transition from an individual to a group perspective is taking place in teaching, research, and economic development. As we have noted, research is increasingly conducted in groups. There has also been a shift from transferring technology to individual firms to fostering regional economic and social development.

A similar transformation in education can be identified in the university's incubator facilities. A recent graduation ceremony at the Pontifical Catholic University (PUC) of Rio de Janeiro of firms from the university's incubator facility exemplified the new role of the university in training organizations as well as individuals. Representatives of firms spoke about their company's accomplishments. The Rector's speech praised the achievement of entrepreneurial dreams. At the end of the ceremony a representative of each firm received a certificate. It was a graduation, not of individuals but of organizations.

Organizational learning is thus transformed from an academic sub-discipline into an academic practice, as well [3]. Expansion of the teaching mission also takes place through organizational endeavors such as the creation of the "popular cooperatives" by the Graduate

School of Engineering (COPPE) of the Federal University of Rio de Janeiro. This project involved taking the organizational learning accumulated in founding high tech incubators and transmuting that organizational model into a way of creating jobs. The university invited low-income people from neighboring "favelas" for training, shaping them into a co-operative to perform services and then sending them out into the world as an organization [19].

University engineering schools have also imported organizational formats from industry into the university. Industrial engineers, employed as professors at the Karlskronna Ronneby regional college in Sweden, introduced team formats from their industrial R&D experience into the teaching process. Babson College will employ a similar format in its new technological college. The College expects that some student teams, including members from its business and technological units, will emerge from the college as firms, either before or after graduation [18]. These innovations augur an expansion of the university's teaching mission from an individual to an organizational format.

THE UNIVERSITY AND TECHNOLOGICAL INNOVATION

We are all familiar with the linear innovation model in which research is conducted at the university, published, disseminated, and then taken up by industry and put to use. It was expected that publication would be enough to allow take up by others to use the research; it has since been realized that there must be help along the way to actually make this model work. Thus, a variety of ways have been invented to encourage the transition of research to industrial use. There is also innovation in the opposite direction, not only starting from research, but from social

and economic needs. Thus, it is well recognized that innovation can also move in a reverse linear direction.

The prototypical example of the reverse linear model is Thomas Alva Edison, who came to New York from Boston in the late nineteenth century because he needed financing for his inventions. He went to work for the finance industry to meet their needs. One of their needs was for a better way to transmit information about the stock market so he made improvements in telegraphy in order to transmit information faster and more reliably. He started from a need in the market, in the finance industry, and then made his invention to meet their needs, rather than starting from a research idea and then making something practical from the research [12].

The reverse linear model is the basis of New York's Silicon Alley. Similar to Edison's initial venture, software firms typically start up to address problems and opportunities in the financial industry; multimedia firms in the advertising and entertainment industries. Rather than starting from the commercial implications of research results, these firms start from problems in the marketplace and use existing technology, sometimes in innovative configurations around a new business concept, to address these problems and create businesses [11]. Some of these firms may later develop new technology themselves and support academic research, following a "science and technology pull" approach in which the research problem derives from a company's product development difficulty or a broader industry issue. Science and technology pull reproduces the classic industrial laboratory style but now increasingly takes place among a variety of firms rather than only within a single company.

The New York model works in the opposite direction to the science and technology push model which is common to the origins of Silicon

Valley and Route 128. In these latter cases, innovation has tended to start from basic research and then move toward the marketplace. Each of these models, linear and reverse linear, are part of a full picture of an interactive innovation model, with both science push and market pull working together simultaneously.

Although university-industry linkages originally implicitly followed the linear model, there has been a revolution in university-industry relations in the classic sense — instead of going in one direction, revolving or turning around and going in both directions. The NSF Industry-University Research Centers and Engineering Research Centers,

formed in cooperation with a group of firms in a productive sector where both the professors and representatives of firms jointly decide on projects and often undertake the projects jointly, exemplify this approach. Such centers implicitly follow an interactive innovation model with research and ideas coming from the university meeting together with the issues of the firms, going in both directions simultaneously.

