# CHAPTER 4

# Curiosity and the Transformative Impact of Fundamental Scientific Research

*Jean-Lou A. Chameau and Carol S. Carmichael* [1]

*"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it is the only thing that ever has."* — Margaret Mead.

## OVERVIEW

Starting with the rise of Silicon Valley in the 1960s and 70s, the different stakeholders associated with U.S. research universities have emphasized and nurtured the relationship between scientific research and technological innovation taking place at these universities and economic development. The perceived importance of this relationship was reinforced by the Bayh-Dole Act, the decline of the large corporate research laboratories, the emergence of clusters of innovation and the rise of venture capital.

In a study of invention reports at Columbia University, Stanford University and the University of California, researchers found that the nature of

---

[1] **Acknowledgements:** We would like to express our appreciation to Carver Mead for helpful and enjoyable discussions on Caltech and its culture. They have had strong influence on the first author since he became the president of the institute. We would also like to thank Fred Farina, director of Caltech's Office of Technology Transfer, and his predecessor, Larry Gilbert, for their work in creating a national model for university technology transfer while bringing Caltech innovations to the marketplace.

emerging areas of research, especially genetics and computer software, along with court decisions on patentable research results, contributed significantly to the expansion of university patenting and licensing activities. The passage of Bayh-Dole, they concluded, served to "accelerate and magnify trends that already were occurring" (Colyvas *et al.*, 2002).

The first part of this paper addresses the most recognized forms of technology transfer engendered by university research. It summarizes several studies examining the direct evidence of innovation inspired by university research such as patents, licences, start-up companies and other forms of economic spillover effects. These are all important measures and reflect a great success story that is emulated globally in both developed and emerging economies.

However, these measures don't adequately capture the contributions of university research to innovation. Several studies of the informal or indirect effects reveal a much more complicated "innovation eco-system". The foundation of this system is built upon fundamental, curiosity-driven scientific research and led by a relatively small number of institutions that create the conditions where "unconventional" people can make discoveries that have a disproportionate impact on society.

The final part of this paper uses a Caltech case study to illustrate the intangible, yet profound, impact curiosity and fundamental research can have on innovation and quality of life (including economic aspects). Such stories lead us to believe that a national "innovation eco-system" needs universities like Caltech that are driven by fundamental, curiosity-driven scientific research, and must include mechanisms to support and leverage the unusual characteristics of some of the best minds in the world. We will conclude with a few remarks on this "Caltech model".

## SCIENCE AS A DRIVER FOR INNOVATION

The expectation for a return on the public investment in scientific research has catalyzed a cottage industry for analysts and researchers interested in documenting the tangible contributions of research to economic development. Several studies included here describe the extent to which inventors draw upon publicly-supported research and the role faculty inventors and their institutions play in the broader innovation ecosystem. Studies show that the involvement of faculty inventors in the innovation process beyond the university walls, as entrepreneurs or consultants to startup firms, is essential to successful technology transfer. And the more eminent the researcher and the home institution are, the more likely this occurs.

Inventors draw heavily upon the results of publicly-supported scientific research. One way to assess the contribution of public science to innovation is to examine the citation linkage between U.S. patents and scientific research papers. Narin *et al.* (1997) examined 100,000 patent-to-science references and found:

- 73% of the papers cited by U.S. industry patents are based on public domain science; only 27% are authored by industry scientists; and
- The reliance on U.S.-based scientific papers by inventors (with U.S. Patents) increased dramatically, with the citations to U.S. papers tripling between 1987 and 1994 (the increase in patents during that period was only 30%).

They found that inventors show a strong preference for science conducted in their own country, with "local" publications exceeding those from other countries by a factor of two to four. And the cited papers are, in general, "… quite basic, in influential journals, authored at top-flight research universities and laboratories, relatively recent, and heavily supported by NIH, NSF, and other public agencies" (Narin, Hamilton & Olivastro, 1997).

