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## Corporate-Sponsored Research at Penn State: Report to the Office of the Vice President for Research

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## **CORPORATE-SPONSORED RESEARCH AT PENN STATE**

### **REPORT TO THE OFFICE OF THE VICE PRESIDENT FOR RESEARCH**

#### **Introduction**

Universities in the United States are currently perceived—and expected—to be founts of innovation for a growing economy. The expectation that universities should optimize their economic contribution is endorsed by a broad coalition of legislators, entrepreneurs, economic growth pundits, and academic leaders; and it is driven by several powerful rationales. First, changes in the global economy have made advanced industrial countries like the United States increasingly dependent on the generation and utilization of sophisticated knowledge.

Second, this view of the economy has been assimilated into public policy. The principal federal science agencies require industrial partners for most major grants, and more targeted policies have been adopted by the states. Third, developments within science itself have greatly expanded the possibilities for basic scientific research to spawn innovations. “Science-based technologies” like biotechnology, nanotechnology, photonics, and informatics have turned basic scientists into inventors and entrepreneurs. Major universities are inherently committed to these areas as rapidly advancing frontiers of scientific discovery; but these fields are also rich with potential for commercially valuable innovations.

The rhetoric and the programs supporting these developments have stressed the significant role of university inventions yielding intellectual property (IP) that can be commercialized by small technology companies or spin-offs. These companies are particularly prized for purposes of economic development, and universities have steadily enlarged their efforts to assure their success in the face of unfavorable odds. However, a far larger volume of innovation is conveyed to the economy by the laboratories of established corporations. Relationships between corporate and university research have grown for generations, but have recently been a source of both controversy and hope. Research is conducted quite differently across industries, and universities have not always been flexible in adapting their policies accordingly. Corporate labs have in fact tended to deemphasize fundamental research and now look increasingly to external performers to complement internal R&D. Capitalizing on this opportunity, at least some universities have become more accommodative to research relationships with industry, and some corporations have established long-term partnerships with university units.

University research contributes to innovation in industry in large measure through its input to corporate R&D. Corporations also represent a valuable source of support for university research in light of the limitations of federal support. It now appears that federal funding for academic research will be stagnant for some time, as it has been since 2005. Prospects worsened in 2008 with an economic slowdown and the political paralysis of an election year. Even when federal funding was rising, competition was growing more rapidly. Universities reported increasing difficulty in obtaining grants from federal agencies. Hence, industry offers a potential source of additional support for research, even though overall support of this kind is dwarfed by federal outlays and can only be expected to benefit select areas of academic research.

Penn State has long been a leader in industry-sponsored research, registering the second or third largest expenditures. The top university for some time has been Duke (\$133 million in 2006), whose total includes the revenues from its contract research unit, the Duke Clinical Research Institute, which conducts clinical trials worldwide. Second in 2006 was Ohio State (\$106 million), which doubled its reported research funds from industry in 2004-2006, partly through a change in accounting. Former leader, MIT, had flat research support from industry from 1999 to 2006 (\$76 million). Of the ten largest recipients of industry support in 1999, five saw that support decline by 2006, and three registered slight gains. Penn State's increase of 36 percent, to \$89 million, was far better than all but meteoric OSU. Clearly PSU has been relatively successful in attracting research funds from industry in an increasingly competitive environment.

This project was undertaken to gain greater understanding of corporate-sponsored research at PSU. These relationships are important for research and education in key sectors of the university. Specifically, the objective was to examine how corporate research relations at PSU compare with national patterns and trends; to gain understanding of corporate motives for partnering with PSU; to gain insight into the ways in which PSU research contributes to innovation in industry and economic activity in the Commonwealth of Pennsylvania; and to identify strategies for increasing participation by industry in PSU research. To these ends, interviews were conducted with selected representatives of corporations with established research ties with PSU. These were supplemented with less structured interviews from a convenience sample. Individuals at PSU who possessed overview knowledge of industry-sponsored research were also interviewed to gain understanding of different relationships across the university. In addition, this project built upon the research on this topic by Roger Geiger and Creso Sá, supported by OVPR in 2005-2006.<sup>1</sup> Finally, scholarly literature and information on industry-sponsored research at other universities provided a major input to this report. All research data employed in this report, unless otherwise indicated, are from the National Science Foundation.

Obviously, individuals directly involved with corporate-sponsored research at PSU have far greater knowledge of specific relationships than could be gained by an external investigator. The purpose of this report is to provide a different viewpoint, a long-range, more general perspective. In this relationship, corporations are the buyers and universities the sellers. Thus, it is essential to appreciate the point of view and the motives of the purchasers, for whom university research represents only a small input to large R&D operations. Above all, this project aimed to comprehend what corporations sought from university research and what arrangements served to fulfill those needs.

### **National Patterns of University-Industry Research**

Corporate-sponsored university research is a small part of industry-funded R&D, barely more than one percent. Universities make a larger contribution to industry research per se, performing c. 16 percent of industry-supported basic research and less than 2 percent of applied research. The contribution of universities has been less volatile than industrial R&D itself. Since NSF began keeping score in 1955, industry R&D has experienced a real decline on only three

occasions: the early 1970s, after the recession of 1991, and during and after the recession of 2001. On the first two occasions, support for university research continued to climb, albeit slowly. In the last downturn, that was not the case.

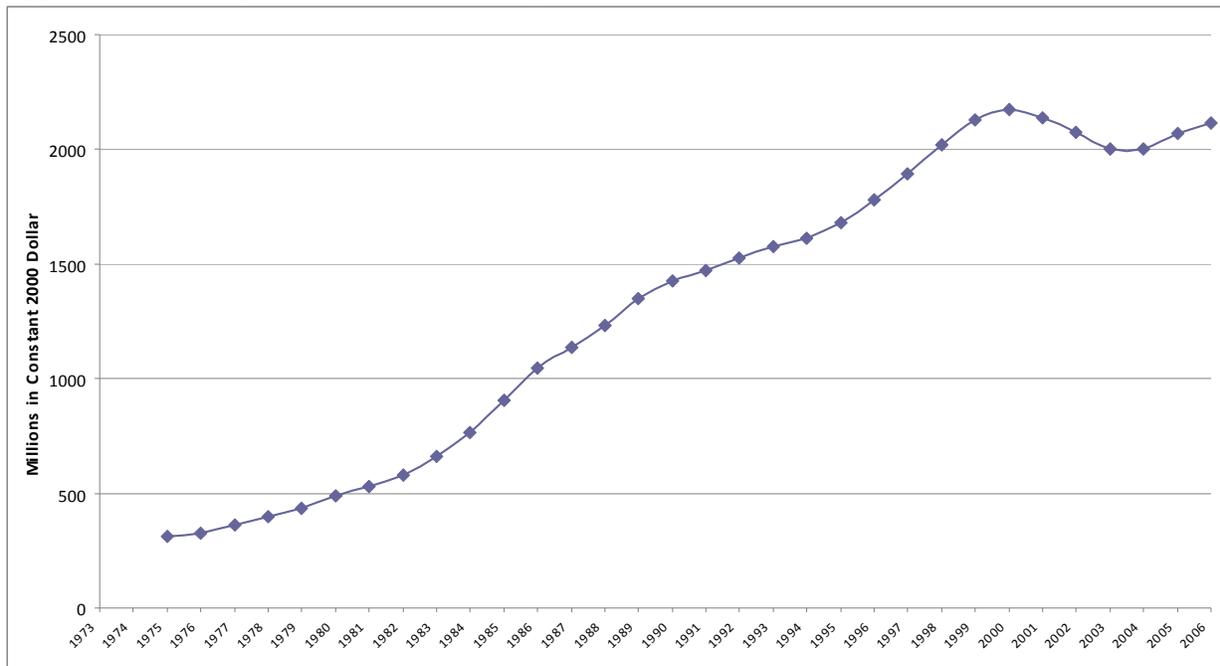
Industry spending for research by all performers peaked in 2000. That peak was exceeded in 2003 for research performed by other firms; in 2004 for internal research; and in 2006 for research performed by nonprofit organizations. In 2006, real industry support for university research remained slightly below the level reached in 2000 (Figures 1 & 2). Thus, two questions are raised: what caused the weakness in industry-supported research? Why was that weakness worst for research at universities?

Corporate research experienced a period of significant upheaval from the late 1980s through the early 1990s. Central laboratories, where long-range basic research was located, fell out of favor for allegedly failing to bolster company competitiveness. In reaction, R&D was decentralized to be closer to customers and suppliers, and focused more narrowly on product development. Central labs were forced to find funding from internal contracts with manufacturing units.<sup>2</sup> Though the full implications of these developments are still not clear, they caused no diminution in support for university research: quite the opposite—until the turn of the century (Figure 1).

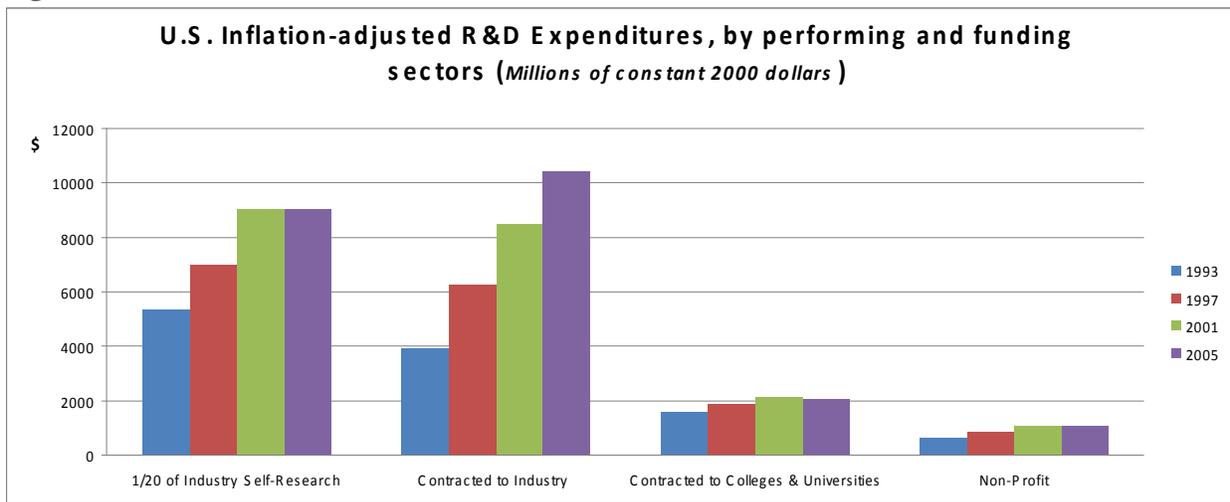
Corporate spending for R&D is fairly sensitive to the economy, both positively and negatively. The expansion of the late 1990s leading up to the dot.com bubble filled corporations with optimistic visions of future technological leaps. Thus, 2000 represented a peak in both research spending and confidence in the future. Both corporate research and confidence were deflated by the recession of 2001. By 2004, despite rising corporate profits, spending for R&D was six percent lower than in 2000.<sup>3</sup> A recovery only began in FY2005.<sup>4</sup> This drop was unprecedented since the 1950s. The economic slowdown does not appear to be a sufficient explanation for the weakening of university-industry research. Rather, three factors seem likely to have depressed corporate support.

