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INNOVATON AND EMULATION: LESSONS FROM AMERICAN UNIVERSITIES IN SELLING PRIVATE RIGHTS TO PUBLIC KNOWLEDGE

ABSTRACT. American universities are purported to excel at technology transfer. This assumption, however, masks important features of American innovation. Attempts to emulate the US example must recognize the heterogeneity of its industries and institutions of higher education. Stanford University and the biomedical cluster in Boston, Massachusetts, illustrate the diversities that characterize this dynamic system.

Introduction

On 18 July 2005, Emory University of Atlanta, Georgia, and Gilead Sciences, a biotechnology firm in Foster City, California, announced that Gilead would make a payment of $US525 million to Emory for all rights to emtricitabine, also known as Emtriva. Emtricitabine, marketed by Gilead, was identified by three Emory scientists, and approved by the US Food and Drug Administration for HIV treatment in July 2003. Emory's president, Dr. James Wagner, commented that: 'We feel privileged and humbled to receive such extraordinary recognition for the value of our intellectual property'.[1]

In April 2000, the University of Rochester was awarded a patent for the use of the entire class of drugs known as cox-2 inhibitors, or 'super aspirins' – such as Celebrex and Vioxx. The University believed that its patent entitled it to royalties on all cox-2 medicines, and promptly filed infringement suits against Searle and Pfizer, the joint marketers of Celebrex. The strategy of sue first, but attempt to negotiate triggered a high-profile legal case, as estimates

[1] Quoted in press release, 18 July 2005 at http://www.news.emory.edu/Releases/emtri/. Accessed 28 August 2005.

of the value of Rochester's patent ran into the billions.[2] A Rochester biochemist, Donald Young, had done initial research on cyclooxygenase in the 1960s, and in the early 1990s, identified the gene that is responsible for producing cox-2. Subsequently, Rochester researchers developed a method to test for selective inhibition of cox-2. In 2000, after eight years of review, the US Patent and Trade Office granted Rochester a broad patent for cox-2 inhibition. But hopes for millions in royalties were dashed in March 2003, when a Federal district judge ruled that the University's sweeping claims to anti-inflammatory drugs were invalid, arguing its patent for a method did not describe a particular compound.

Recent successes and close calls such as these have triggered a gold rush. In the United States of America, universities have embarked on all manner of commercial ventures, while across the Atlantic, the European Commission has encouraged universities to engage with industry.[3] Following the Single European Act of 1987, in a climate of anxiety about competitiveness in science and technology-based industry, numerous programmes have been developed to encourage productive relations between universities and firms. Over the past ten years, European universities have also been pressed to diversify their sources of funding.[4] Many initiatives are underway in Europe and the USA to foster local economic development and increase revenues, including science parks, venture funds, intermediary organizations that assist in technology transfer, start-up companies, and legal reforms.

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[2] See University of Rochester Medical Center press release, 12 April 2000 at http://www.urmc.rochester.edu/Cox-2/pr.html. Accessed 6 September 2005; David Malakoff, 'Patent Headache for Rochester University', *Science Now* (11 March 2003) at http://sciencenow.sciencemag.org/cgi/content/full/2003/311/4. Accessed 6 September 2005; Seth Shulman, 'A Painful IP Ruling', *Technology Review,* 105 (5), (June 2003), 75; and Rakesh Mehta, 'University of Rochester Corp. v. G.D. Searle and Co., Inc.: '"How to Lose Millions in Patent Royalties"', Delaware Journal of Corporate Law, 29 (2), (2005), 547–585.

[3] For example, a 2003 communication from the European Commission contended that universities in Europe are lagging in acquiring intellectual property (IP) title to research results, and are not transferring technology to industry via licensing. 'A major obstacle to better application of university research results is the way intellectual property issues are handled in Europe. Another factor is the lack of familiarity of many university staff with the economic realities of research, particularly issues regarding intellectual property.' European Commission (com 58 final 2003), 'The Role of Universities in the Europe of Knowledge', 15–16. However, this embrace of intellectual property comes with little thought of potential risks. Guena and Nesta comment that 'the policy literature seems committed to hoping for the best and avoids the pessimism in thinking about the probable'. See Aldo Guena and Lionel Nesta, 'University Patenting and its Effects on Academic Research: The Emerging European Evidence', *Research Policy*, 35 (6), (2006), 790–780.

[4] Guena and Nesta, *ibid.*

This paper examines the standard explanations for the purported success of US research universities at technology transfer, and suggests that 'policy borrowing' may be misinformed. Drawing upon interviews with scientists and administrators, we offer an account that stresses competition and decentralization, institutional diversity, and the organization of scientific careers. Attempts to emulate policies must recognize the distinctive institutional features of the US system. We illustrate two auspicious examples of successful technology transfer, and conclude with cautionary remarks about potential dangers that accompany too close an embrace of industry.

The Conventional Wisdom

There is little doubt that US universities are focused on commercialization. Since 1980, patents assigned to research universities have increased by more than 850%.[5] Much of this increase is based on the life sciences. In 1976, just under 18% of university patents were related to biomedical research; by 1998, this had climbed to more than 46%.[6] Over this period, licensing income grew, the number of university spin-off firms increased, and patents are now treated as commensurate with publications. Increasingly, academics list patents on their resumes, and universities trumpet their intellectual property.[7]

Patents serve as fences, and their reward is pecuniary.[8] They are based on a legal fiction of novelty, usefulness, and non-obviousness. In return for disclosure, the inventor or the assignee is granted proprietary rights. Hence, patents represent a toll booth.

[5] Jason Owen-Smith, 'Public Science, Private Science: The Causes and Consequences of Patenting by Research One Universities', (Unpublished PhD dissertation, Department of Sociology, University of Arizona, 2000); Jason Owen-Smith, 'From Separate Systems to a Hybrid Order', *Research Policy,* 32 (6), (2003), 1081–1104; and Rebecca Henderson, Adam B. Jaffe, and Manuel Trajtenberg, 'Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting 1965–1988', Review of Economics and Statistics, 80 (1), (1998), 119–127.