Faculty inventors develop the results of basic research both within and outside the university. Thursby *et al.* (2009) examined a sample of over 5,000 patents involving faculty members at Research I universities. Their study addressed some interesting questions about the "outside" activities of faculty inventors, including concerns about university technology transfer policies and technology "going out the back door" of the university (Link, Siegel & Bozeman, 2007). What this study found, instead, was evidence of legitimate faculty activity leading to economically useful results. They found that:

- 62% of the patents involving faculty members were assigned solely to the university.
- 26% of faculty patents were assigned solely to firms.

The faculty patents that were assigned to firms tended to be "more incremental" (less transformative) than those assigned to universities. Nearly one-third of those patents assigned to firms were to firms which identified the faculty inventor as a principal. The authors concluded that the assignment of faculty inventions to firms is primarily the result of consulting and not faculty inventors circumventing university policy (J. Thursby, Fuller & Thursby, 2009).

## THE UNIVERSITY IN THE INNOVATION ECO-SYSTEM

Numerous studies have found that proximity to the talent and technical resources of leading research universities is a key factor in technology-oriented economic development. Michael Porter identified the competitive advantage of such "clusters", with some of the most successful ones being Silicon Valley in California or Boston's Route 128 (Porter, 1998, 2007). It isn't surprising that most startups locate geographically close to the universities where the faculty-inventors reside. The success of such startups in moving an innovation into the marketplace may be due, in part, to the role of tacit knowledge embodied in the inventor that is not easily communicated through formal patent and licensing documents (Di Gregorio & Shane, 2003; J. Thursby *et al.*, 2009). According to one study, faculty/university led startups are "disproportionately successful" among startup firms and some universities generate more of these new businesses than their competitors. In 1998, nearly 70% of the 2,578 faculty/university startups created since 1980 were still in operation (AUTM, 1998).

One reason other firms may locate within a regional cluster is to gain strategic advantage, for example, through the placement of key individuals within an innovation network (Colyvas *et al.*, 2002). The importance of geographic proximity, however, likely varies with the type of research and its relevance to the technology base of an industry sector. In one study of innovations among 66 firms in 7 manufacturing industries, the researchers found that geographic proximity was less important for those innovations that drew upon basic research (Mansfield, 1995). For applied research, they concluded that close location was important to support face-to-face interaction between academic and industrial researchers (Mansfield, 1995).

An increasing number of universities have established technology transfer organizations to facilitate the movement of intellectual capital from the campus into the marketplace, especially since the passage of the Bayh-Dole Act in 1980. Researchers at the Kauffman Foundation expressed concern about the goals and expectations of technology transfer activities: whether technology transfer organizations are gatekeepers focused on revenue maximization or facilitators of commercialization. These different goals have implications for innovations with longer- versus shorter-term potential, or for innovations "that might be highly useful for society as a whole, even if they return little or nothing in the way of licensing fees". They worry that an over-emphasis on licensing revenue may lead many universities to overlook innovations important to society as a whole (Litan, 2007).

Some studies provide insight into the effectiveness of various university approaches to technology transfer. A case study of 11 inventions in software and molecular biology from Columbia University and Stanford, for example, provides some insight into the role of technology transfer organizations (Colyvas *et al.*, 2002). They found that such organizations were not critical for making contacts with industry, marketing the inventions, or inducing industry interest. They were useful, however, in making arrangements for licensing, facilitating the patent application process, and defining/protecting the university interests.

Di Gregorio and Shane (2003) examined the variation in startup activity among 101 research universities (including 89 of the top 100 research universities, by research expenditures, accounting for 85% of the patents assigned to universities in the U.S.). They found little or no effect from university incubators, internal venture capital funds, the level of local venture activity, or the commercial orientation of the university research. They found a strong influence on startup activity from university policies related to equity investments and inventor share of royalties. They found that higher inventor-shares of royalties correlated with lower rates of startup company formation. "Intellectual eminence" of the university significantly predicts startup activity in that it attracts resources to establish companies (by reducing perceived risk associated with "asymmetric information" about inventions). They concluded that "better quality researchers are more likely to start firms to exploit their inventions" (Di Gregorio & Shane, 2003, pp. 210-212).