First, corporate resentment of university ownership of intellectual property (IP) resulting from corporate-funded research seems to have grown in recent years. It is not immediately evident why this long-standing tension has worsened—whether reorganized tech transfer offices became more assertive or industrial R&D labs more focused on near-term product development. However, when choices can be made, corporations have apparently supported research at other performers that made no such claims on IP.

**Figure 1. Industry Funds for University Research, 1975-2006 (\$2000)**



**Figure 2.**



Second, domestic corporations have been procuring increasing amounts of research off shore. For example, DuPont in the last decade established technical/R&D centers in Germany (1999), Japan (2000), Taiwan (2004), China (2005), and Korea (2006). When making location decisions, firms seem to balance four factors—markets, costs, quality, and protection of intellectual property.<sup>5</sup> Conducting R&D in emerging countries—principally China and India—is motivated most strongly by the desire to have a presence in those growing economies. Actual R&D is more likely to be focused on local products and markets, although both those countries have developed centers of scientific excellence, and undoubtedly will develop more.<sup>6</sup> Costs are

lower in these locales, but protection of IP can be problematic, especially in China. High quality research at a very low cost is also available in Russia as a result of special programs intended to sustain scientists after the fall of the Soviet Union. For some topics, researchers with very different backgrounds have an additional value of seeing problems from fresh perspectives.

Still, companies are far more likely to seek basic research in developed countries. The most important consideration here is research quality, and in most cases this means connections with universities and university faculty. Higher costs are not a deterrent when the objective is to obtain access to the best scientists and engineers. This is clearly the great strength of the U.S., although by no means a monopoly. One attraction of universities in other developed countries is the ease of negotiating research agreements, *sans* the IP hassle. Sensitivity to this issue probably varies by industry, but has clearly intensified. According to one research manager in materials, “this much more favorable treatment of IP is causing companies to do more of their sponsored research abroad.”<sup>7</sup>

One indicator of the growing use of offshore research is that performed by foreign affiliates of U.S. multinational corporations. From 1998 to 2004 this figure increased from 11 to 15 percent of research performed by these companies.<sup>8</sup> For universities, it seems safe to say, foreign laboratories constitute growing competition for corporate research support.<sup>9</sup>

Third, it seems likely that increasing competition is coming from the corporate sector itself, chiefly from small tech firms. From 1994 to 2004 the amount of corporate R&D that was contracted out rose from 3.7 percent to 6.6 percent, and all of that increase was accounted for by other firms.<sup>10</sup> Who performed this research? In all likelihood, firms with fewer than 500 employees played a large role. Over two decades the proportion of industry research performed by this sector rose from 9 to 18 percent.<sup>11</sup> Medium-sized firms (500 to 4,999 employees) increased their share from 12 to 20 percent. Buried within the former category are an increasing number of ‘technology shops,’ or ‘research boutiques,’ largely devoted to research. Often launched as university start-ups, they attempt to advance inventions toward functioning products. Such firms have been encouraged by state economic development programs as well as the federal SBIR and STTR programs. Although many of these firms intend to develop their own inventions, they have also become important sources of technology for corporations (see below).

Despite the evidence of weakening corporate research, some underlying conditions should induce industry to utilize increasing amounts of university research. First, the general cutbacks in internal R&D would suggest that firms need to seek more research services externally. Second, an increasing number of firms explicitly embrace the philosophy of ‘open innovation,’ which encourages them to focus on core competencies and seek other, complementary innovations externally. Third, the growing salience of research-based technologies makes the frontiers of scientific research more relevant to industry products. Still, the impact of these trends is to date uncertain.

Many types of corporate-sponsored university research could be performed by other organizations. For clinical trials and materials characterizations, to take two examples, universities might offer some advantages, but other performers might be cheaper or timelier or

more cooperative. Nevertheless, for cutting-edge research academic expertise is indispensable. Here there are only a few competitors to U.S. universities—national labs or a handful of foreign world-class universities. The open question is how much of this type of research does industry need? The supply seems ample, but the volume of demand is no doubt variable and to a large extent discretionary. It will depend not only on the scientific and technological requirements of each industry, but also on its confidence and financial wherewithal to invest in the future.

### **Patterns of Industry Use of University Research**

Industries vary considerably in the ways they utilize R&D, and these differences are naturally reflected in their relationships with universities. The common thread is the kinds of knowledge and research that universities supply, but even here universities supply these things in numerous ways, as will be seen in the next section. For industries, the critical variables are the importance of IP, the ability or inability to cooperate, and their different needs for specialized, directed basic research, especially the proximity of products to the research frontiers. This project has identified four basic paradigms which, despite some overlap, possess distinctive features: Pharmaceuticals and biotechnology; electronics, informatics, and communications; chemistry and materials; and what used to be called the military-industrial-academic complex.

Big Pharma and Biotech. The pharmaceutical industry has shaped university practice in matters of intellectual property. Besides relying on patenting and maintaining close relations with basic biological research, the industry draws more heavily from external sources than any other. In 2003 it devoted more than seventeen percent of its R&D budget to contracts outside the firm, more than three times the average.<sup>12</sup> A good portion of these contracts support clinical trials, which are unique to the industry. This situation also reflects the powerful effects of the biotechnology revolution superimposed since the 1970s on the research traditions of large pharmaceutical firms.

The pharmaceutical industry is a prodigious performer of R&D. The \$39 billion it expended in 2005 is nearly equal to the total research expenditures for all U.S. universities. Moreover, since 1970 that figure grew steadily by twelve percent per year, although that pace has been closer to eight percent since 2000 and will probably slow further going forward. Only one-quarter of these expenditures is devoted to “prehuman/preclinical” activities where research rather than development takes place.<sup>13</sup> “Big Pharma” as these enormous multinationals are called, has had close ties with university research since the 1930s, but this relationship was used far more to develop new drugs than to invent them.

Today, pharmaceutical scientists are probably the most academic of corporate researchers. That is, most have Ph.D.s and participate in ‘public science’ through conferences, meetings, and journals. Big Pharma consequently has multiple ties with universities covering all forms of interaction. Contract research tends to fall within three broad categories. 1) Clinical trials take many forms, but most are tightly structured and rigidly controlled to assure validity across different patients and different sites. University health centers appear to welcome this revenue, but have little scientific input once the design is set. 2) A good deal of research activity emanates from the mutual interest of corporate and academic scientists in common molecules or

compounds. This interaction generates research contracts and ‘material transfer agreements,’ which play a large role in this field. Big Pharma tends to be demanding about IP in these transactions, fearful of allowing any claims against its property or products. 3) These companies have entered into some extended partnerships with select universities, aiming to further basic scientific understanding in strategic areas. Such commitments have been one possible entrée for Big Pharma into biotechnology.

For the last generation pharmaceutical firms have struggled to adapt to the biotechnology revolution. The companies and their labs were built around chemical analysis (small molecules), and hence were distant from the intellectual wellsprings of biotech (large, protein molecules), culturally as well as geographically. They have consequently had difficulty recruiting biotech scientists to corporate labs, and have been laggards in the intense competition for biotech advances. They have compensated by establishing some multi-year, multi-million dollar contracts with a few universities. Merck has entered a series of partnership agreements with Harvard Medical School and MIT; and Pfizer, besides closing a chemistry-based laboratory in Ann Arbor, signed a \$100 million agreement with Scripps Research Institute and opened a “biologics” laboratory in San Francisco—and recently a \$25 million research agreement with Washington University (immune system/inflammation).

The inability of Big Pharma to get in on the ground floor of biotech has allowed that industry to develop through small start-up firms. Although a handful of these early firms grew into large corporations themselves (still not Big Pharma size), the most remarkable feature of this industry is that the relentless advance of fields such as genomics and proteomics has resulted in ever more new, research-based firms. Instead of following the normal pattern for new industries, that of firm proliferation followed by consolidation into larger firms, biotech firms have continued to proliferate, developing a symbiotic relationship with Big Pharma and the larger biotech corporations based on division of labor. These firms now constitute a vital source of innovation and drug development for the older, larger firms, and a distinct sector of the industry. A remarkable feature of this industry is the centrality of university science. In an analysis of biotech patent activity from 2002 to 2006, eleven U.S. universities were in the top twenty-four (>100 patent families) compared with ten corporations.<sup>14</sup>

The typical biotech firm was launched on the basis of discoveries in university laboratories, and most continue to have close relations with academic research. Their chief task is performing highly specialized applied research aimed at developing proprietary technologies.<sup>15</sup> Their own IP is their most valuable asset, but that value can only be realized when a workable product is at least in sight. Furthermore, those proprietary technologies are now, since the low-hanging fruit has been picked, less likely to be consumer products like drugs than inputs to therapeutic processes controlled by larger corporations. The vast majority of these firms are small and unprofitable. According to the CEO of Genentech, biotech is “the biggest money losing industry of all time”: Since 1976 when Genentech was founded, the industry “has lost \$90 billion.... [F]or most of the 1,300 to 1,400 companies—300 or 400 of them public—this is a money-losing enterprise.”<sup>16</sup> These losses must be covered through venture capital or the proceeds from selling stock. The market structure of the biopharmaceutical industry thus concentrates innovation and technical risk in this sector, along with speculative financing. Rewards come from developing a real product and usually result in movement up the food

chain—being absorbed by a larger firm either through outright purchase or licensing and marketing agreements. The biopharmaceutical industry has thus evolved a large commercial sector, drawing on multiple sources of funding, that has become an intermediary between academic research (in universities or independent laboratories) and the development and sale of health products.<sup>17</sup>

Electronics and Computing. In the electronics and computing industries an entirely different pattern has evolved for acquiring and incorporating new knowledge. Although this field is based on science and technology, fierce competition has favored internal generation of knowledge and few academic ties. These industries have the lowest percentage of externally contracted R&D (1.4 percent). As they developed, they depended heavily on manufacturing expertise rather than scientific breakthroughs. Speed was rewarded; patents had limited value, often merely to slow down competitors.