[6] Carol Ganz-Brown, 'Patent Policies to Fine Tune Commercialization of Government Sponsored University Research', Science and Public Policy, 26 (6), (1999), 403–414.

[7] In a recent affirmation of this trend, Texas A&M University Regents voted unanimously to consider patents and research commercialization efforts in tenure reviews. Sara Lipka, 'Texas A&M Will Allow Consideration of Faculty Members' Patents in Tenure Process', *Chronicle of Higher Education,* 52 (40), (9 June 2006), A12.

[8] Arie Rip, 'Mobilizing Resources Through Texts', in Michel Callon (ed.), *Mapping the Dynamics of Science and Technology* (Basingstoke: Macmillan Press, 1986), 84–99; Kathryn Packer and Andrew Webster, 'Patenting Culture in Science', *Science, Technology, and Human Values*, 21 (4), (1996), 427–453.

By contrast, academic science is based on information sharing, and the rewards of open science are reputational. This is seen as critical to the growth of knowledge.[9] The reward systems of patenting and publishing differ, but American universities measure their accomplishments in terms of both.

The growing commercialization of academic science is reflected in the creation of technology transfer offices by American universities. These were unusual prior to 1980, when there were fewer than twenty, but by 2000, there were more than 200.[10] They were soon accompanied by a professional association, the Society of University Patent Administrators (SUPA), now the Association of University Technology Managers (AUTM). AUTM had nine members in 1975, but more than 3,500 by 2005, including many from the private sector and from universities outside the USA.[11] Over the years, university licensing income has also increased sharply, from $US123 million in 1991 – the first year reported by AUTM – to slightly more than $US1 billion in 2002.[12] This heightened attention is captured by a biology professor whom we interviewed:

> Patents are much more an issue now. Twenty years ago the chances that basic research, no matter how beautiful and fundamental, would have recognizable commercial potential was relatively low. That's less true now. Patenting is more on everyone's radar screen.[13]

A conventional story has emerged to explain this transformation. One element depicts a virtuous cycle, in which universities play a key role as engines of growth, stimulating regional economic development and fostering technology clusters. In 1999, a front page story in the *New York Times* proclaimed, 'Across America, high technology is creating localized boomlets, like the one in Kendall Square, Massachusetts, which is home to companies not only in the biotech sector,

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[9] For further discussion of open science, see Robert K. Merton, *The Sociology of Science* (Chicago: University of Chicago Press, 1973); Michael Polanyi, 'The Republic of Science: Its Political and Economic Theory', *Minerva,* (1) (1962), 54–74; Diana Crane, *Invisible Colleges* (Chicago: University of Chicago Press, 1972); Derek de Solla Price, *Little Science*, Big Science (New York: Columbia University Press, 1963); and Partha Dasgupta and Paul David, 'Towards a New Economics of Science', *Research Policy,* 23 (5), (1994), 487–521.

[10] David Mowery, Richard R. Nelson, Bhaven N. Sampat, and Arvids Ziedonis, *Ivory Tower and Industrial Innovation* (Stanford: Stanford University Press, 2004).

[11] Jon Sandelin, 'A History of the Association of University Technology Managers', commissioned by AUTM and available from the author at Stanford's Office of Technology Licensing.

[12] Annual Report, Association of University Technology Managers, 2002.

[13] Interview with Professor of Biology, Private University, 10 March 2000. Staff members were promised anonymity in return for open discussion of the commercialization of science.

but also in software and related fields.'[14] The story went on to document how biotechnology has blossomed in what were once decaying factories, becoming the most concentrated cluster of biotechnology firms in the world, with close ties to the Massachusetts Institute of Technology, the Whitehead Institute, and Harvard University.

Such vibrancy has spurred politicians and investors. University involvement in business has become an important resource, both tangibly and symbolically. To the extent that university-based invention and discovery highlights their role as engines of economic development, universities are recast as motors of the economy.[15] Such a lofty status has strong cachet; in the words of an NSF program director, 'universities have become both a resource and a catalyst to economic innovation'.[16]

The co-mingling of technology-based companies and universities has had important consequences. A handful of thriving clusters, such as Kendall Square in Cambridge; the Research Triangle in North Carolina; Austin, Texas; and Silicon Valley in California, have altered the ambitions of nearly all US universities from knowledge incubators to market partners. As a consequence, the commercialization of science has become not just acceptable, but a key part of the mission of US universities. This transformation has occurred over a relatively short period, involving a wide array of participants, and a new set of practices and categories has become institutionalized.[17]

The second part of the story is the claim that the USA has its legislation right. Over the past three decades, an intellectual property regime has encouraged university entrepreneurship. *The Bayh-Dole Patent and Trademarks Act of 1980* (PL 96–517), which gave permission to those performing federally funded research to file for patents and to grant licensees to others, was the turning point. This legislation facilitated university patenting and licensing in several ways. First, it replaced individual agreements with a uniform policy. Second, it conveyed Congressional support for the negotiation of licences between universities and firms, and encouraged the

[14] Carey Goldberg, 'Across the Country, Universities Generate a High-Tech Economic Boom', *New York Times*, 8 October 1999, 1.

[15] Irwin Feller, 'Universities as Engines of R&D Based Growth: They Think They Can', Research Policy, 19 (4), (1990), 335–348.

[16] Daryl E. Chubin, 'How Large an R&D Enterprise?' in D.H. Guston and K. Kenniston (eds.), *The Fragile Contract: University Science and the Federal Government* (Cambridge, MA: MIT Press, 1994), 118–144.