## 'CROSS-BOUNDARY' INTERACTIONS IN THE INNOVATION ECO-SYSTEM

Numerous studies and reports on the contributions of fundamental scientific research to innovation and economic development acknowledge that a focus on patents, licences and startups is incomplete and would grossly underestimate the value of basic science in the innovation ecosystem. The development of science and engineering talent for the workforce, open scientific publications, conferences and consulting are just a few ways science diffuses into the broader economy. Another way to think about the contribution of fundamental scientific research is through the natural give and take between basic and applied research, between science and technology.

Stokes (1997) coined the term "Pasteur's quadrant" for "use-inspired" basic research, reframing the relationship between scientific understanding and technology, and suggesting a way to renew the compact between the scientific community and the public that supports it. Stokes argues that research in "Pasteur's quadrant" will lead to support for pure research because as "the emergence of goal-oriented basic research within a scientific field strengthens the case for public investment, it also strengthens the case for public investment in the pure research that will enhance the capacity of the field as a whole to meet the societal goals on which it bears" (Stokes, 1997, p. 104).

Use-inspired research may support the "co-evolution" of science and technology in emerging science-based fields. Murray (2002) set out to examine such co-evolution in the field of tissue engineering. In a study of the 56 patents and 158 papers associated with tissue engineered cartilage, she found little overlap in scientific and technological networks in this field, but significant "cross-boundary" ties not captured formally in patents and papers. This co-evolution occurred through key scientist involvement in patenting and technology development, the creation of startup companies, consulting and informal science advising and mentoring (Murray, 2002).

Studies of industrial research and development (R&D) managers support the idea that fundamental- and use-inspired scientific research contribute significantly to the innovation process. In a study of R&D managers from 66 firms in seven manufacturing industries, researchers found that scientific research provided new theoretical and empirical findings as well as new types of instrumentation “essential to the development of a new product or process” (Mansfield, 1995). They found that approximately 10% of innovations from the industry sample could not have been developed or completed without recent academic research. And when asked to identify key researchers, the firms’ top R&D managers most frequently cited “world leaders” in science and technology (Mansfield, 1995).

In the Carnegie Mellon Survey on Industrial R&D, researchers attempted to assess the contributions of public science to industrial R&D (Cohen, Nelson & Walsh, 2002). Using data obtained from over 1,000 industrial R&D managers in 1994, they found “… [t]his conception of a more interactive relationship where public research sometimes leads the development of new technologies, and sometimes focuses on problems posed by prior developments” (Cohen *et al.*, 2002). Public research contributed about equally as a source of ideas for new projects and for information needed to complete projects:

- 31.6% of the R&D managers indicated that university or government research was the source for new ideas or projects.
- 36.3% of the R&D managers indicated that university or government research provided information used in the completion of a project.

Researchers in industry and in the academy share similar perceptions of the relative importance various forms of knowledge transfer have on innovation. Cohen *et al.* (2002) asked industrial R&D managers about the importance of public research to a recently completed “major” R&D project. A survey of faculty in mechanical and electrical engineering at MIT asked about the relative importance of various mechanisms for knowledge transfer (Agrawal & Henderson, 2002). We have placed results from the two studies into the table below (Table 1). Though drawn from very different study designs and sample sizes, the results show similarities nonetheless.