However, the initial linear format of university-industry relations, going a step beyond publications to move knowledge from the university, involved the establishment of a liaison office. The purpose of the office was to learn what researchers in the university are doing and then to invite firms to come to the university to engage consultants, the university playing a role in the transfer of knowledge. The second level of development is to embody that knowledge in a technology,

going in a linear direction from research produced in the university, moving it out. This typically involves the development of a technology transfer office which identifies potentially commercializable technologies, and patents, markets, and licenses them to industry.

When scientific knowledge is appropriated to generate income, science itself is transformed from a cultural process into a productive force that generates new income.

UNIVERSITY BUSINESS INCUBATOR

The third organizational format of the linear model is the incubator where the knowledge and technology is embodied in a firm and is moved out of the university by an entrepreneur. Instead of licensing to an existing firm, it is transferred in the form of a company. University incubators originally adhered to a linear model of starting from academic research but soon also followed a reverse linear model, as well. When incubators were established, there were often not sufficient academics interested in starting companies to fill the facility. Engineers and technical entrepreneurs, learning about the incubator from local publicity, asked if they could join the incubator as well. They were often former employees of nearby large companies who were starting their own firms. Some of these entrepreneurs were simply interested in moving their

firms out of their homes to a prestigious location, near common support services (secretary, photocopying, reception, etc.), with easier access to university facilities, faculty, and students afforded by membership.

The individual incubator, in addition to providing a support structure and a director to mentor the firms, allows the university-originated firms and the firms originating outside the university the opportunity to interact and learn from each other. This convergence between firms arising from the linear and reverse linear approaches opens the way for the incubator to be a key node in an interactive non-linear academic-industry relationship.

NETWORKED INCUBATORS AND INCUBATOR NETWORKS

The transformation of university-industry linkages from a linear to an interactive innovation model can especially be seen in the evolution of the university business incubator from an isolated to a networked entity. The incubator has evolved into a support structure for innovation, a broader purpose than the original concept of developing firms from academic research [17]. Incubators have also been utilized to develop business ideas into an array of firms and to form research centers by bringing together heterogeneous R&D entities from university, government, and industry. I have identified three types of incubator networking: internally among firms within incubators or intra-networking; externally, among incubators and firms from different incubators or inter-networking; and the formation of new organizations in incubators from heterogeneous elements or extra-networking

PRIVATE INCUBATOR: TYPE 1: INTRA-NETWORKING

Venture capitalists and individual entrepreneurs have found the incubator format to be a useful way to start new Internet business-

es [10]. Although some university incubators have recently focused on thematic areas such as software or biotechnology, the university incubator was theoretically open to ideas for firms from all parts of the university. The private incubator, on the other hand, typically starts from a single business idea, which is then divided up into its constituent parts. Since each firm develops part of a broader concept, at a very early stage each firm in the private incubator starts doing business with other firms in the incubator, for example, doing each others coding or graphics. I call this form of networking within the incubator intra-networking to distinguish it from the networking among incubators and firms from different incubators, or inter-networking, to be discussed next.

BRAZILIAN INCUBATOR MOVEMENT: TYPE 2: INTER-NETWORKING

Since the introduction of the incubator concept in the mid-1980s, incubators have developed rapidly in Brazil, gaining support not only from universities, their original sponsors, but from government, at various levels (federal, state and local), and from industry associations. Several permutations of the university business incubator have been created such as the “hotel for firms,” a pre-incubation space for the firm-founder to hone their concept, find partners, and raise funds.

Inserted into federal and state universities with a strong “public” tradition, there was initially considerable resistance among many faculty members to incubators on the grounds that they represented the “privatization of the university.” Instead of building new facilities immediately, early incubators developed firms in temporary space, incubating themselves, until official approval could be gained. Nevertheless, this resistance also inspired a creative transformation

of the incubator concept to fulfill the university’s public mission, in traditional terms, through the invention of the “popular cooperatives” discussed above.