[17] Jeannette Colyvas and W. W. Powell, 'Roads to Institutionalization: The Remaking of the Boundaries Between Public and Private Science', *Research in Organizational Behavior,* 27 (2006), 315–363.

transfer of federally funded research results. Third, it signalled a change in policy away from a fear of the exploitation of public funds, and towards the acceptance of strong intellectual property rights.[18]

Many have seen the Bayh-Dole Act as critical in the commercialization of science. Jonathan Cole, Provost of Columbia University, referred to Bayh-Dole as 'prescient', and emphasized its role in spurring universities to commercialize their basic science.[19] In 2002, *The Economist* called the Bayh-Dole Act 'possibly the most inspired piece of legislation to be enacted in America over the past half century. More than anything, this single policy measure helped reverse America's precipitous slide into industrial irrelevance'.[20] Rebecca Zacks, in acknowledging former Senator Bob Dole's role as a spokesman for Viagra, noted that the Bayh-Dole Act turned out to be

> Viagra for campus innovation.... Universities that would have previously let their intellectual property lie fallow began filing for, and getting, patents at unprecedented rates. Coupled with other legal, economic, and political developments that also spur patenting and licensing, the result seems nothing less than a major boon to national economic growth.[21]

Indeed, it is precisely the Bayh-Dole Act that the OECD and the European Commission repeatedly cite when they promote ownership and exploitation of academic inventions.[22] An OECD report suggested in 2002 that such legislation 'provides greater legal certainty, lowers transactions costs, and fosters more and efficient channels for technology transfer'.[23]

The conventional wisdom also cites the role played by venture capital (VC). European start-up companies face difficulties in raising capital. As a US-born chief executive of a British-based wireless company puts it, 'The biggest challenge is funding. We could have been three years further ahead at this point if it had been easier to find adequate funding. European technology is fine but companies fail because they are underfinanced.'[24] In some cases, universities

[18] Maryann Feldman and Pierre Desrochers, 'Truth for Its Own Sake: Academic Culture and Technology Transfer at the Johns Hopkins University', *Minerva,* 42 (2), (2004), 105–126.
[19] Jonathan Cole, 'Balancing Acts: Dilemmas of Choice Facing Research Universities', *Daedalus,* 122 (4), (1993), 1–36.
[20] 'Innovation's Golden Goose', *The Economist*, 14 December 2002, 3.
[21] Rebecca Zacks, 'The Technology Review University Research Scorecard 2000', *Technology Review*, 103 (4), (2000), 88–90.
[22] By 2000, Austria, Denmark, and Germany, as well as Japan, had abolished the so-called 'professor's privilege' that granted academics the right to own patents, and transferred ownership to universities.
[23] OECD, *Benchmarking Science–Industry Relationships*, (Paris: OECD, 2002), 3.
[24] David Wither, CEO of Sarantel, quoted in Alan Cane, 'FT Series: Reforming Europe, Exploiting Ideas: Why Progress Requires Ambition and Risk', *Financial Times*, 10 March 2005.

have used their endowment income to create venture funds. In Germany and Sweden, public monies have been transformed into venture funds, and risks have been taken with pension funds. These moves worry analysts, who emphasize that advising, monitoring, and managing are the key elements. Moreover, venture capital is remarkably concentrated. In biotechnology, for example, nearly half of all investments occur within a thirty-minute drive of the venture capitalist's home office.[25]

These three factors – economic ambition, favourable legislation, and venture capital – are taken to explain the successful marketing of American university science. Thus, these have been promoted around the world.

An Amended View

When organizational practices travel, their successful transfer depends on local circumstances.[26] David Mowery and Bhaven Sampat observe that emulation is common in technology policy.[27] They point to a well known example of R&D collaboration – Sematech R&D Consortium – established in Austin, Texas, in 1987. Sematech was created in response to Japanese advances in semiconductors. In the 1990s, Japan developed R&D consortia, copying US and European programmes that were based on Japanese models. But isomorphism, or organizational borrowing, is often selective, and can fail to recognize local contingencies.[28]

Successfully emulating US technology policy depends upon understanding the nature of US higher education. Mowery and colleagues have shown that university patenting began well before

[25] W. W. Powell, K.W. Koput, J.I. Bowie, and L. Smith-Doerr, 'The Spatial Clustering of Science and Capital: Accounting for Biotech Firm – Venture Capital Relationships', *Regional Studies,* 36 (3), (2002), 291–306.

[26] See, for example, Barbara Czarniawska and Guje Sevón (eds.), *Translating Organizational Change* (New York: deGruyter, 1996); Hokyu Hwang and W.W. Powell, 'Institutions and Entrepreneurship', S. Alvarez, R. Agrawal, O. Sorenson (eds.), *Handbook of Entrepreneurship Research* (New York: Springer, 2005), 179–210.

[27] David Mowery and Bhaven Sampat, "The Bayh-Dole Act of 1980 and University–Industry Technology Transfer: A Model for Other OECD Governments?' Working Paper, 2004.

[28] For a broader discussion of organizational borrowing, see Paul DiMaggio and Walter W. Powell, 'The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields', *American Sociological Review*, 48 (2), (1983), 147–160.

Bayh-Dole.[29] Indeed, university involvement in commercial activities would probably have increased without legislation.[30] However, proficiency at commercialization is unevenly distributed. Figure 1 shows that the ten most active US universities account for the lion's share of growth in patenting. Royalty income derived from licences is similarly skewed, with a small number of universities garnering most revenues. Indeed, most university technology transfer offices barely break even, once full costs are taken into account.[31]

Profits from the sale of intellectual property (IP) are precariously dependent upon a handful of blockbusters. Some research administrators describe their strategies in the language of baseball – 'swinging for the fences', hoping for a spectacular 'home run', – such as Emory University's success with Emtriva. The Vice President for Research at a large public university has commented that

> What you want is one really big winner, and then you can reinvest and build some other winners off that. Then you are out of the gate. Eventually, we are going to hit one. We've got a bunch of technologies that, I think, have a one billion a year projected market. Everybody needs to get their first big hit; we just haven't had it yet.[32]

But it is difficult to identify blockbusters *ex ante*; and such patents often protect a technology that requires extensive development by a commercial partner.