Intel, for example, long resisted establishing a central lab, keeping its R&D staff relatively small and closely focused on semiconductors and microprocessors. According to its legendary founder, Gordon Moore, it operated on the principle of “minimum information”: that is, Intel engineers attacked problems with intuition as far as possible, and only resorted to deeper analysis when these informed guesses failed. Originally it derived much new technology from industrial sources, notably Bell Labs. More recently, however, “Intel looks to universities for much of the basic research of interest to it.” By 2007, Intel was supporting research projects at 150 universities in 34 countries. Some Intel projects were leveraged further through faculty proposals for government grants on related topics (testimony of the pervasive role played by public science). Its chief scientist expected universities “to play an increasingly major role in the longer-term research topics,” including novel forms of collaboration (discussed below).<sup>18</sup>

Indeed, closer cooperation with university science would seem to be the long-term trend. At Hewlett Packard a product-oriented research lab was gradually reconfigured to occupy the middle ground between basic university research and internal product development. It has devised a “partnership continuum” that extends from traditional kinds of support toward an ideal of “holistic engagement” with universities. Disk-drive maker Seagate Technologies, coping with data storage demands that posed increasingly difficult scientific challenges, created a new research center in Pittsburgh in order to work with scientists at Carnegie Mellon University.<sup>19</sup> Still, the university’s role in this industry faces inherent limitations. For example, Moore considered it “impossible for universities to afford the equipment required to support work with state of the art semiconductor technology.”<sup>20</sup> For these needs, Intel and other manufacturers turned to industry consortia, especially SEMATECH. Launched in 1986 with federal subsidies to revitalize the U.S. semiconductor industry, SEMATECH is now an international consortium focused on several aspects of semiconductor manufacturing. It performs pre-competitive research that each company can utilize in its own manner for manufacturing its distinctive product line. This arrangement is typical of the electronics industry, where leading firms have resorted to cooperation to push the science/technology frontiers in industry-wide organizations. But even here the university role is growing: SEMATECH finalized agreements in 2007 to establish new operations in conjunction with the University of Albany’s College of Nanoscale Science and Engineering.<sup>21</sup>

Another electronics consortium with university ties is the Microelectronics Advanced Research Corporation, or MARCO—a wholly owned subsidiary of the Semiconductor Research Corporation, associated with DARPA, and funded by the DoD, the Semiconductor Industry Association, and semiconductor suppliers. This labored description identifies the numerous interested parties for this technology. MARCO supports four major labs, at Berkeley, Carnegie Mellon, Georgia Tech, and MIT, each with multiple participants—altogether a complex information system with specific activities at each node. At Berkeley, for example, the Gigascale Silicon Research Center aspires to create a chip containing one billion transistors.<sup>22</sup> The Semiconductor Research Corporation was originally established in 1982 as the university research arm of the Semiconductor Industry Association. In the 1980s it established Centers of Excellence at several universities for longer-range, pre-competitive research, and it currently sponsors four separate programs that harness different aspects of university capabilities. Hence, a good deal of IT research is sponsored by this non-profit corporation rather than individual companies.<sup>23</sup> Universities are highly relevant to the information technology industry, but in quite different ways from biotech.

The strong patenting regime practiced by universities is incompatible with the IT industry for two reasons. First, the industry has evolved from producing single products to complex systems, which might embody thousands of patents. As explained by the Hewlett-Packard Vice President for University Relations, “due to the large number of patents in a typical IT product, companies will not pursue royalty-bearing licenses with universities.” Second, the pace of innovation in IT has accelerated the product development cycle and shrunk product life times. The patenting system, and indeed the whole process from university invention disclosure to technology transfer, is too slow for this industry (and this would be even more the case for software). Instead, it seeks collaborative relationships in which emerging technology can be incorporated into the firm’s continual process of innovation.<sup>24</sup> The industry has evolved extremely complex organizational forms in order to found and fund ‘neutral’ sites where pre-competitive research can address major future challenges that will subsequently be developed independently by competing firms.

Materials. The materials industries present a third pattern for utilizing university research. Chemistry was the first academic discipline to develop direct links with industry, and these exchanges thrived throughout the twentieth century. The sophistication of materials science and engineering merely added more channels to this knowledge flow. Compared with drugs and electronics, materials technologies advance at a more languid pace, which in the past made access to cutting-edge science a less critical factor. In addition, although the aim of R&D is to add value to materials, these firms still sell commodity materials to manufacturers. The use of more advanced, and more expensive, materials is often constrained by the pricing limits of the final products into which they are incorporated. In working with universities, materials firms have tended to favor informal arrangements and long-term relationships. These are often established with individual scientists and their laboratories, and they result in combinations of consulting, contract research, lab support, gifts in kind, supporting or hiring students, and informal interaction. They are uncomfortable with some charges for indirect costs, university demands for intellectual property, and above all the possibility of running royalties. Their profit margins are too narrow, they argue, to shave off percentages of royalties for a small university contribution to their own far larger efforts.<sup>25</sup>

The materials industries in many ways typify university relations with innovation in mature manufacturing corporations. Changing conditions in the 21<sup>st</sup> century have both favored and obstructed those ties. A research director at Dow Chemical spoke for these industries in observing that Bayh-Dole and university patenting have made

U.S. universities ... substantially less attractive as research partners for companies. As U.S. universities focus on controlling intellectual property and maximizing their revenues from licensing inventions they have become more like competitors than partners to companies that sponsor research with their faculty and students.<sup>26</sup>

Industry resents having to pay twice—once for the research and a second time to use university-patented findings. They object that this arrangement ignores the far-larger industry investment in perfecting and developing products. When lawyers for both sides become involved in negotiate contracts, legal costs can exceed the value of the research project. Another negative is the time required for these negotiations, on average more than five months. Yet industry often needs timely answers to research questions. It has become increasingly common for research agreements to be scuttled over IP negotiations. Such an impasse, moreover, can poison a relationship: “long after a single negotiation has failed, the reluctance to participate in other areas of support such as gifts, grants, endowments, research contracts, consulting arrangements, and others lives on.”<sup>27</sup> As a result of these irritations, industry reports contracting for less research at U.S. universities than would otherwise be the case, becoming more receptive to seeking knowledge from other sources.

On the other hand, not everyone believes this relationship is deteriorating. Scaling back investment in industrial labs has caused firms to tap university resources. Dow Chemical, for example, now has universities perform materials characterizations that were formerly done in house. Air Products and Chemicals, Bayer, and DuPont, among others, have consciously sought to implement the doctrine of ‘open innovation’—looking to external sources of knowledge and innovation to supplement internal R&D. Air Products has concluded general ‘alliances’ with PSU, UC Santa Barbara, and Imperial College; and DuPont boasts an ‘alliance’ with MIT for biomaterials as well as other long-term relationships with academic and non-academic partners.<sup>28</sup> Focused partnership agreements are apparently becoming more prevalent. They are most effective when companies seek university expertise to address a broad spectrum of topics spanning several fields and intended to lay the foundation for future product development. In these situations, IP issues are more easily resolved, often with non-exclusive, royalty-free licenses. At least one firm emphasized that flexibility on IP was a necessary precondition for establishing a partnership. Long-term relationships are becoming more common as industry seeks access to emerging science-based technologies in which expertise is in limited supply. For materials, nanotechnology is the most salient example.

Nanoscale science and engineering promises enabling technologies that will be applied to the life sciences, electronics, and materials. For the first two, relations with universities largely conform to the patterns for those industries. That is, start-up firms are developing nanoscale applications to biotechnology in areas like drug delivery; and in semiconductors the connection between nano and SEMATECH at Albany has been noted. For materials, some of the simpler applications of nanotech have already reached the marketplace, primarily coatings with novel

properties. However, more advanced and more remarkable applications lie in an indeterminate future, and the structure of the industry that will deliver them is uncertain as well.

At this stage, universities are very much involved in shaping that future. Like biotech, the advancement of nanotechnology rests heavily upon basic science and requires inputs from the multiple disciplines that can be found in large research universities. It also may rely more heavily on patents than any previous enabling technology.<sup>29</sup> In terms of research equipment, it depends on even more expensive instruments and facilities. To date, NSF has supplied much of this infrastructure at universities, and recipients have had little difficulty attracting the industrial partners that NSF insists upon. The California Nanoscale Institute likewise recruited corporations from the three relevant industry sectors as supporting partners.

University scientists have perceived a sharp dichotomy in the field: “you have the large companies ... who are keeping an eye on what’s developing ... and working on some technical developments themselves”; as well as “very young companies looking to try to engineer some of these materials into real products.”<sup>30</sup> In other words, at this early stage nanotechnology seems to be evolving toward a structure similar to biotechnology, where a great deal of product innovation and technical risk is concentrated in start-up companies, mostly university spin-offs. Moreover, also like biotech, this commercialization is concentrated around those universities that lead in nanotechnology research.<sup>31</sup> Already enough of these companies have gone public to provide a basis for an exchange-traded nano fund.<sup>32</sup> But no Amgens or Genentechs have emerged, and the huge profit potential of key biotech discoveries seems to be lacking. Instead, the more successful among the nanotech firms will most likely partner with large materials corporations. Air Products, for example, established a toehold in the field by forming a partnership with one such firm, proclaiming “the keys to successful nano projects are alliances and partnerships.”<sup>33</sup> Corporations may well be looking to universities for learning, but to the start-up sector for more relevant technologies.

Military-Industrial-Academic Innovation System. The wellspring of this sector of corporate-sponsored university research is the Department of Defense. Of its \$6 billion in research obligations (2006), DoD labs accounted for almost one-third, industry two-fifths, and universities nearly one-quarter. However, more important than the different performers is their inter-connectedness. Cooperation in research among DoD labs, defense contractors, and universities is standard practice. In fact, the DoD over the years has provided a regular stream of investments to develop expertise and research capabilities in critical technologies in all of these locations. In developing weapons systems, defense contractors come to universities to tap into these same reservoirs of expertise. Viewed together, defense research constitutes an enormous, integrated ‘innovation system,’ one that probably has greater coherence than those featured in academic writings on this subject.

Key nodes in this innovation system are several large university affiliated research centers (UARCs) that are largely offshoots of Pentagon R&D. Penn State’s Applied Research Laboratory (ARL) and the Georgia Tech Research Institute (GTRI) differ only slightly from officially designated Federally Funded Research and Development Centers (which ARL once was) like Johns Hopkins’s Applied Physics Laboratory and Caltech’s Jet Propulsion Laboratory. In such labs much corporate research is supported by flow-through or sub-contracts of federal

funds. Such work tends to be contract research with deliverables. It is typically performed by teams of full-time researchers in specialized research units. Given the existence of highly specialized teams and equipment, industry consortia are often organized to share in the sponsorship of pre-competitive research. These labs are above all known for their special capabilities, which make them indispensable to corporations that supply the DoD. Small companies too, often holding SBIRs or STTRs from the DoD, participate in these centers. One additional element is essential for this sector: these are secure facilities where sensitive research can be protected through different grades of security clearance.