As incubators spread (200 by 1999, and a total of 400 expected in 2000), networking among incubators, and firms from different incubators, occurred extensively. For example, at the incubator in the Federal University of Fluminense (UFF) a content firm was based on a software platform from a firm in another incubator. A network of experienced directors was mentoring the director, who had come to the job from the university library. Regional and national incubator associations (ANPROTEC) provide training and information about new development to their members at regular meetings. The Rio de Janeiro network meets on a monthly basis to discuss common issues. The national meetings of ANPROTEC bring together academic analysts of incubation together with incubator directors and personnel, providing ongoing feedback of research to the incubation process, sponsored by the association itself, as well as by Brazilian research agencies.

ALBANY MODEL: TYPE 3: EXTRA-NETWORKING

Finally, there is a third type, the “Albany model” of the extra-networked incubator, which brings together heterogeneous elements from various sources to create new hybrid organizations. The State University of New York at Albany did not yet have a sufficient research base in order to systematically develop new firms, the traditional incubator function. As the incubator director stated the problem, “We don’t have the services we need to increase our research support and recruit faculty. We don’t have the resources of a major research university, we aspire to be a major research university so we are looking a non-traditional paths

to get to that goal.” To generate critical mass, the university invited local high tech start-ups, R&D units of larger firms, laboratories from the state government and research groups from the university into the incubator. The objective was to attract funds from the state and federal governments to develop new research centers.

The impetus to form the Center for Comparative Functional Genomics was initially the need to create a transgenic molecular biology facility for the biological sciences to build a support structure for research and to attract researchers by providing infrastructure. The director of the incubator said that, “When we started thinking about [organizing a center], we went to Taconic Biotech (a firm). They will do all the animal husbandry so we don’t have that headache.” Out of that effort came a center which was subsequently expanded into bio-informatics, microscopy, and biochemistry, all fitting under the heading of a center for Genomics.

The emerging role of the Albany incubator was to speed up the academic development process. Frederick Terman, who as Provost of Stanford University built that university into a research powerhouse during the early post-war by concentrating on “steeple of excellence,” or selected areas of faculty expertise, held that it took a generation to achieve academic distinction in a field. Several centers were organized along the themes of the university’s incubators, one in biotechnology and a second in the areas of micro-electronics, semi-conductors, computers, software, and atmospherics.

The Albany incubator encouraged intra-networking and inter-networking, knitting together organizations within and without the incubator. Thus, “Every research center is connecting with another research center is connecting with a company and the lines go in

every imaginable way. The reason is that they come up with projects by looking at their unique expertise, unique technologies and think ‘If we combine these two, we can go after joint funding.’

Since the region had various business and financial services available the primary objective of the incubator was to introduce its member firms to these services rather than to attempt to develop them within the incubator facility. Whether it makes sense for an incubator to develop its own services largely depends upon their availability within the surrounding region. A region that is rich in business development requisites such as venture capital may not have to develop them in direct association with the incubator. On the other hand, a region that is lacking such tools may find it necessary to develop them in association with the incubator project in order to achieve the goal of knowledge-based economic development. Thus, regions may be viewed as “thick” or “thin” depending upon the presence or absence of business development services. Whether it is necessary or useful for an incubator project to internalize such services depends upon their availability in the area.

An entrepreneurial ethos is a common characteristic of grant seeking academics and start-up firm founders. Whether the participants in the incubator were from an academic or business background, they shared a common culture. The facility was, “a place filled with very entrepreneurial people, both in the research centers, which are non-profit university, and in the companies. That is part of it; people running research centers are incredibly entrepreneurial but they are in a different business. But because they all have the same kind of creative outlook they find opportunities to work together.” Thus, the common assumption that academic and

business cultures are inevitably at odds is at least partially disproven.

ENTREPRENEURIAL UNIVERSITY

The development of economies has been viewed as an evolutionary process in which new combinations develop as old ones interact with each other. This is one way that innovation can take place, through “mutation” and “natural selection.” However, the difference between biological and social evolution is that as social actors we have the possibility of making an analysis of the environment and consciously introducing changes into it. We can invent new organizational models. This can especially be the role of the social sciences in the innovation process, to make an analysis of the gaps and also to make proposals and come up with new ideas for new types of organizations to fill the gaps.