To illustrate the importance of blockbusters, Figure 2 shows data on Stanford University's five most lucrative licences over the period 1970–2000. According to a 2002 survey of the Association of University Technology Managers, Stanford rated among the top five universities in several performance metrics, including licence income received, invention disclosures, US patents issued, start-up companies formed, and licences executed with equity. Even at Stanford, however, only about 25% of invention disclosures make it to the licensing stage, and many active licences fail to earn net income. Looking at figure 2, a mere five licences accounted for nearly 72% of more than $450 million dollars in revenues generated by Stanford's technology transfer activity over the thirty-year period. The

29 Mowery, *et al.*, *op cit*, note 10.

30 Rebecca Eisenberg, 'Public Research and Private Development', *Virginia Law Review*, 82 (8), (1996), 1663–1727.

31 D. Trune and L. Goslin, 'University Technology Transfer Programmes: A Profit/Loss Analysis', *Technological Forecasting and Social Change*, 57 (3), (1998), 197–204; Bob Mullins and Jan Crowe, 'Technology Transfer: A Road Map', *College and University Auditor*, 43 (1), (1999), 4–17.

32 Interview with public university vice president, 17 November 1999.

Figure 1

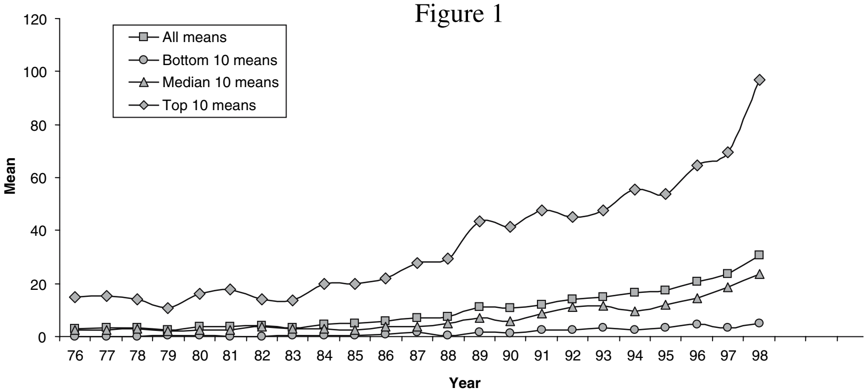

Figure 1. Patenting Success is Highly Stratified: Yearly Means – Top, Median, and Bottom Ten Overall Patenting Universities.

Figure 2

INVENTION	REVENUES	% OF TOTAL REVENUES
1.) Process for the construction of biologically functional molecular chimeras (1974) ***1979***	**$254,782,500**	**56%**
2.) Fluorescent conjugates for analysis of molecules and cells (1981) ***1981***	**$30,791,762**	**7%**
3.) FM sound system (1971) ***1979***	**$22,903,124**	**5%**
4.) Tiny Tera (1997) ***1998***	**$9,536,399**	**2%**
5.) Computer X-ray section scanner (1974) ***1975***	**$8,908,172**	**2%**
Total, top 5	**$326,921,958**	**72%**
Total, all inventions, 1970–2000	**$453,685,418**	**100.00%**

Figure 2. Blockbuster Successes Account for Large Percentage of Total Revenues: Five Most Successful Stanford University Licences, and Their Share of Cumulative Licensing Revenue. (Source: Stanford University Office of Technology Licensing.)

date, in bold type, indicates the first year that royalty income was received. The Cohen-Boyer gene-splicing invention had a five-year lag before revenues were obtained, and the frequency modulation sound system took eight years. Three of these innovations occurred, and one was in the works, before the Bayh-Dole Act was passed.

Most university technology transfers take place in the life sciences, hence the emergence of the biotechnology industry played a decisive role. Drawing lessons from this distinctive realm to other areas is risky. Moreover, data from AUTM show that the revenues generated by technology licensing pay only a small fraction – typically less than 5% – of the overall costs of university research. It is important to ask whether the same results might have taken place in the absence of any legislation, and whether 'new' policies merely augmented and standardized a set of existing practices.

Given the current emphasis on IP ownership, it is useful to assess the broader consequences of legislation that has encouraged the privatization of science. Donald Kennedy, former President of Stanford and currently editor-in-chief of *Science*, has observed that interpretations of the Bayh-Dole Act differ in tandem with other values: 'To those who had worried about technology transfer, it's a huge success. To others, who expressed concern about university/corporate relations or mourn the enclosure of the scientific 'knowledge commons', it looks more like a bad deal.'[33] Perhaps the best way to approach this situation is to recognize two facts: that there are multiple channels for university–industry relations; and that there is strong inter-industry variation in the use of technology. Let us look at each in turn.

Many US research universities and industrial partners have long standing relationships.[34] However, most such relationships flourish in the early stages of technology development. The life sciences are an important exception, where universities continue to play a fundamental role long after discoveries are commercialized. Linkages include the circulation of papers, the hiring of graduates, consulting, conferences, gifts, the exchange of research instruments, the use of academics on advisory boards, and co-patenting. Note that most of these relationships depend on open science. In her work on tissue engineering, Fiona Murray has chronicled how non-proprietary contacts promote knowledge transfer and contribute to a densely connected technological community.[35]

[33] Donald Kennedy, *Science*, 307 (4 March 2005), 1375.

[34] See Richard R. Nelson and Nathan Rosenberg, 'American Universities and Technical Advance', *Research Policy*, 23 (3), (1994), 323–348; Roger L. Geiger, *To Advance Knowledge: The Growth of American Research Universities, 1900–1940* (New York: Oxford University Press, 1986).

[35] Fiona Murray, 'Innovation as Co-evolution of Scientific and Technological Networks', *Research Policy*, 31 (8–9), (2002), 1389–1402; Fiona Murray, 'The Role of Academic Inventors in Entrepreneurial Firms', *Research Policy*, 33 (4), (2004), 642–659.