The defense sector differs from other industries in the lack of concern for IP. There is little incentive to patent or found start-ups in these labs, and actually some disincentives. Most research is intended ultimately for the federal government, which does not pay royalties. Defense contractors rely more heavily on trade secrets for their complex systems, and often do not wish to publish these secrets as patents. In addition, no exclusive licenses are permitted by the DoD for these kinds of discoveries.

To appreciate the role of UARCs in this innovation system, one needs to identify the knowledge exchanges. Scientifically, the relationship with the university is important. UARCs possess highly sophisticated equipment and instrumentation that present university scientists with unique opportunities for research. Penn state's top-rated acoustics program is one example. Conversely, the university's broad scientific capabilities are available, if needed, for defense research. One long-term contract with a Penn State unit put it bluntly:

this contract will provide the U.S. Army a mechanism to effectively access the full research and development capabilities of the University to meet the current and future requirements of the Army.<sup>34</sup>

The involvement of graduate and undergraduate students in these research centers adds an important human capital component to the innovation system.

A second important exchange occurs when technologies developed by the DoD are made available for civilian products. This process has been ongoing since at least 1945, but in the last two decades it has become an avowed goal, especially for federal labs and UARCs. GTRI has consistently advertised itself as an agent for economic development, even though the bulk of its research is for the DoD.<sup>35</sup> Penn State's Electro-Optics Center, a recent satellite of sorts of ARL, also embraces this role, including launching start-up companies. The combination of deep technological capacity and a willingness to perform applied research makes such units fertile sources of innovation for private industry. Growing demand from these sources, piggy-backed onto DoD research investments, have propelled their expansion. GTRI has eight branch locations, including a recently opened center in Ireland.

The military-industrial-academic innovation system was developed to achieve vertical integration—the ability to move quickly from basic research to applications and products. This is similar to the goal of translational research embraced by NIH. The capacity of UARCs to accommodate vertical integration is unusual for academic research, and its potential value for civilian technologies is now increasingly recognized.

## Forms of University-Industry Research Relationships

From the perspective of the industrial lab, the utilization of external knowledge and technology is intended to complement the internal process of innovation. The highly specialized staff are often resistant to external inputs—the ‘not-invented-here’ syndrome. Maintaining relations with universities frequently require an internal champion to remind the lab of the longer-term advantages of these partnerships. More immediately, sponsored research with universities needs to be carefully managed to maintain communications and take advantage of results. Without support from management, the greatest barrier to tech transfer can be the culture of the corporate lab. Thus, assimilating external knowledge is a challenge faced by all industrial R&D labs.

Exacerbating this difficulty is the sensitivity of lab operations to costs. R&D by itself represents a large fixed cost, with a somewhat precarious status in company budgets, often disdained by bean counters and vulnerable to belt-tightening. And, cutbacks are likely to fall hardest on external expenditures. These projects are evaluated by price as well as contribution. As one representative firm explained, projects up to \$50,000 could be readily authorized, and research contracts under \$75,000 were preferred. Projects over \$100,000 were “painful,” and those above \$250,000 had to prove their worth to management.

Cost is only one among many considerations when firms decide where to seek R&D services. U.S. universities are storehouses of expertise and a pretty good deal as well. A typical small, low-risk project might support a doctoral student for a year (cheap labor) and a sliver of the professor’s time (a bargain for access to a professor’s knowledge and lab). Often such projects are used to maintain a working relationship with a scientist whose research is valued by the company. By comparison, contracting for a portion of a full-time scientist at a national laboratory or an independent research corporation might cost more for personnel and have higher indirect costs. However, the nature of the research, more than costs, determines these choices. It also tends to determine where research is sought.

In general, when firms seek access to basic research they look to partner with high quality universities and faculty wherever they are located. When more applied forms of research are the object, nearby universities are likely to be more convenient and cost-effective.<sup>36</sup> Access to the latest thinking in cutting-edge fields is invaluable for large, research-based corporations that depend on their technological edge. Often these firms are less interested in specific research results, but simply wish to maintain relationships with key researchers. Local universities, on the other hand, may prove more accommodating for the near-term problems of nearby industries. Most firms probably pursue both strategies. Many examples could be given of mutually beneficial relationships between regional firms and universities, usually involving more than research. However, given the dispersed operations of multinational corporations, little of the economic fallout from any single university-assisted innovation is likely to remain near home. A previous study at Penn State found only one-fifth of industry support coming from Pennsylvania companies, and another fifth from the six contiguous states. Moreover, the further from Pennsylvania, the larger the average grant, with contracts from international corporations more than twice the median size of \$62,000.<sup>37</sup> For the bulk of industry-sponsored research at major universities, globalization is the rule.

**Figure 3: Forms of Corporate-University Research Relationships**

Individual Projects	Institutional Links	Personnel
Contract research, deliverables	Collaborative Research in Consortia	Internships for students
Unrestricted grants	Participation in Federal Centers	Programs to support faculty
Straight licensing	Partnerships or Alliances	Graduate student support
Sponsored research projects	Satellite Laboratories	
Faculty consulting		
Material transfer agreements		

When considering industry sponsored research at universities, it is important to keep in mind both the differences across industries, described above, and the multiple ways in which firms purchase access to university expertise (Figure 3). Within this complex picture, two general trends are evident. First, the modest, discrete grant for sponsored research (\$50-75,000) continues to be a kind of baseline for industry contracts for academic research. The reasons for this are the cost considerations explained above coupled with a need for multiple, dissimilar knowledge inputs. Second, the prevalence of larger-scale, longer-term, institutional arrangements appear to be growing. These take multiple forms under sponsorship from governments, universities, industry groups and single corporations. Many of these arrangements are of long standing, but their increasing numbers represent an effort by corporations to tap more directly the economic relevance of academic science.

The discrete research project is the most common way in which industry obtains external knowledge, particularly from universities, but it may be the least studied aspect of this relationship. In theory the goal is quite simple. As stated by Air Products,

industry views university research as one of many tools it may wish to use to maintain a competitive edge. The goal is to get the best research results for the lowest possible investment. The value of the research is in its extraction of commercial value from those results.... Industry views university collaboration as a stepping-stone to help augment the innovative ideas of its own scientists.<sup>38</sup>

However, when Air Products took the additional step of formally evaluating the contribution of its external research projects, the criteria it developed were anything but simple.

The scheme that Air Products developed, and then published, provides insight into what a firm expects to gain from purchasing university research.<sup>39</sup> The company recognized four different levels of external research projects: fundamental studies; learning/evaluating external technologies; assimilation of external technologies to internal uses; and applications/process development. Expectations obviously differed for each type, but all were rated according to ten criteria, which can be summarized as follows:

*New ideas or new expertise/skills* (2 criteria): the highest scores were given to scientific advances or “world-class” understanding likely to be derived from basic research.

*Time or net R&D saved* (2): these criteria measured the value of the contribution to internal R&D in terms of development time or person-years saved.

*Access to existing IP or generation of new IP* (2): this emphasis underlines the company's ubiquitous concern for IP.

*Long-term access*: this criterion refers to building relationships with other organizations and hence access to their capabilities, measured in dollar value.

*Program emphasis*: evaluated as offensive (highest) or defensive, critical or non-critical.

The last two criteria were given greater weight (5 possible points versus 3):

*Commercial impact*: measured as the dollar volume of resulting sales or savings.

*Technical leverage*: the overall contribution to technological advancement.

The Air Products exercise illustrates the general point that external research enhances the capabilities of internal R&D.<sup>40</sup> It contributes to efficiency (time and R&D saved), intellectual capital (new ideas and expertise), access to the resources of other organizations, and technical leverage. In terms of outputs, it may produce new IP and increased sales, but in this case income is one factor, not the bottom line. R&D labs see their role chiefly as strengthening the company's competitive position, leaving subsequent financial consequences to other corporate divisions. Otherwise, the stance is aggressive in terms of seeking to extract advantageous information from other organizations.

The managers who implemented this evaluation found proximate benefits. The forty-two projects they evaluated each saved on average two person-years of effort. Ironically, this exercise seemed to raise dissatisfaction with the usual terms of research contracts, and for a time adversely affected Air Products' long standing relationship with PSU. The company anticipated continued use of this exercise to improve the effectiveness of external research, but the process apparently proved too cumbersome. Another company felt that because the chief benefits from university research are inputs (stepping-stones) to an early stage of product development, efforts to value it are a hindrance and possibly misleading.<sup>41</sup>

The Air Products exercise reveals the multiple dimensions of each research project, and confirms the status of the discrete project as the baseline for university-industry research. The explicit inputs listed by Air Products are not likely to be realized through informal interactions. Public science, in the form of publications and meetings, is obviously an important supplement to industry R&D and particularly useful for identifying potential research partners, but cannot by itself yield technological advantage.

Companies have two alternatives to discrete grants, but they appear to use them selectively. Instead of a formal research agreement, firms often make gifts to universities, designated for a particular scientist or laboratory, with the understanding that it will support research or a student in a specific area. These arrangements are usually based on an established relationships and mutual understanding. However, a research-related gift cannot include

deliverables and must be otherwise disinterested. The trend in corporate funding has run strongly in the direction of greater focus and more explicit links with benefits for the corporation.<sup>42</sup> Accountability and targeting tend to discourage transactions like research gifts.

Consultants offer a way to avoid university entanglements and the IP problem entirely. Consulting by its very nature is highly individualized, and for that reason probably depends heavily on personal relationships. Interviewees indicated that consultants are used most often for specific purposes—assisting with the completion of projects, supply train issues, or addressing problems.<sup>43</sup> Consulting thus plays an important role, but not one that matches the greater breadth of purpose of discrete research projects.

The second general pattern has been for industry to establish larger and more sustained research relationships with universities. In the past, these arrangements arose haphazardly as universities formed consortia to accommodate industry interests in specialized fields. Beginning in the 1980s, state and federal programs promoted collaborative research as a means of encouraging technology transfer. Since the late 1990s, corporations have increasingly utilized a second approach: independently concluding extended partnerships between individual firms and universities. All these approaches are designed to further the deeper kinds of ongoing collaboration advocated by the IT industry, but appreciated throughout the corporate world. The last form allows collaborations to be tailored more closely to each corporation's objectives.

The largest effort to promote collaborative research has been the NSF program for Engineering Research Centers (ERC). From 1985 to 2006 it supported 43 successful centers in the first two generations of awards.<sup>44</sup> An evaluation of industry experience with ERCs found anticipated benefits that were essentially the same as the inputs to R&D identified by Air Products—most prominently, new ideas and expertise, but also access to university knowledge and facilities and relevant new technologies.<sup>45</sup> Similarly, actual benefits realized were strongest for knowledge transfers and weakest for tangible outcomes, like products or patents. When participating firms rated the factors related to those benefits, the most important were all associated with connectedness—either the closeness of ERC activities to those of the firm or the firm's ability to assimilate ERC results. This critical finding reveals a limitation of this model, since consortia organized by universities or government represent 'supply-side' approaches to meeting industry needs (discussed further below) and are likely to approximate, at best, the specific interests of companies.