The development of variants of the incubator model is a creative instance of “institution formation.” Innovation in the regulation of intellectual property created an environment that stimulated entrepreneurship in a broader range of academic institutions. In 1980, Congress created the virtual equivalent of a second “land grant” in the Bayh-Dole Act, turning over to the universities intangible intellectual property arising from federally supported academic research. Despite persisting tensions between teaching and research and ongoing conflicts between research and economic development, as each new activity has been incorporated into the university, ways have been found to make it more or less compatible with the others. This ability to take on new tasks has driven the expansion of individual schools and encouraged the development of distinctly different types of institutions of higher education.

One vision of the university of the future is as a generator of spin-

off enterprises, creating income and employment by infusing a local, regional, or national economy with a series of science based firms. The entrepreneurial university is also becoming an economically self-generating institution; it is shifting from being solely a donor-driven organization, entirely dependent upon other institutional spheres for its resources. The generation of economically relevant research allows the university a larger social space in which to negotiate the terms of its relationship to the larger society. These academic-industry linkages do not necessarily subordinate the university to other institutional areas of society. In fact, a reverse process is set in motion in which entrepreneurial universities increase their

benefits. A new “social contract” is drawn up between the university and government in which public funding for academic research is made implicitly contingent upon a more direct contribution to the economy. Eschewing the ideal of knowledge for its own sake as the sole goal of research, universities are becoming an increasingly significant factor of production in regional and national economies.

The sources of the capitalization of knowledge, past and present, and the changing values and practices of academic scientists in dealing with the practical implications of their research has been identified in the origins of modern science [14]. The creation of pathways between university and industry at M.I.T. in the late 19th and early 20th century and how the resolution of disputes over these ties became models for future relationships created an exemplar of the entrepreneurial university [6]. The Second Academic Revolution is the spread of relations with industry throughout the U.S. academic system, and world-wide.

The two academic revolutions often take place in tandem with each other as local and regional teaching institutions attempt to upgrade themselves into research universities. To foster knowledge-based economic development, industry and government alike have revised their view of the university. Their expectations have grown far beyond the provision of trained personnel, as universities have become a factor of production, translating intellectual property produced on campus into products and businesses. This transformation of the university into an engine of economic devel-

opment brings with it a shift in values that is still underway. Universities are becoming hybrid institutions, integrating the tasks of research, teaching, and economic development, in various combinations, with persisting tension over the appropriate balance among them. The university of the future will be part of a “triple helix” of university, industry, government relations to foster knowledge-based social and economic development [7].

The academic revolutions combine aspects of the Marxian and Kuhnian concepts of social and scientific revolution. In Marx’s theory of social revolution, capitalism lives on within the context of socialism, even as it is transformed. Despite each revision, the university retained its old tasks while taking up the new. On the other hand, in Thomas Kuhn’s view of scientific revolutions, the old mode of science is forgotten as it is displaced by the new. The innovations of successive eras — research and economic development — persist in tension with each other. In that respect the academic revolutions have been “Marxian” in style. There is also a certain loss of memory that the academic enterprise, especially in the sciences, was virtually a different species prior to the Second World War and the advent of federal research funding. In this respect the academic revolutions are akin to a Kuhnian paradigm shift.

As science displaces labor, land and machines as the underpinning of the forces of production, knowledge-producing institutions such as the university play a more central role in society. Scientific knowledge is becoming an increasingly important source of capital. As professors and university administrators take account of the economic potential of research on campus and orient themselves to its disposition, academic science is transformed from a cultural arti-

Faculty members and graduate students are learning to assess the commercial as well as the intellectual potential of their research.

status, legitimation and, in time, their access to public resources by virtue of their enhanced role in local economies.

The transformation of knowledge into an economic good is encouraged by government policy, the private sector, and universities themselves. Universities are assuming tasks in the development of new technology that were formerly the province of industry. Since the end of World War II, government has funded scientific research in the universities, apart from military and health research, with the expectation of long term

fact consumed by other scientists into a valuable object or commodity that can be utilized to generate future income. When scientific knowledge is appropriated, whether by scientists or others, to generate income, science itself is transformed from a cultural process that consumes the surplus of a society into a productive force that generates new income out of an aspect of culture. The capitalization of knowledge affects the material conditions of scientists in the universities as well as the inward calling of science.

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