Faculty consulting is important for technology transfer, but some forms of consulting may actually support the development of new insights and technologies. Perkmann and Walsh (2008) describe three types of faculty consulting and their relationship to innovation in firms: opportunity-driven, commercialization-driven and research-driven. Opportunity-driven consulting builds upon knowledge commonly held in the academic community, is generally short-term and plays little role in innovation as it focuses on solving

**Table 1**

| **MIT Faculty Survey (n = 68) (Agrawal & Henderson, 2002)** | | **Industrial R&D Managers Survey (n = 1229) (Cohen *et al.*, 2002)** | |
|---|---|---|---|
| Consulting | 26% | Informal Information Exchange (conferences, consulting, meetings) | 31-36% |
| Publications | 18% | Publications and Reports | 41% |
| Recruitment of Graduates, Collaborative Research | 12-17% | Recruitment of Graduates, Joint/cooperative Ventures | 17-21% |
| Patents and Licensing, Co-supervising Students, Informal Conversations, Conferences | <9% | Licences and Personnel exchanges | <10% |

immediate problems as opposed to proposing new ideas for development (Perkmann & Walsh, 2008).

Patent and licence documents often provide insufficient information to licensees to develop successfully inventions for the marketplace. To fill this information gap, faculty inventors engage in commercialization-driven consulting. Such consulting strives to "capture such latent knowledge" and is often motivated by the faculty inventors' desires to commercialize their own inventions (Perkmann & Walsh, 2008). Such consulting, as noted by Jerry and Marie Thursby and their colleagues, is essential for the successful commercialization of nearly three-quarters of inventions licensed from universities and may result in additional patents assigned to the licensees (J. Thursby *et al.*, 2009; J. G. A. Thursby, Jensen & Thursby, 2001).

Research-driven consulting, Perkmann and Walsh argue, forms a "circular relationship" between faculty members conducting fundamental scientific research and the industries that develop technologies. Perkmann and Walsh note the synergistic effect when "research is recursively intertwined with technological development." Faculty will be motivated to participate to obtain access to "research challenges, data, materials and instrumentation" and industry will gain insight into development opportunities. The authors predict that research-driven consulting would not shift academic research into applied areas and would "be practised mostly in Pasteur-type fields, i.e. those fields that combine fundamental scientific understanding with practical usage considerations" (Perkmann & Walsh, 2008).

## EXTRAORDINARY PEOPLE IN THE INNOVATION ECO-SYSTEM

The studies discussed in this paper and common sense tell us that faculty inventors and researchers conducting scientific research are essential components of our national innovation ecosystem. Over the past decade or so the decline in U.S. students studying engineering and science has been alarming. It is a concern for our national competitiveness in a technology driven world which requires a technologically savvy workforce. From the standpoint of innovation per se, it leads us to think about whether innovation is driven by a large number of engineers and scientists, or a smaller number of truly creative, game-changing scientists and engineers. It reminds us of a favourite quote from Margaret Mead:

*"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it is the only thing that ever has."*

What conditions lead to game-changing innovation? What allows researchers to take the risks they need to break through conventional understanding with insight that creates new opportunities? In his long-term study of researchers in elite universities, Edward Hackett describes risk-taking as a choice between "answering research questions or forming research questions to answer; between studying phenomena or investing in the creation of phenomena to study and the means to do so." He said: "… the most intense and consequential competition in science is the competition to avoid competing" (Hackett, 2005).

It is ironic then, as some have noted, that one of the main methods for evaluating the creativity of scientific work is the peer review: pitting plausibility and validity (or conformity) against originality (Heinze, Shapira, Rogers & Senker, 2009). Several national groups lament the relatively low amount of exploratory, high-risk research in the U.S. public research portfolio and its implications for our innovation ecosystem (U.S. Committee on Prospering in the Global Economy of the 21st Century, 2007). And others have noted that mechanisms to foster university-industry research collaborations have a tendency, when spun off federal funding, to become more near-term and applied in focus (Feller, Ailes & Roessner, 2002).