Despite the overall favorable assessment of ERC contributions, evaluators found that "industry support for consortia-based fundamental engineering research is fragile."<sup>46</sup> Firms participated because the low membership fee provided access to millions of dollars of state-of-the-art engineering research and facilities. But that research, available to all members, did not provide the competitive advantage that companies sought. Nor are companies necessarily consistent in their aims. One ERC explained, "companies have chosen to withdraw based on the shortening of their time horizons. Simply stated, companies and their timeframes change quite often, with some companies coming and going."<sup>47</sup> Companies interviewed for this project expressed reservations about consortia. They were useful for learning about specific areas, figuring out 'is there anything here?' But they had little to offer for the firm's core competencies.

With the exception of electronics, described above, the tenuous nature of industry commitments represents the weak reed of consortia arrangements for universities.

From the perspective of universities, consortia are in many ways an ideal arrangement for supplying research to industry. Consortia are usually established in specialized areas of fundamental scientific or engineering research—the strength of universities. They provide a select group of faculty and students with infrastructure, support, and interaction with real-world problems. Thus, they are accretive to university learning and to economic relevance. For industry, consortia appeal predominantly to research-based corporations, which ration their investments for this kind of generic research. Smaller companies, in particular, tend to focus their R&D narrowly on achieving tangible results, and can spare few resources for longer-term enhancements.<sup>48</sup> This dichotomy is reflected in IP policy. Consortia usually grant non-exclusive, royalty-free licenses (called NERFs in the tech transfer world) to their affiliates for any patents emerging from the research. NERFs suit the practices of large corporations well, which meld these patents with their own IP and above all wish to avoid royalties; but smaller tech companies rely heavily on exclusive licenses to protect their technology. The success of consortia ultimately rests with the mutual benefits derived by both parties, but here the fragile economics reflect the limited price that industry will pay for rather intangible benefits. Thus, consortia generally need subsidies to overcome the fragility of this relationship.

Science-based corporations have increasingly sought arrangements to tap more deeply into basic research in strategic areas and to transcend the limitations of discrete research projects. Their goals are typically long-range—to gain foresight into possible future technologies, enrich the capabilities of their own research staff, or accelerate their capacity to act on relevant discoveries. The ideal would be a seamless mode of continuous collaboration so that companies not only had access to cutting-edge research, but could assimilate it into their own R&D—what H-P called “holistic engagement.” One crucial objective is to secure access to partners engaged in state-of-the-art research, whether universities or government labs. Generically, these efforts can be called ‘partnerships.’ Companies have taken different approaches and have achieved different degrees of seamlessness or engagement.

The ‘alliances’ of Air Products represent one step in this direction. They include master agreements to cover the usual contractual issues and are intended to provide a basis for long-term relationships. Air Products established alliances with Penn State, UC Santa Barbara, and Imperial College, London. Boeing has relationships with some 300 universities, and more extensive, ongoing ties with about forty, half of which are in the United States. However, for research designed to open new frontiers in an 8 to 15 year time frame, it has established ‘strategic partnerships’ with seven universities—Caltech, Carnegie Mellon, Illinois, MIT, Stanford, the University of Cambridge and the Indian Institute of Science. These partners receive \$500,000 annually for at least five years to investigate designated areas. The universities can retain any IP, but Boeing gets a NERF.<sup>49</sup> IBM too has relationships with virtually every major university, but about twenty of these links have the special designation of “collaborations.” In these, an IBM scientist is assigned to work directly with a university investigator, thus contributing to staff development and a long-term relationship beyond any project results. Often partnerships are frameworks for formalizing ongoing relationships in which specific research projects are initiated as needed.

Perhaps the most far-reaching partnership model has been implemented by Intel, which has inverted the usual pattern of collaboration by creating its own labs adjacent to key universities to foster joint research.<sup>50</sup> Dubbed the Open Collaborative Research Model, the centerpiece is a master agreement designed to avoid the usual conflict over IP rights. Research is open and publishable; patents are not an expected outcome, but any that arise are licensed on a non-exclusive basis. Labs were opened in Berkeley and Seattle in 2001. A Pittsburgh lab followed in 2002, which moved into the Collaborative Innovation Center on the Carnegie Mellon campus in 2005. The directors of the labs are faculty from computer science departments at the respective universities who take three-year leaves of absence to fill that position. They can use this unusual arrangement to focus intensively on ‘mutual skill sets.’ Other university scientists are welcome to participate, encouraged in some cases by Intel support for their graduate students. An Intel scientist serves as co-director of each lab and takes responsibility for communications with the company. Intel regards these labs as windows on the future. As the Berkeley director put it, “when you have collaborations going on with ... the best universities in the world ... you will hear about every important new research concept.”<sup>51</sup> Research projects are not aimed at Intel’s core manufacturing technologies (the role of SEMATECH), but at exploring future markets for Intel products. In probing frontier areas, such as intensive computing in distributed systems (Pittsburgh), the aim is no different from that of purely academic research.

Partner universities praise the Intel labs as valuable assets. Their presence increases the critical mass of expertise in subfields of computer science. They also expand the facilities available for certain kinds of research. The Intel labs particularly value the participation of students as a resource in themselves, but also because working with Intel can encourage future ties. At Berkeley, Intel scientists also teach courses on campus in their specialties. Intel’s Open Collaborative Model appears to offer considerable leverage to both parties. Intel is able to enhance the breadth and depth of its advanced research; and each university receives access to resources that increase the size and effectiveness of its computer science program. In Pittsburgh, moreover, collaboration has steadily expanded. The University of Pittsburgh and its Medical Center signed Open Collaborative Agreements, and at Carnegie Mellon participation has spread well beyond the computer science department.

The Open Collaborative Research model has been mutually beneficial because its aims are congruent with academic research. Intel finds the participation of students particularly stimulating, and the combination of professors and students together, as a result of their funding, especially “powerful.” Since its founding, the Pittsburgh lab has assisted with eight doctoral dissertations and filed for zero patents.<sup>52</sup> Even so, initiating or sustaining the right chemistry for this kind of collaboration can be problematic. A fourth Intel lab at the University of Cambridge was closed in 2005, partly for lack of participation. The model itself may not translate to other industries either, but the principles probably would. To tap into the best of university research, industry must accept the academy’s terms of open, publishable research on theoretically challenging themes without competition over IP rights.

More commonly, companies have made large investments to promote singular lines of research at individual universities. Such agreements first appeared in the 1970s and became more frequent during the biotech boom of the early 1980s. Industry predilection for long-term commitments seemed to wane in the 1990s, but reappeared at the end of that decade. The

motives were familiar: to establish lasting relationships with the highest quality academic research, to anticipate the next generation of innovation, and to inform internal R&D. However, these motives are usually attached to an open-ended technology with great promise for future development. In some of the earlier partnerships research was intended to target specific problems, and this is still the case with most biopharmaceutical partnerships; but recent agreements have been broader, aiming more at fundamental discoveries that will point the way toward future products and markets.

Among universities, MIT has led all others in establishing comprehensive industry partnerships. After forming its first ‘strategic alliance’ with Amgen in 1994, MIT concluded seven more such agreements from 1997 to 2000. Each called for \$3 to \$5 million of annual research, usually for five years.<sup>53</sup> According to then-president Charles M. Vest, such long-term agreements were based upon challenging research— “bottom-up faculty and company interest and commitment.” Partnerships provided both sides with benefits that transcended normal university-industry interactions: “all of these partnerships engaged multiple academic departments, and indeed multiple schools, and all ended up with significant educational objectives—development of new courses and pedagogy, as well as student support.” Faculty participants found these relationships to require “high maintenance,” but they were also a valued source of new ideas. MIT extends its normal policies to partnerships, namely, university ownership of IP and open publication of research results. An underlying concern was nevertheless present that working so closely with industry might bring distortions to academic research. However, when the Institute surveyed the faculty in 2002 “no one could site [sic.] an instance in which they believed it actually had.”<sup>54</sup>

Such partnerships were by no means easy to establish or maintain, even for MIT. The original impetus owed much to a corporate relations officer recruited from industry. His efforts were strongly supported by President Vest, who felt that MIT had relied too heavily on federal sources for research support and needed fresh stimulation from industry. Nonetheless, the most productive partnerships were based on pre-existing “deep relationships,” while those lacking such long-standing ties experienced greater tension. At least three partnership negotiations fell through for undisclosed reasons. Thus, besides basic agreement among scientists over aims and research objectives, partnerships require a commitment from the highest corporate officers, and even then were vulnerable to changes in leadership or corporate fortunes.<sup>55</sup>

The shortcomings of these generally successful partnerships pale in comparison with the most notorious—and misunderstood—partnership of this new era, that between the agricultural R&D unit of the Novartis Corporation, located in La Jolla, California, and the UC Berkeley Department of Plant and Microbial Biology [PMB]. This dismal tale sheds light on how major partnerships should and should not be structured.<sup>56</sup>

In terms of collaboration and potential innovation, the Novartis Agreement represents an opportunity lost. Two sets of highly qualified scientists with complementary research assets might have formed a larger critical mass and been able to drive advances in plant biotechnology; but campus opposition poisoned the relationship even before corporate developments undermined it. The extra funding and freedom afforded the Berkeley scientists by Novartis funds were a windfall while they lasted, and no doubt furthered individual research agendas. However,

the basis for enduring university-industry partnerships should be mutual benefit—*quid pro quo*. The critics naively assumed that the *quid* Novartis sought was a tangible product—a lucrative patent or genetically modified organism. But the real goal, at least originally, was greater learning that could feed into the internal R&D process and help prepare for future markets and products. Still, this kind of mutually beneficial learning is difficult to accommodate within an academic department. In this respect, the seeds of failure of the Novartis Agreement lay in its origins.

PMB recruited Novartis to resolve its own funding predicament, and thus could not avoid problems arising from having a corporation directly linked with an academic department. This situation rightly agitated critics. Partnerships would seem to require some degree of separation from the teaching and degree-granting core of universities. This can be accomplished through consortia, centers, or institutes, or separately organized labs. The strategic alliances at MIT involved such units but also were linked with departments and schools. Most important, separation should allow participation to be strictly voluntary, for faculty and for students. The separation of financial accounting also precludes the kinds of jealousy and backbiting that occurred at Berkeley over finite university resources, like lab space. And it permits meaningful participation by the corporate partner.