There are, however, important inter-industry differences in university–industry contacts. In many fields, basic research is commercialized only after a considerable lag. Many scientific advances have to first be incorporated into technology before commercial value can be realized. Research has shown that publications, the supply of trained labour, conferences and informal interactions are the most important forms of contact.[36] Only in the biomedical sector is importance assigned to obtaining patents and licensing agreements.

Thus, the US system for transferring science into application has evolved in a distinctive context, in which relations between universities and industry are often informal and non-contractual. Three features of this system are critical – its restless and decentralized nature, its diversity, and its career structure.

Higher education in the USA is decentralized and competitive. Government, industry, and foundations support research, and tuition, gifts, and endowments reduce dependence on government. Even American public universities, such as the University of Michigan which styles itself as 'state-assisted', increasingly find that government support now makes up less than 25% of their operating budgets.

Jason Owen-Smith has drawn upon the idea of cumulative advantage to argue that US higher education has a pecking order.[37] Robert Merton famously characterized the 'rich-get-richer' dynamic of scientific accomplishments in biblical terms.[38] The process of increasing returns, attracting staff and students, and strengthening university–industry relations leads to a concentration of resources, revenues, and reputation. Those who want to emulate the USA example should be mindful of the way in which a competitive funding system, drawing upon multiple sources, has also led to enduring patterns of institutional inequality.

The organizations that comprise the US innovation system are institutionally diverse, including public and private universities, large and small firms, non-profit institutes, research hospitals, and government laboratories. When market conditions are poor, the

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36 Richard C. Levin, A. Klevorick, R.R. Nelson, and S.G. Winter, 'Appropriating the Returns from Industrial Research and Development', *Brookings Papers on Economic Activity*, 3 (1987), 783–820; Wesley M. Cohen, R.R. Nelson, and J.P. Walsh, 'Links and Impacts: The Influence of Public Research on Industrial R&D', *Management Science,* 48 (1), (2002), 1–23.

37 Owen-Smith, *op. cit*., note 5.

38 Robert K. Merton, 'The Matthew Effect in Science', *Science*, 159 (3810), (5 January 1968), 56–63; 'The Matthew Effect in Science 2: Cumulative Advantage and the Symbolism of Intellectual Property', *Isis*, 79 (4), (1988), 606–623.

public sector is buffered; when public funding lags, private initiatives grow. These competing systems, with divergent politics and economic criteria, function in counterpoint, and their productive tensions foster innovation.

The third element of the US system involves the organization of careers. The US system is essentially a 'sink or swim' model in which young researchers are given a great deal of discretion. There is considerable job mobility; few take jobs at universities where they receive their PhDs, and moving to win promotion is common. Research and teaching are closely integrated in the USA, and for medical school staff, clinical activities are combined as well. There is considerable fluidity between basic and goal-oriented research, and a mixing of disciplines.[39]

These factors combine to create a system that is highly decentralized, but stitched together by overlapping networks that encourage movement across organizations and roles. The reputation-driven nature of the system creates a 'winner-take-most' dynamic in which resources, promising students and staff, and new ventures gravitate to centres of success. This process of accumulative advantage stratifies outcomes – individually, organizationally, and regionally.

Local Features Of Technology Transfer

We turn now to two cases of successful university technology transfer, both of which have generated widespread interest. The first is at Stanford, one of the earliest to create an office of technology licensing. The second is the cluster of biomedical activities located in Cambridge, Massachusetts. Both illustrate the gains to be had from diversity, fluidity, and experimentation.

Stanford's Office of Technology Licensing (OTL) was founded in 1968 by a former aerospace engineer who had worked in the university's sponsored research office, and believed there were opportunities to capture benefits from academic research. Neils Reimers, the OTL's founder, went on to a remarkable career in university licensing, from advising MIT and the University of California, San Francisco, to consulting with universities and governments worldwide. Meanwhile, Stanford's OTL grew rapidly.

[39] See Michele Gittelman, 'Mapping National Knowledge Networks: Scientists, Firms, and Institutions in Biotechnology in the United States and France' (Unpublished PhD dissertation, University of Pennsylvania, 2000); M. Morange, *A History of Molecular Biology* (Cambridge, MA: Harvard University Press, 1998).

By 1980, it had annual revenues of more than $US1 million, and had, to its credit, two inventions that would prove to be among the university's most lucrative and best known.

Reimers decided that Stanford 'would have an office that was primarily a marketing organization and would contract out its legal work'. As he later recalled, 'my idea was to focus on the forest of collaboration between researchers and industry, not on the trees of a patent claim; that is, we could have an agreement in place before a patent even issued.' Another of his ideas was to write the agreements in plain English rather than 'legalese'.[40]

By 2005, the OTL had more than twenty-five employees and annual gross income of nearly $US50 million. The office never employed attorneys for licensing work, opting instead to rely upon outside counsel. The Stanford office viewed technology transfer as a means to build relationships. Indeed, its current director, Katharine Ku, sees the licensing agreement as the beginning of a relationship that can last many years. Not only is it important for licensing associates to understand the technology, the market, and the strengths of the technology; they must also have a direct hand in negotiations. Ms Ku has observed that:

> The lack of attorneys was a totally conscious decision. We think of ourselves as a business office. We think that lawyers are trained to be risk averse and so our founding director, Neils Reimers, felt strongly against hiring them and I fundamentally agree. We feel that our agreements represent business relationships rather than legalistic ones. Even the good licenses and relationships are going to require modification along the way. We take a much more Japanese attitude, which is to say that the license is the beginning of an ongoing relationship, and if the situation changes, we can always renegotiate. We renegotiate a lot.[41]

A number of other key decisions also influenced policy. In the case of the Cohen-Boyer gene-splicing discovery, Reimers negotiated institutional patent agreements with different funding bodies. He recalls:

> We got the inter-institutional agreement with the University of California worked out. The research at Stanford had been sponsored by the National Institutes of Health, and by the National Science Foundation and the American Cancer Society at the University of California at San Francisco. The American Cancer Society had never released rights in an invention before. So I contacted them and explained the situation. I said that what I would like to do is have it managed under our institutional patent agreement with the NIH. And I explained the patent

[40] All quotations from Eric Grunwald, 'OTL Turns 25 But Doesn't Get a Break on Insurance', *Stanford Technology Brainstorm,* (5) (1), (1996), 1–4. This is a quarterly publication of the OTL.
[41] Interview with Katharine Ku, Director, OTL, Stanford University, 6 November 2004.

system and how the net returns would go back into research. They eventually agreed.[42]

Reimers was not convinced that this gene-splicing invention could turn out to be something big, observing:

I didn't know much about it. Because a great excitement was developing regarding this area, I maintained from the beginning this work of Cohen and Boyer might underlie the whole field of biotechnology. I repeated it and I repeated it. When I first went licensing, a lot of companies, the business people, they didn't really understand the technology. They had just been reading about its potential, so we had to go through a tutorial as well.[43]

So the OTL built connections and deepened relationships. By contrast, many technology-transfer offices at US universities are staffed by patent attorneys, who focus more on contracts, and less on relationship building.[44]

One of Stanford's most remunerative inventions is the fluorescence-activated cell sorter (FACS) developed in the 1970s, which enabled scientists to sort and count cells with fluorescent tags, initially at a rate of 10,000 cells per second.[45] The FACS grew from a multidisciplinary collaboration between Leonard and Leonore Herzenberg in genetics, engineers and technicians in a Stanford electronics lab, and Becton-Dickinson (BD), a commercial firm, with support from the National Cancer Institute. Initially, there was little faith in its commercial viability. Leonard Herzenberg recalls that Bernie Shoor, the BD representative who sought help in making antibodies, felt that 'maybe we could sell 10 of these instruments worldwide'.[46] Herzenberg's aspirations were not much higher, '30, or possibly as high as 100 sales were more likely, but neither number seemed high enough to support turning the FACS into a commercial machine'.[47]

But the relationship continued, spurred more by the enthusiasm of the Herzenbergs and Shoor than any sign of commercial opportunity; and two prototypes were built, one for Stanford and one

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[42] Neils Reimers, Regional Oral History Office, The University of California Berkeley Bancroft Library, 1997. Available from the online archive at http://content.cdlib.org/xtf/view?docId = kt4b69n6sc&doc.view, 8.

[43] *Ibid*, 11.

[44] Lawrence M. Fisher, 'The Innovation Incubator: Technology Transfer at Stanford University', *Strategy and Business*, 13 (4), (1998), 76–85.

[45] Jeannette Colyvas, Annetine Gelijins, and Nathan Rosenberg, 'Intellectual Property Rights and Academic Health Centers', in O. Granstrand (ed.), *Economics, Law, and Intellectual Property* (Dordrecht: Kluwer, 2003), 166–170.

[46] Leonard A. Herzenberg and Lenore A. Herzenberg, 'Genetics, FACS, Immunology, and Redox: A Tale of Two Lives Intertwined', *Annual Review of Immunology*, 22 (2004), 15.

[47] *Ibid*, 15.

for the National Cancer Institute. Eventually, a remarkable array of flow cytometry technologies was developed, dozens of Stanford PhDs went to work at BD, and BD supported research at Stanford. The FACS machine eventually generated $US4.8 million in licensing revenues for Stanford. Had the initial decision been based on a transactional assessment, the synergies between the Herzenbergs, Stanford, and BD would not have been realized.

Another advantage of having early, unexpected successes like the Cohen-Boyer patent and the FACS is that the hefty revenues mitigate the need for blockbusters. This cushion helped the OTL pursue an array of staff members with promising research programmes, including younger faculty, as well as post-docs and graduate students, which contributed to a favourable impression of the OTL across the campus.

In the 1980s, the OTL opted to forego annual licensing income from start-up companies. Typically, with an open licence for a major invention, there is an initial payment and an annual fee. However, the OTL decided that, with firms involved in ongoing collaborations with Stanford, they would forego the fee in return for a small percentage of proceeds from work based on the patent. In the case of Cohen-Boyer, this proved profitable. While most small start-up companies that used the Cohen-Boyer patent never developed medical products, 77% of the total revenues from Cohen-Boyer – which exceeded $US250 million, shared between Stanford and the University of California at San Francisco (UCSF), and administered by Stanford – came from just ten companies, seven of which were recent start-ups.[48] These younger firms were among those from which Stanford had chosen not to require a licence fee.

We turn now to Cambridge and Boston, home to the largest concentration of dedicated biotechnology companies in the world. Boston has a rich array of public research organizations, including Harvard, MIT, and Tufts; research hospitals, such as Brigham and Women's, and Massachusetts General; and medical institutes like the Dana Farber Cancer Center. During the 1990s, the Boston area also developed an active venture capital sector that helped biotechnology companies. By 2001, Kendall Square in Cambridge was home to a thriving cluster of biotech and pharmaceutical firms, as well as MIT and the Whitehead Institute for Biomedical Research,

[48] Maryann Feldman, Alessandra Colaianni, and Kang Liu, 'Commercializing Cohen-Boyer 1980–1997', DRUID Working Paper No. 05–21. Available at http://www.druid.dk/wp/pdf_files/05–21.pdf.

an international leader in the Human Genome Project. Recently, pharmaceutical firms, such as Pfizer and Novartis, have moved their R&D facilities to Kendall Square, as has the Los Angeles-based biotech company, Amgen. By one account, the Boston region in 1999 had a total of fifty-seven independent dedicated biotech firms, nineteen public research organizations (including universities and hospitals), and thirty-seven venture capital firms, linked by an network of relationships.[49]

The first burst of biotech start-ups in Boston took place in the late 1970s and early 1980s, long before venture capital became prominent. Unlike California, where biotechnology was seen as the new alchemy, Massachusetts saw debates over the possible dangers. In the summer of 1976, the city of Cambridge banned research involving DNA, fearing it would contaminate the local water supply. By 1977, the city council overturned this ban, but in the interim, Harvard researcher, entrepreneur, and Nobel laureate Walter Gilbert had moved his work to the United Kingdom. One of Cambridge's most notable biotech firms, Biogen, co-founded by Gilbert, established its legal charter in Switzerland to avoid American restrictions. The controversy boiled over again in the early 1980s, when there was much debate at MIT over the creation of a non-profit research centre, the Whitehead Institute, which was bankrolled by private industry.