Innovative people thrive in universities that share some important characteristics. One study examined the organizational context of research groups involved in 20 "creative events" in human genetics and nano-science/technology (identified through awards of prestigious prizes and a peer nomination survey) (Heinze *et al.*, 2009). They found that a "combination of small work units in rich research contexts with requisite scientific variety" allowed the researchers to eliminate dead-ends, thereby improving the effectiveness of high-risk research. Other characteristics include:

- small groups composed of a highly selective community of scholars
- effective student-supervisor relationships;
- stable and flexible research funding; and
- multidisciplinary contact among those who share "mutual curiosity and interest".

They found that truly creative discoveries were made by “bright and curious minds” who had the freedom to define and pursue interests both within and outside of broadly defined or long-term research agendas (Heinze *et al.*, 2009).

Let’s turn now to a case study of one such bright and curious mind in the “right” institutional context. Carver Mead, the Gordon and Betty Moore Professor of Engineering and Applied Science (Emeritus) at Caltech, is interested in the fundamental properties of materials and their relationship to the design and development of a wide array of technologies. Winner of the National Medal of Technology in 2003, his story as a rural California native captivated in his youth by power plants and radio technology has been told by many (Brown, 2003; Kilbane, 2004; Spice, 2002). He arrived at Caltech in 1952 as an undergraduate and took mathematical physics from a young Richard Feynman and chemistry from Linus Pauling, whom Mead credits with helping him understand quantum mechanics. Since his arrival in 1952, Mead has helped shape and been shaped by the context of a small institution highly focused on fundamental science and technology research.

*“… [Y]ou can sit down at any table in the Athenaeum [Caltech faculty club] over lunch and have a discussion with someone and you find out what the real fundamental things are in a particular field. And that, to me, is what sets this place apart from anywhere else” (Mead, 1996).*

Mead studied the “detailed physics of the contacts between metals and semiconductors” and his insights led to the development of a new kind of transistor. When challenged by Gordon Moore of Fairchild Semiconductor (and later, Intel) to determine the smallest size possible for transistors, Mead not only predicted the size to be two orders of magnitude smaller than thought possible by other scientists in the field (0.15 micron versus 10 microns), he also realized that the challenge for future development of microchips would be the design of chips with millions of transistors (Kilbane, 2004). His innovative response was the development of an automated process for chip design, called very large-scale integration (VLSI), involving a “silicon compiler” that would chart the silicon circuit and plot the design to be etched on a silicon chip (Brown, 2003).

At Caltech, curious minds can meaningfully explore other disciplines, sometimes leading to the creation of new fields or academic programmes. In 1980, a new professor of chemistry and biology sparked Mead’s interest in “neural stuff” and it relationship to computation in silicon, an interest that had its origins to a time in the late 1960s when Mead collaborated briefly with Nobel laureate and Caltech professor of biology Max Delbruck (on a study of nerves and lipid bilayer membranes). He and this new professor, John Hopfield — joined one year later by Richard Feynman — co-taught a course called the Physics of Computation. This course became a learning-laboratory of sorts in which they argued, reasoned and fermented ideas that became a course on neural networks for Hopfield, a course on neuromorphic analog circuits for Mead, and a course on physics and computation for Feynman (Mead, 1996).

This collaboration ultimately led to the formation of the programme in Computational and Neural Systems at Caltech involving faculty in cognitive and behavioral biology, electrical engineering and computer science. Mead says: "It's a really remarkable concentration of talent with quite a good shared vision [neuromorphic way of looking at systems]. That's really an amazing thing; I mean, at Caltech usually everybody goes their own way. We have no mechanism for corralling people at Caltech. Thank God, we don't have that mechanism. That's why I'm still here" (Mead, 1996).