These lessons may have been learned. After this tumultuous marriage dissolved, both parties found their way to the partnership alter again in 2007. Berkeley joined with energy giant BP to create the Energy Biosciences Institute. This partnership was structured as a separate institute, where faculty from numerous departments, including PMB, and BP scientists will perform their own and collaborative research. The corporation will be on campus for purposes of collaboration, but entirely removed from the academic core. Novartis concluded a ten-year, \$65 million agreement to create the Novartis-MIT Center for Continuous Manufacturing. Actually a virtual center, MIT scientists and Novartis researchers will work in their own laboratories but collectively focus on developing processes for the continuous manufacture of drugs—a potentially valuable improvement over the prevailing batch method of production. In both cases, corporations wished to harness university expertise for challenges that spanned multiple fields and could scarcely be tackled through discrete grants. Although results will not be known for years, organizational arrangements in both cases seem consistent with productive partnerships and quite unlike the ill-fated Berkeley-Novartis pact.

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Large corporations maintain both extensive and intensive relations with university research. Extensively, they may sponsor limited research projects at literally hundreds of universities and other research facilities worldwide. These contacts create an information network touching an enormous array of expertise that can feed the innovative capacity of internal corporate R&D. In this arena, U.S. universities compete with other research performers. However, corporations have an incentive to support multiple nodes in order to maximize the power of the information grid, and this goal as much as anything explains why their contacts have been widening. Intensively, corporations have been making large, multi-year investments in research partnerships that will significantly advance innovation in targeted areas. For the most part, these agreements are highly congruent with university research and public science. That is,

they are usually consigned to an appropriate research unit; mutually satisfactory IP provisions are negotiated for the entire relationship; research is usually basic or long-term applied and thus consistent with the academic mission; student participation is encouraged and valued; and the collaboration is accretive to learning for both partners. These kinds of collaboration are most effective when industry's goals are pegged to future innovation, either in products, processes, or markets. When industry seeks to learn from basic research, partnerships with universities can be readily arranged, and common objectives are likely to be achieved. Thus, the payoff from these partnerships is not so much in the findings as it is in the doing, and as such represents a unique contribution of academic research to the enhancement of corporate innovation.

### **Corporate-Sponsored Research at Penn State**

The respective research paradigms of different industries and the various forms that corporate-sponsored research assumes combine to suggest a complex matrix in which conditions vary from cell to cell. An overview of all industry-sponsored research at PSU was undertaken in previous research, but did not probe these nuances.<sup>57</sup> This section discusses the qualitative findings of this project based on interviews with selected individuals associated with corporate-sponsored research at PSU. The specific aim was to gain an appreciation of the corporate point of view—how the purchasers of research services perceive the benefits or drawbacks of interacting with PSU. This research has major limitations. Scheduling difficulties restricted the number of interviews. The relatively small number of interviews could not encompass the complexity just alluded to. Contacts were suggested by the Industrial Research Office, and thus represent corporations with regular and, on the whole, friendly relationships with PSU. The richness of these data nevertheless provides some insight into corporate-sponsored research at PSU, and certain conclusions are made more credible by being consistent with the national trends discussed above.

Among the positive comments:

“One-stop shopping.” Perhaps the most frequent comment about PSU was the great breadth of research expertise existing at University Park. Especially for PA-based companies, Penn State offers convenient and high-quality research services across a wide range of needs—“world-class people in every field,” as one person put it.

Instrumentation. Similarly, the sophisticated instrumentation available at PSU was mentioned as an important attraction. Expertise in nanotechnology was specifically identified.

Industrial Research Office. Respondents relied on the IRO more than was anticipated. I had expected that corporate labs would seek out scientists from reputation, publications, or previous contacts, but apparently the ‘one-stop shopping’ phenomenon led corporations to use the IRO frequently to identify experts. The interviewees all worked regularly with the IRO, but their appreciation of its effectiveness seemed to exceed what might be expected from familiarity alone. When asked what steps by PSU might be helpful, one person said “double the size of the IRO.” Other comments indicated that many universities lacked this capacity to connect companies with the appropriate researchers.

Penn State Grads. Corporate-sponsored research cannot be separated from the positive attitudes toward PSU graduates. Often, access to well-trained students for potential hiring is a corporation's first goal of university relationships. It is a credit to the Colleges of Science and Engineering (in particular) that their students are valued so highly. Companies seem eager to hire more graduates, and supported internships and other programs to maintain this pipeline. PSU graduates sometimes play instrumental roles in suggesting or arranging research contracts. On campus, corporate research projects provide support and 'real-world' problems for students, which also facilitate recruitment. Thus, access to human capital is an important inducement for corporations to partner with PSU.

Federal Connection. Another unanticipated finding was the important role of federal research for companies (other than defense contractors). Corporate R&D labs seek federal contracts to leverage their own research and help to support lab overhead costs. These contracts can comprise one-quarter of a lab's R&D. Universities are valuable partners in these arrangements not least because they lend credibility to research proposals. This is also the case for SBIRs linked with corporate labs, where university ties seem to improve the chances for approval. With its abundant federal ties, Penn State would seem to be an especially good partner for securing federal contracts.

\$ value. Air Products, through the exercise described above, was the only firm that could put a monetary value on Penn State research. In 2002, based on 33 projects at Penn State, they estimated on average, each project saved one to two person-years of internal R&D and several hundred thousand of R&D expenditures. Thirty percent of this research resulted in the development of new research options. Most of the projects resulted in average commercial impact and only a few (5 projects) were estimated to result in \$10 million to \$50 million in sales. In most cases, however, contributions from university research occur too early in the product cycle to be usefully or accurately valued.

The following comments reflected critical observations of research relations with PSU:

Intellectual Property. There is nothing new about this long-standing grievance. Industry used to complain about having to pay twice—once for the research and then to license any discoveries, but this seems more of a rhetorical point. Their deepest objections stem from IP risk—the fear of compromising their own IP or being forced to pay an indeterminate amount of running royalties on goods they produce. Companies are fearful that their own IP might be compromised if universities patent an invention related to their proprietary technologies. They also refuse to countenance running royalties because any product incorporating a university patent will still depend on a large company investment in development. In addition, profit margins on commodity products are too narrow to allow royalty payments.

Companies object that universities take too hard a line on IP, that negotiations are time-consuming, and that legal costs can equal those for the proposed research. However, one could equally argue that firms are the ones taking intransigent positions. What is clear is that companies are acting on their aversion to university IP claims. They report seeking foreign partners who permit them to retain IP rights. Some companies have turned to smaller universities, eager for the research and accommodating on terms. Big Pharma will apparently

black-ball universities if contract negotiations require too much legal intervention. And, firms report terminating research relationships because of disagreements over IP, and this has reportedly occurred at PennState. Some respondents stated flatly that they would do more research with PSU if it were not for the university's claims on IP.

It is impossible to resolve this issue on the basis of conflicting and inconsistent anecdotal evidence. Penn State claims to be "flexible" in negotiating research agreements, and has successfully reached partnership agreements with Chevron and Bayer, for example. Several companies found Penn State relatively easy to work with in this respect, and one even interpreted PSU's low licensing revenues as reflecting an absence of greed! Another company was pleased that its agreement placed a cap on potential licensing royalties, thereby eliminating the possibility of unlimited claims. But all companies clearly would not agree that IP is no problem. Even when master agreements are in place, it is not unusual for special terms to be proposed for a new project in spite of these templates. In the eyes of industry, Penn State seems to be better to work with than some universities, but more difficult than others.

If any conclusion seems warranted, it would be that efforts should be made to minimize these conflicts. The potential rewards from increased research should far outweigh potential losses from concessions on licensing IP. Air Products, for example, has been adamant about IP issues,<sup>58</sup> but all of its research cooperation with PSU seems to have yielded a single joint patent. There are too many variables involved in negotiating unique research agreements to make specific recommendations about terms for IP. Nor is it clear that a more cooperative spirit on the part of PSU would be reciprocated by firms. However, a relaxation of licensing terms—offering NERFs, for example—in areas other than the life sciences might be advantageous in the long run. Compared with the IP issue, other negative comments were minor indeed.

Research timetables. A fairly standard complaint, universities are not well suited to produce research results in a timely manner for industrial needs. This is particularly true for faculty-student research. The need to support graduate students for one or more academic years ill fits industry projects. However, UARCs and institutes having full-time researchers ought to be able to perform projects on acceptable schedules.

Curriculum. Also standard are complaints that the curriculum is too theoretical and that students are not trained to work in teams. Such dissatisfaction may be dismissed as reflecting basic differences between industry and academia. In fact, several companies found PSU grads to be better suited for industry in these respects. A more serious kind of criticism alleges that universities are not teaching certain emerging fields. No such charges were made in these interviews. However, IBM has proposed a new curriculum in Services Science, Management and Engineering, and Intel has also offered curricular models. DuPont seeks to promote curricular updating through its Young Professor Awards. Where industry perceives theoretical lacunae, universities should recognize opportunities for constructive engagement.

Cross-disciplinary links. One company expressed the impression that linkages across the physical and biological sciences were poor. Another found the internal structure of Penn State to be a hindrance. These comments may reflect that university science is configured differently

from the company's scientific emphases, but these observations are worth pondering in light of Penn State's ongoing efforts to promote interdisciplinarity.

Persistence of long-term relationships. It emerged from some interviews that apparent long-term relationships between PSU and firms can actually be rather unstable, tending to thrive for a time and then become almost dormant. One explanation, as seen above, is that a single case of conflict can poison a relationship for years. More likely, these relationships are critically dependent on individuals and their career paths. When 'champions' depart the company, or favored collaborators leave the university, relationships can falter. Universities would do well to be sensitive to both of these situations and take steps to counter these effects.

### **University Supply and Industry Demand for Research**

Penn State has an avowed interest in expanding corporate-sponsored research, particularly substantial, long-term partnerships with large corporations. Many of these same corporations have, like Bayer, DuPont, and Air Products, embraced the Open Innovation model that directs them to seek ideas and inventions outside of corporate walls. Why then has the growth of university-industry research been so sluggish, even if less so at PSU? The foregoing material provides a basis for pondering this question, but also for reframing it. When the issue is framed in terms of university supply and industry demand, the limiting conditions presented by the nature of this research become apparent.

Existing patterns of corporate-sponsored research, at PSU or nationally, represent conditions in which supply meets demand—the point where supply and demand curves intersect. Yet, universities have far greater potential supply of research, and industry potentially greater demands. In this case pricing does not determine the slopes of these curves, but rather the nature, terms, and arrangements of research. Understanding how these conditions affect supply and demand should suggest ways in which university supplied research might be able to stimulate or attract additional industry demand.

Corporations have considerable discretion in the amounts they spend for R&D, and all the more so for spending for external and forward-looking research. With an average of 94 percent of R&D performed in-house, corporate labs are not necessarily open to Open Innovation. They are notorious for having a "not-invented-here" culture, and internal champions are sometimes needed to sustain productive research-relations with universities. Management of external research arrangements, to keep academic researchers on task and to ensure that findings will be assimilated internally, is an ongoing challenge. For major partnerships, the consensus holds that they must be supported at the highest level of management for any hope of success.