The comparative absence of venture capital in Boston stamped biotechnology in notable ways. Three of the early firms – Biogen, Genzyme, and Genetics Institute – followed unusual trajectories. After its Swiss beginnings, Biogen settled in Cambridge, where it followed a strategy of licensing projects to large pharmaceutical companies, rather than pursuing its own independent path, like its rivals in California. Genzyme was much influenced by 'refugees' from Baxter, the healthcare corporation, notably its blood plasma division.[50] However, Genetics Institute (GI) followed the more upstart approach of California biotechs, and attempted to develop a genetically engineered biotech alternative to an existing pharmaceutical product for heart attacks. But GI lost out in this race to the Bay Area firm, Genentech, and was subsequently acquired by the

[49] Jason Owen-Smith and Walter W. Powell, 'Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community', *Organization Science,* 15 (1), (2004), 5–21.
[50] Cynthia Robbins-Roth, *From Alchemy to IPO* (New York: Perseus, 2000); Monica Higgins, *Career Imprints* (Boston: Harvard Business School Press, 2005).

large pharmaceutical firm, American Home Products.[51] Still, GI scientists refused to accept the loss of autonomy, and continued to publish and patent under the GI name. Eventually, American Home Products and Wyeth merged, and GI re-emerged as the biotech branch of Wyeth.

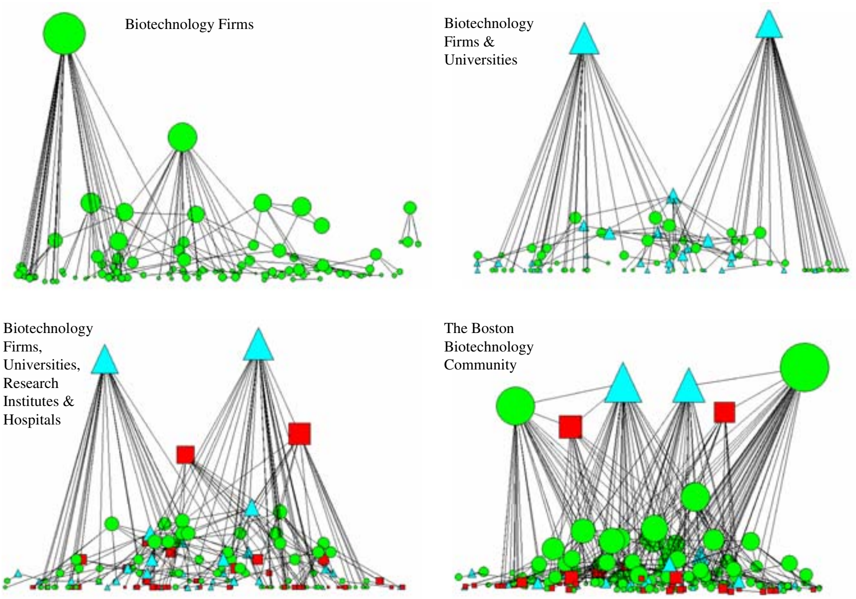
As part of a larger project on the evolution of the life-science industry over the past two decades, we have collected detailed data on formal and informal collaborative networks in Boston.[52] Our database includes information on the founding teams, strategic alliances, science boards, and inventors that today constitute a community of practice. Our most striking finding is that public research organizations were the foundation on which the Boston community was built. For example, more than half of the 131 people involved in creating biotech companies between 1980 and 1997 are academics, and the large majority (48 of 67) are from Boston-area universities. Of these, nearly all retained some form of university affiliation. None of the six scientists who started Biogen left their academic jobs. Only 34% of company founders worked full time for their companies. The others held part-time jobs, retaining positions at their 'home' organization. The founders were also locally based, with few coming from outside the region.

In Boston, public research organizations – including MIT, Boston University, Tufts University, Harvard University, the Dana Farber Cancer Center, Massachusetts General Hospital, and the New England Medical Center – are well connected. In 1988, Boston's biotech network depended upon these organizations and four early companies, Biogen, Genetics Institute, Genzyme, and Seragen. If the public organizations are removed, the network

[51] Walter W. Powell and Peter Brantley, 'Magic Bullets and Patent Wars: New Product Development and the Evolution of the Biotechnology Industry', in T. Nishiguchi (ed.), *Competitive Product Development* (New York: Oxford University Press, 1996), 233–260.

[52] These include the formal contractual ties – R&D partnerships, licensing, finance, and commercial development – involving biotech firms and their partners, as well as the scientific advisory boards of Boston companies, and co-patenting activity between universities, research hospitals, and Boston-area biotech companies. For further discussion of the data, see Kelley Porter, 'You Can't Leave Your Past Behind: The Influence of Founders' Career Histories on their Firms' (Unpublished PhD dissertation), Department of Management Science and Engineering, Stanford University (2004); Walter W. Powell, Douglas White, Kenneth Koput, and Jason Owen-Smith, 'Network Dynamics and Field Evolution: The Growth of Inter-Organizational Collaboration' *American Journal of Sociology*, 110 (4), (2005), 1132–1205; Kelley Porter, Kjersten Bunker-Whittington, and W.W. Powell, 'The Institutional Embeddedness of High-Tech Regions: Relational Foundations of the Boston Biotech Community', in S. Breschi and F. Malerba (eds.), *Clusters, Networks, and Innovation* (New York: Oxford University Press, 2006), 261–96.