But the knowledge and technology transfer process isn't a one-way street from the university to the marketplace. Like his interaction with Gordon Moore that provided insight into the scaling challenge in microchip design, Mead's collaboration with a variety of Silicon Valley firms fed his research curiosity. His discussion of his relationship to industry describes the type of use-inspired basic research advocated by Stokes in Pasteur's Quadrant:

> *"I've gotten most of my research issues, down through the years, from my interaction with Silicon Valley, but not because they told me to work on [particular projects]. It was because I was working with them and I could figure out, 'Gee, that's an interesting fundamental thing and they don't have time to look at it.' So I would go off and look at it, and then I'd go back to [someone like Gordon Moore] and say, 'Hey, I did this and this and this.' "Oh, that's interesting.' So there was always a good mutual back-scratch" (Mead, 1996).*

Mead's curiosity in the scientific underpinnings of technology is matched by his entrepreneurial talent. His work on "neurally-inspired chips" found its way into several innovative technologies and associated spinoff companies, including touchpad systems (Synaptics), digital hearing aids (Sonic Innovation) and high-fidelity imaging systems (Foveon). His ability to get students interested in his research has resulted in the creation of more than 100 high-tech companies by his former students (Kilbane, 2004)!

## THE CALTECH MODEL

As noted earlier, the philosophy for technology transfer at many universities is based on either a "home-run" or revenue maximizing model or a "volume" model, with the latter focusing on the number of innovations and the speed at which they are commercialized (Litan, 2007). Carl Schramm, President and CEO of the Kauffman Foundation, places Caltech in the "Big Five" of an elite group of institutions involved in technology transfer:

*"… Just five schools, in fact, constitute the elite of the technology transfer world. They are Berkeley, Caltech, Stanford, MIT and Wisconsin. The list of universities reporting new discoveries changes from one year to the next, but each of these five schools consistently garners around 100 patents per year. Not every patent becomes the basis of a business, of course, but some do. And what is remarkable about the five schools above is that, in addition to producing new ideas, they consistently rank at the top of the list of universities in terms of how many businesses are built around the technologies created in their labs. Along with teaching and doing research, they seem to be in the business of inventing companies" (Schramm, 2006).*

Schramm argues that the Big Five's secret to technology transfer success is that they (1) "treat business people as allies and equals;" (2) "encourage students to think about the business potential of their academic research;" and (3) resist "the temptation to monitor and regulate business relationships aggressively" (Schramm, 2006).

Many people not intimately familiar with the descriptive statistics of Caltech are often surprised to learn that it has only 295 full-time tenure-track faculty members, roughly 925 undergraduate students, and 1,200 doctoral students. Caltech scholars have garnered 32 Nobel prizes, 49 National Medals of Science and 10 National Medals of Technology. Our community also includes 105 members of the national academies of science and engineering.

The Caltech office of technology transfer (OTT) was established in 1995, much later than many of our peers. The OTT operating philosophy is based on trusting, collaborative relationships with the scientists so no extensive technology evaluation is needed. It supports our belief in the intrinsic value of the Caltech discoveries over revenue, encourages faculty and staff to pursue patents aggressively, and actively encourages start-ups founded with faculty inventions. Caltech scientists and engineers have, on an annual basis, filed 150-200 invention disclosures, been awarded 120-140 patents, licensed 40-50 inventions and established 8-12 new start-up firms.

These numbers suggest Margaret Mead is correct and that unusual talent is the key to extraordinary results. We should also note that even in the rarefied air of Caltech a number of faculty members repeatedly innovate at levels above the "average". In addition, faculty innovation is supported by critical contextual factors: access to first-class laboratories, outstanding students and post-doctoral fellows, and an environment that encourages curiosity driven research and interdisciplinary work.

Caltech faculty and students want to have an impact disproportionate to the size of the institution. We believe they do and the perception of the public at-large is that they do. Scientific discoveries with a transformative impact on knowledge and subsequent innovation are more than often conducted or at least inspired by unusual individuals. At the level of a nation, we believe it is critical to assure the portfolio of research investments include the support of organizations and programmes which nurture such individuals.