On the positive side, firms commission university research for a variety of reasons. Nearly 70 percent of this research is basic in character. But basic research comprises less than 5 percent of industry R&D, and universities garner only 16 percent of that. Industry purchases a variety of research services from universities, which might be basic or applied. Interviewees noted Penn State's advanced instrumentation as an important attraction. However, industry has a limited demand for the more theoretical kinds of basic research in which universities specialize.

One person said that basic research was too expensive for his company, and thus better left to universities. Firms seek basic exploratory research when they perceive its direct relevance to technologies they wish to develop; for example, the support for nanotechnology at PSU by Bayer MaterialScience. Some engagement with universities can be justified as ‘listening-posts,’ which was one motive for Intel’s distinctive model. Firms find universities particularly valuable for learning new or unfamiliar fields. The enormous BP-Berkeley Bio-energy partnership should be seen in this light; BP wished to enter this field but had few internal biologists.

Of these three motives—directed exploratory research, listening posts, and new learning—probably the first stimulates the most university-industry cooperation. Listening posts are expensive and fairly focused, and acting on any intelligence acquired presupposes an internal capacity for assimilation. Large learning initiatives are rare and require major corporate commitments, although research for new products or markets frequently requires getting up to speed in unfamiliar areas. In this respect, consortia represent learning opportunities for pre-competitive knowledge. But focused basic research that promises to contribute to the development of new products is probably the area having the greatest potential for stimulating additional demand for university research. This rationale would fit the PSU-Chevron partnership for coal-conversion technologies or the MIT-Novartis pact for continuous manufacturing. DuPont’s partnership with MIT similarly represents initiatives in biomaterials that have yielded publications and patents—knowledge and potential products. Where fundamental research topics are involved, universities are generally eager to provide supply.

When conceptualizing the university supply of research one should be wary of stereotyping a continuum from pure, theoretical (and highly desirable) to mundane, applied (and low status). This simplistic distinction was always suspect, and has been further undermined by the prominent role of science-based technologies. There are vast differences in problem preferences from physics to engineering. ‘Practical’ industrial research can stimulate the advancement of knowledge with real-world problems and technological challenges. Charles Vest, for example, felt industry partnerships would stimulate research at MIT that had become overly theoretical.<sup>59</sup> Nevertheless, there are significant differences in the types and attractiveness of industry research.

Practical limits to the supply of university research are posed by the number of potential investigators and the physical infrastructure. Still, some forms of research can be expanded more readily than others. Two ideal types might be imagined—a faculty model and an institute model. For the first, research projects must pass the critical threshold of being sufficiently interesting for faculty and their students. Faculty members are intellectually sovereign: as one said, “academics do what they want to do, regardless of research contracts.” Thus, research involving faculty and students is bounded by suitably challenging subject matter as well as by finite available time. Such limits are greatly relaxed for research institutes that employ full-time staff. Most such units want to perform additional research for financial reasons and because it is their mission. They are less squeamish about doing ‘work-for-hire’ if it will support the operation.

The different forms of university-industry collaboration represent different conditions of supply and demand. The definition of ‘work-for-hire’ research would be that explicit deliverables are the stipulated outcome. Clinical trials and materials characterizations would fit

this description, as would some uses of unique university instrumentation. A competitive market exists for these kinds of services, but universities—or other providers—may offer advantages for particular services. These differences are sorted out in the marketplace. However, university research units seem willing to supply such services without apparent limits. The learning value for these services may be low for advancing knowledge, but they may play a role in training students. Above all, they enhance cash flow to the unit, thus enabling other learning activities.

It was suggested above that \$50-60K contracts for faculty-student investigations were the baseline for corporate-sponsored research. Here faculty interest is the threshold condition limiting supply. However, once that condition is met, supply seems ample. In fact, the eagerness of PIs for these contracts apparently leads them to under-price their services by charging too little for their own time or for university costs. For faculty scientists and engineers these projects represent valued inputs: cash flow to their laboratories; financial support, real-world problems, and possible future jobs for their students; a potential source of theoretical problems for PIs; and a foundation for future, possibly larger collaborations. These inducements help explain why PIs tend to under-price their research.

For corporate R&D these projects represent discreet inputs of knowledge, but demand is limited by several factors: IP risk; distant links between these inputs and competitive advantage; constraints to assimilating external research; and the informational challenge. This last factor refers to inefficiency in recognizing that external research might solve internal problems or in identifying external researchers who could do so. University action can only influence two of these factors. As argued above, minimizing IP risk might attract more of this kind of research to a university rather than to other providers. The informational challenge might be attenuated through better lines of communication. For example, the planned meetings between research directors at PSU and their counterparts at Northrup-Grumman (Baltimore) holds possibilities for increasing the scale and efficiency of matching of research needs with research capabilities—of connecting demand with supply.

For universities, greater benefits can be had by establishing larger and longer-lasting modes of performing corporate-sponsored research that support faculty-building, graduate programs, and infrastructure. Consortia and government-supported centers for collaborative research represent supply-side approaches for accomplishing this. Engineering Research Centers, now in their third generation, have been largely successful exemplars of this approach. Universities determine the focus of research and recruit industry partners; NSF vets the science, chooses winning proposals, and provides most of the funding. Industry can benefit from this large investment in state-of-the-art science/engineering at relatively little cost. Still, benefits seem to depend heavily on the fit between corporate R&D and the ERC focus. The terms of trade are reversed for the smaller Industry/University Cooperative Research Centers. NSF functions largely as a facilitator and industry must furnish the bulk of operating funds. Here demand from industry is essential to bring these initiatives to fruition.

Consortia are not always attractive options for universities, particularly in the absence of government subsidies. They are generally high-maintenance operations, which diminishes their appeal for faculty. Where members are given voice in research selection, as is usually the case, the focus can drift toward less academic and more applied problems. The interests of both parties

best coincide in areas where universities have strong commitments and spillovers to industry can be expected.

Supply-side initiatives are congruent with the university's natural role of exercising leadership in advancing knowledge. When taken in strategically chosen areas they can provide vehicles for mobilizing government and corporate support. The Electronic Design Center at Georgia Tech is an outstanding example of organized research supplied to anticipate and to create industry demand. The energy initiatives taken at Penn State in accordance with the "Report of the 2006 Energy Task Force" also promise to supply research that will be significant for industry.<sup>60</sup> The catch is that such initiatives often require extensive front-end funding, just like the ERCs, for their joint mission of advancing academic and industrial knowledge.

Partnerships can be the most valuable form of corporate collaboration. They represent industry demand for basic university research and access to research frontiers, as well as a preference for trusting, conflict-free relationships. Corporate demand for such relationships has clearly been growing in the 21<sup>st</sup> century. In the computer industry, Hewlett-Packard called it 'holistic engagement,' and Intel, DuPont, and IBM have pursued similar goals. For the energy giants the challenge has been to develop strategies and products in entirely new fields where they lacked expertise. DuPont seeks to advance critical technologies at each of its long-term partner universities. Big Pharma takes a focused approach, seeking university expertise to attack specific, multifaceted problems. These partnerships benefit universities by furthering the development of key fields of knowledge. The investments are not major commitments for these huge corporations, yet they are not taken lightly by publicly owned, profit-fixated firms. Investing in knowledge with possible but uncertain future value seems to require confidence in the future of the economy and the company.

Since the impetus for partnerships comes from corporations, universities have limited ability to influence such decisions. Even at MIT, which deliberately sought to form partnerships, they often depended on long-standing 'deep relationships.' Above all, corporations seek to partner with academic leaders of particular fields. The keys to partnerships are thus good practice for any university: cultivate deep and trusting relationships with technology-based corporations and strive for academic excellence.

### **Strategic Directions for Enhancing Corporate-sponsored Research**

This Report has examined corporate-sponsored research at Penn State and nationally from a general perspective. It cannot recommend specific actions to the myriad units that perform and facilitate this research. Rather, this analysis has highlighted general features of this relationship that should suggest strategic directions for future university policies.

- *Supply and Demand:* Industry demand for university research is variable in two ways: 1) this market is highly competitive and growing more so; firms have numerous choices among research performers; and 2) for basic, university research, company needs are largely shaped by intangible factors. As for supply, Penn State has the capacity to perform additional corporate-sponsored research and would benefit from doing so.

Hence, Penn State could potentially enhance corporate-sponsored research by competing more effectively for existing research demands and by stimulating corporate consumption of basic research through close relationships. Competition for discretionary corporate research dollars has intensified, and the competition is less from universities than other sectors. Future progress will require deliberate competitive strategies.

- *Cultivating Deep Relationships:* Penn State has developed relationships of trust with many of its industrial partners, but probably not all. These deep relationships have the potential for large payoffs: namely, continuing research contracts; employment opportunities for graduates; the possibility of larger partnerships; and the potential for corporate gifts. Hence, the benefits of deep relationships should be emphasized. Where they exist, vigilance toward possible problems is needed to avoid deterioration.
- *Enhanced Communications:* Greater communication with the R&D arms of corporations helps to build relationships and also to identify more situations where Penn State supply can match industry demand. One industry rep commented that Materials Day was a valuable and low-cost opportunity for his company. These networking activities consume scarce human resources, but these costs should be measured against the possibility for productive outcomes. In addition, several companies reported having searchable databases for faculty expertise. Strategies should be considered to ensure that the expertise of Penn State scientists is included in these databases.
- *Minimize Conflict over IP:* Little trust will exist when firms fear that their IP is at risk. Similarly, faculty resent having research relationships obstructed by stipulations for what they regard as improbable IP outcomes. The problem is not with university ownership but with the terms for licenses. This difficulty can apparently be overcome for larger partnerships; it should also be handled flexibly for routine contracts in the interest of building relationships.
- *Publicizing Penn State Initiatives:* Regardless of the university's substantial achievements in this area, it might be advantageous to send a louder message about the university's commitment to provide greater services to industry and economic development. Appropriate occasions might be found—some new initiative, the new Materials Research Building, filling a new position in corporate relations—to publicize what Penn State is doing and intends to do more of.
- *State Policy to Bolster Corporate Research:* Given the contribution to the economy of corporate-sponsored research, particularly by Pennsylvania companies, it should be a legitimate object for support from the Commonwealth. Since 'corporate welfare' is not politically attractive, and neither is 'university welfare,' finding a suitable target is a challenge. The best hope might be a program similar to "Eminent Scholars" of the Georgia Research Alliance. The GRA offers matching grants for faculty chairs in economically relevant fields. Usually the other half of the match is provided by a company that wishes to work with the appointed professor. These are complicated to arrange—and hence not very expensive or numerous (currently, \$27 million/year), which might make them palatable to the Commonwealth. But the benefits are substantial—an

eminent appointee who will bring in federal and corporate funding and advance a strategically important field. For Pennsylvania, such a program might be open to all ranks and restricted to Pennsylvania-based companies.