Figure 3



Circles = Biotech companies

Triangles = Universities

Squares = Research Institutes and Hospitals

Size of node = degree centrality (# of alliances)

Figure 3. Inter-Organizational Alliance Networks in the Boston Biotechnology Community, 1988–1999.

dissolves.[53] As we move from 1988 to 1998, the Boston network became more dense. Local venture capital secured key positions. MIT, Harvard, and Brigham and Women's still played an important connective role, but their dominance declined and was partly replaced by venture capital firms. Cambridge and Boston underwent a transition from early dependence upon public research organizations to a market-oriented regime.

Figure 3 presents a graphic representation of the Boston network, covering the period 1988–1999. The degree of connectivity is reflected in the size of the node, while shape represents the type of organization. In the upper-left panel, we see alliances between dedicated biotechnology firms, with the most connected companies represented by the larger circles. The two largest circles are first-

[53] Owen-Smith and Powell, *op cit*. note 49.

generation companies, Biogen and Genzyme. In the upper right, we add universities, represented by triangles, and see the network of ties between universities and biotech. The two largest nodes reflect the linkages of Harvard and MIT, on the left and right, respectively. Research hospitals and medical institutes, the most active of which are Massachusetts General Hospital and the Dana Farber Cancer Center, are added on the lower left as squares. Note how the set of affiliations becomes more complex and intermingled. The fully expanded picture of all organizations is presented at the lower right. The complete Boston community has something of the appearance of rival cliques with trios of firms, universities, and hospitals at the head, vying with one another. This tightly connected, interdependent network is linked by multiple affiliations.

The Boston biotech community grew from a commitment to open science, in which information, knowledge, and human capital irrigated a broad community.[54] Public institutions contribute to innovation by performing commercially important research under academic arrangements. The dynamism of biotech in Boston springs from the universities acting as wellsprings of knowledge, engaging in research partnerships, rather than revenue-maximizing activities. We take this insight as fundamental to any attempt at successful emulation.

Conclusion

The experience of Stanford and the Boston region demonstrates that the elements that make technology transfer possible are highly contingent. Fruitful university–industry relations are difficult to imitate. They require knowledge sharing, in which information-rich communities develop and reinforce each another.

This recipe is not easy to follow. The ingredients include a community based on a competitive approach to high-risk technology and norms that encourage cooperation. This combination is not widely available. Stanford and MIT have adopted a marketing model that focuses on relationships, rather than on contractual deal-making. Equally, institutional diversity is vital. Public and private universities, non-profit organizations, private firms, technology transfer offices, venture capital, and intellectual property law firms all contribute to the process of innovation. What Donald Stokes

[54] *Ibid.*

has called 'Pasteur's Quadrant' – that is, basic science with a public purpose – is a commitment that can be shared by companies and universities alike.[55]

Universities are important sources of innovation. But the responsibilities of partnership can put academic values at risk. As universities learn to patent, they may meet perils.[56] As ties increase, and as the pull of for-profit partners becomes stronger, corporate capture may be inevitable. When this happens, a university's R&D portfolio will narrow. Too close a linkage to corporate R&D may make innovation less easy. Paying excessive attention to blockbuster patents and potential licences, and not enough to planting seed corn, can produce a failure to 'restock the R&D pantry'.

We believe that commercialization involves a responsibility to scrutinize carefully the relationship and its direction. Today, industries and non-profit organizations are becoming increasingly attractive to academics, and universities are becoming much like other organizations. However, the future of commercialization depends upon the universities retaining their distinctive character. It is the capacity of research universities to generate public science that makes them essential.

Critics of university–industry relationships have highlighted these conflicts of interest, and observe that corporations will never finance the university's primary mission of teaching and research.[57] But they overlook second- and third-order effects, by which academics are forced to struggle to keep public science alive, and to limit the haemorrhage of talent. A neurobiology professor we interviewed is not alone in observing that US 'industry is skimming off the really outstanding young people who go to work in firms instead of becoming professors. They tend to be the very best people, the ones you would like to become research leaders in the universities of the future'.[58] And even for those

[55] Donald Stokes, *Pasteur's Quadrant* (Washington, DC: Brookings Institute Press, 1997).

[56] Jason Owen-Smith and Walter W. Powell, 'The Expanding Role of University Patenting in the Life Sciences: Assessing the Importance of Experience and Connectivity', *Research Policy,* 32 (9), (2003), 1695–1711.

[57] See, for example, Jennifer Washburn, *University Inc.: The Corporate Corruption of Higher Education* (New York: Perseus, 2005); Sheldon Krimsky, *Science in the Private Interest* (Lanham, MD: Rowman and Littlefield, 2003); and Donald Stein (ed.), *Buying In or Selling Out? The Commercialization of the American Research University* (New Brunswick: Rutgers University Press, 2004).

[58] Interview with Professor of Neurobiology, Public University, 11 January 2000.

who do pursue academic careers, the pressure to patent stresses 'hot' areas and intellectual property. A professor of medical genetics echoes this fear:

> It would be rare indeed for faculty members to decide not to patent. Even if you were so inclined, it would be hard to ignore how wealthy some of your peers are. You notice the kinds of cars they park in your lot and your children interact with their children. It would be astonishing not to notice.[59]

University–industry partnerships will never generate the returns that politicians and administrators covet. Nor will curiosity-sparked research ever find wide industrial support. But it is precisely this research that produces breakthroughs and spawns new industries. Few corporations appreciate this fact, much less support it financially. But universities that become obsessed with intellectual property threaten the culture of inquiry that is the soul of the academy. The current tendency to favour exclusive licences, and to regard science as property may, if unchecked, have negative consequences for economic growth. Those who wish to emulate the US experience would be well to recognize this possibility, and to avoid its uncritical acceptance.

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[59] Interview with Professor of Genetics, Private University, 11 March 2000.

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