## REFERENCES

Agrawal, A., & Henderson, R. (2002). Putting patents in context: Exploring knowledge transfer from MIT. *Management Science,* 48 (1), 44-60.

AUTM. (1998). AUTM Licensing Survey. Norwalk, CT: Association of University Technology Managers.

Brown, D. (2003). *Inventing Modern America: From the Microwave to the Mouse.* Cambridge, MA: MIT Press.

Cohen, W. M., Nelson, R. R. & Walsh, J. P. (2002). Links and impacts: The influence of public research on industrial R&D. *Management Science*, 48 (1), 1-23.

Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R. R., Rosenberg, N. *et al.* (2002). How do university inventions get into practice? *Management Science*, 48 (1), 61-72.

Di Gregorio, D. & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy,* 32 (2), 209-227.

Feller, I., Ailes, C. P., & Roessner, J. D. (2002). Impacts of research universities on technological innovation in industry: evidence from engineering research centers. *Research Policy,* 31 (3), 457-474.

Hackett, E. J. (2005). Essential tensions: Identity, control, and risk in research. *Social Studies of Science*, 35 (5), 787-826.

Heinze, T., Shapira, P., Rogers, J. D. & Senker, J. M. (2009). Organizational and institutional influences on creativity in scientific research. *Research Policy*, 38 (4), 610-623.

Kilbane, D. (2004). Carver Mead: A trip through four eras of innovation. *Electronic Design*, Retrieved May 15, 2009 from: *http://electronicdesign.com/Articles/Print.cfm?ArticleID=8683*,

Link, A. N., Siegel, D. S. & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer. *Ind Corp Change*, 16 (4), 641-655.

Litan, R. E., Mitchell, L. & Reedy, E. J. (2007). Commercializing university innovations: Alternative approaches. Unpublished Working Paper Series. Available at SSRN: http://ssrn.com/abstract=976005.

Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *The Review of Economics and Statistics*, 77 (1), 55-65.

Mead, C. A. (1996). Interview by Shirley K. Cohen. Oral History Project. California Institute of Technology Archives. Pasadena, CA. Retrieved May 10, 2009 from *http://resolver.caltech.edu/CaltechOH_Mead_C* Unpublished manuscript.

Murray, F. (2002). Innovation as co-evolution of scientific and technological networks: exploring tissue engineering. *Research Policy*, 31 (8-9), 1389-1403.

Narin, F., Hamilton, K. S. & Olivastro, D. (1997). The increasing linkage between U.S. technology and public science. *Research Policy*, 26(3), 317-330.

Perkmann, M. & Walsh, K. (2008). Engaging the scholar: Three types of academic consulting and their impact on universities and industry. *Research Policy*, 37(10), 1884-1891.

Porter, M. E. (1998). Clusters and new economics of competition. *Harvard Business Review*, 77-90.

Porter, M. E. (2007). Understanding competitiveness and its causes Competitiveness Index: Where America Stands. Washington, D.C.: Council on Competitiveness.

Schramm, C. (2006). Five universities you can do business with. *Inc. Magazine*, February (Retrieved on May 1, 2009 from www.inc.com/magazine/20060201/views-opinion).

Spice, B. (2002). Carver Mead's career is based on practical problem-solving. *Pittsburgh Post-Gazette*. Retrieved May 15, 2009 from: *http://www.post-gazette.com*.

Stokes, D. E. (1997). *Pasteur's Quadrant*. Washington, D.C.: The Brookings Institution.

Thursby, J., Fuller, A. W. & Thursby, M. (2009). US faculty patenting: Inside and outside the university. *Research Policy*, 38(1), 14-25.

Thursby, J. G. A., Jensen, R. A. & Thursby, M. C. A. (2001). Objectives, characteristics and outcomes of university licensing: a survey of major U.S. universities. *Journal of Technology Transfer*, 26 (1), 59-72.

U.S. Committee on Prospering in the Global Economy of the 21st Century (2007). Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: National Academies Press.