*South Carolina Model:* A similar program was established in South Carolina in 2002 for creating ‘Centers of Economic Excellence’ at the three state universities. The state committed \$200 million over eight years, but these funds are not awarded until the match is in hand. To date thirty-four centers have been approved. Each center receives a \$2-5 million grant from the program, which must be matched by other funds. This provides up to \$10 million in endowment for research programs that promise high economic impact and high academic quality. Proposals receive a scientific review and an onsite panel review before being submitted to the politically appointed Review Board. The South Carolina Centers stimulate universities to develop new initiatives in those fields having greatest relevance to the state economy, and thus contribute to both academic and economic development.

- *Policy Analysis for Technology-Based Economic Development:* The Universities of Arizona and California support offices that conduct research on such topics as high-tech industry clusters, commercialization of university research, and economic impact. Their studies help to inform state officials, the press, and the university community about tech-based economic development. Penn State has such an enormous economic impact that it might be worthwhile to provide a locus for synthesizing, analyzing, and disseminating such findings.

## Notes

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- <sup>1</sup> Roger L. Geiger, “Patterns of Industry Sponsored Research at Penn State: Implications for Economic Development” (August, 2006); Creso Sá, “Local Industry and University Roles in Technology-Based Economic Development” (July, 2006).
- <sup>2</sup> Robert Buderer, *Engines of Tomorrow: How the World’s Best Companies Are Using Their Research Labs to Win the Future*, (New York: Simon & Schuster, 2000).
- <sup>3</sup> NSF, *Science and Engineering Indicators, 2008*, Appendix tables 4-6, 4-10.
- <sup>4</sup> Calculated from *S & E Indicators, 2008*, Appendix table 4-6; Scientific publications by industry scientists peaked in the first half of the 1990s, but fell to a lower level thereafter: *S & E Indicators, 2006*: Figure 5-51.
- <sup>5</sup> See Jerry Thursby and Marie Thursby, *Here or There? A Survey of Factors in Multinational R&D Location* (Washington, D.C.: National Academies Press, 2006); idem., “Where Is the New Science in Corporate R&D?” *Science*, 314 (8 December 2006): 1547-8; also, John Tao and Vincent Magnotta, “Open for Business: the Air Products and Chemicals Story,” in Edward Kahn, ed., *Innovate or Perish: Managing the Enduring Technology Company in the Global Market*, (Hoboken, New Jersey: Wiley, 2007), 189-222, esp. 204-8; and interviews by author.
- <sup>6</sup> Thursby and Thursby make an important distinction between research for new products vs. familiar products: the latter is more like development, and the former more likely to involve basic research: *Here or There? The story of Microsoft’s basic research lab in Beijing illustrates the complexities and potential of conducting research in China*: Robert Buderer and Gregory T. Huang, *Guanxi (the Art of Relationships): Microsoft, China, and Bill Gates’s Plan to Win the Road Ahead* (New York: Simon & Schuster, 2006).
- <sup>7</sup> Testimony of Susan B. Butts, Dow Chemical Company, before the Subcommittee on Science and Technology, U.S. House of Representatives: “Bayh-Dole—the Next 25 Years,” (July 17, 2007).
- <sup>8</sup> NSF, *S & E Indicators, 2008*, I, 4-53.
- <sup>9</sup> Of course, this is a two-way trade. NSF estimates show slightly more foreign R&D investments in the U.S. than vice-versa. The balance of trade almost certainly favors universities, but this figure is unknown: Ibid., Figure 4-29.
- <sup>10</sup> Author’s calculations from Ibid., II, Appendix tables 4-5 & 4-50.
- <sup>11</sup> Author’s calculations from NSF, “Survey of Industrial Research and Development: 1995,” Table A-7; NSF, “U.S. Industrial R&D Performers Report Increased Expenditures for 2004,” (NSF 07-304: December, 2006). From 1985 to 2004 the research share of the largest corporations ( $\geq 25,000$ ) declined from 58% to 41%; firms with 500-4,999 employees also gained nearly 9%.
- <sup>12</sup> *S&E Indicators, 2006*, Chapter 4.
- <sup>13</sup> Data from Pharmaceutical Research and Manufacturers of America, *Pharmaceutical Industry Profile 2006*. For a critique of industry R&D claims, Marcia Angell, *The Truth about Drug Companies* (New York: Random House, 2004), 37-51.
- <sup>14</sup> Marks & Clerk, “Biotechnology Report 2007,” reported in Cambridge Network; <http://www.cambridgenetwork.co.uk/news/article/default.aspx?objid=35257>. The other three patenters were Japan Science and Technology Agency (#1), NIH (#3), and the University of Tokyo (tie #22). Patent families are multiple patents for the same invention. Marks & Clerk is a trademark attorney.

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- <sup>15</sup> Michael P. Gallaher, Albert N. Link, and Jeffrey E. Perusa, *Innovation in the U.S. Service Sector* (New York: Routledge, 2006), 90-92.
- <sup>16</sup> Arthur D. Levinson, quoted in *Wall Street Journal*, (June 5, 2007), B2; see also, Joseph Cortright and Heike Mayer, "Signs of Life: the Growth of Biotechnology Centers in the U.S." Brookings Institution Center on Urban and Metropolitan Policy, (2002).
- <sup>17</sup> Jason Owen-Smith and Walter W. Powell, "'Accounting for Emergence and Novelty in Boston and Bay Area Biotechnology,'" in Pontus Braunerhjelm and Maryann Feldman, eds., *Cluster Genesis: the Emergence of Technology Clusters and their Implications for Government Policies* (New York: Oxford University Press, 2006), 61-86.
- <sup>18</sup> Gordon E. Moore, "Some Personal Perspectives on Research in the Semiconductor Industry" in Rosenbloom and Spencer, *Engines of Innovation*, 165-74, quotes pp. 168, 170; Buderer, *Engines of Tomorrow*, 325-42, quote p. 332. Intel now has programs to promote entrepreneurship in universities and recommendations for engineering curriculum: <http://www.intel.com/education/highered/index.htm>.
- <sup>19</sup> Buderer, *Engines of Tomorrow*, 310-11; *Guiding Principles for University-Industry Endeavors*, Report: National Council of University Research Administrators and Industrial Research Institute, (April, 2006), p. 12; Roger L. Geiger & Paul Hallacher, "Nanotechnology and the States: Public Policy, University Research, and Academic Development in Pennsylvania," Report to the NSF, Grant #0403783, (July 2005), p. 23.
- <sup>20</sup> Moore, loc. cit., 172.
- <sup>21</sup> Discussed in Roger L. Geiger and Creso Sá, *Tapping the Riches of Science: Universities and the Promise of Economic Growth* (Cambridge: Harvard University Press, in press).
- <sup>22</sup> David L. Kirp, *Shakespeare, Einstein, and the Bottom Line: the Marketing of Higher Education*, (Cambridge: Harvard University Press, 2003), 207-220; [www.gigascale.org](http://www.gigascale.org).
- <sup>23</sup> The four units are: Global Research Collaboration, Focus Center Research Program, Nanoelectronics Research Initiative, and Education Alliance: [www.src.org](http://www.src.org).
- <sup>24</sup> Wayne Johnson, Testimony before the Committee on Science and Technology, Subcommittee on Technology and Innovation, "Bayh-Dole—the Next 25 Years," (July 17, 2007), quote p. 4.
- <sup>25</sup> John Tao and Vincent Magnotta, "Open for Business: the Air Products and Chemicals Story," in Edward Kahn, ed., *Innovate or Perish: Managing the Enduring Technology Company in the Global Market*, (Hoboken, New Jersey: Wiley, 2007), 189-222.
- <sup>26</sup> Susan Butts, Testimony before the Committee on Science and Technology, Subcommittee on Technology and Innovation, "Bayh-Dole—the Next 25 Years," (July 17, 2007).
- <sup>27</sup> Johnson, Testimony, loc. cit., quote p. 9.
- <sup>28</sup> Rick Mullin, "Troubled Partnership," *Chemical and Engineering News* (March 19, 2007): 25-28; Tao and Magnotta, "Open for Business."
- <sup>29</sup> Mark Lemley, "Patenting Nanotechnology," *Stanford Law Review*, 58 (2005); 601f.
- <sup>30</sup> Radhika Prabhu, "Knowledge Creation and Technology Transfer in Nanotechnology at Research Universities," Ph.D. Thesis (Pennsylvania State University, 2007), 108, 120.
- <sup>31</sup> Michael R. Darby and Lynne G. Zucker, "Grilichesian Breakthroughs: Inventions of Methods of Inventing and Firm Entry in Nanotechnology," NBER Working Paper 9825 (Revised November 2003); Lynne G. Zucker and

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Michael R. Darby, "Socio-economic Impact of Nanoscale Science: Initial Results and Nanobank," NBER Working Paper 11181, (March 2005).

<sup>32</sup> The PowerShares Lux Nanotech Portfolio ETF (PXN) has traded since November, 2005.

<sup>33</sup> Martha Collins, Director, New Applications Research, quoted by Henry W. Chesbrough, "Why Companies Should Have Open Business Models," *MIT Sloan Business Review*, 48, 7 (Winter 2007): 22-8, quote p. 26.

<sup>34</sup> Press Release for Electro-Optics Center (October 5, 2006).

<sup>35</sup> For FY2006, 60 percent of GTRI contract awards were from the DoD, and another 19 percent from "industry/federal subcontracts": Georgia Tech Research Institute, *2006 Annual Report: Research for the Real World*, [www.gtri.gatech.edu](http://www.gtri.gatech.edu).

<sup>36</sup> Edwin Mansfield and Jeong-Yeon Lee, "The Modern University: Contributor to Industrial Innovation and Recipient of Industrial R&D Support," *Research Policy*, 25 (1996): 1047-58; Lucien Paul Randazzese, "Profit and the Academic Ethos: the Activity and Performance of University-Industry Research Centers in the United States," Ph.D. diss., Carnegie Mellon University, 1996; Feller, et al., "Impact of Research Universities," 467-8; Geiger, *Knowledge and Money*, 182-6.

<sup>37</sup> Roger L. Geiger, "Patterns of Industry Sponsored Research at Penn State: Implications for Economic Development," Unpublished Report to the Vice President for Research, Pennsylvania State University, (August 2006).

<sup>38</sup> Tao and Magnotta, "Open for Business," quotes pp. 195-6. Air Products has long analyzed university partnerships: John C. Tao, "Building Industry-University Research Partnerships: Corporate Perspective" in Chemical Sciences Roundtable, *Research Teams and Partnerships: Trends in the Chemical Sciences: Report of a Workshop*. (Washington, D.C.: National Academy Press, 1999), 50-65.

<sup>39</sup> Merrill S. Brenner and John C. Tao, "You Can Measure External Research Programs," *Research-Technology Management* (May-June, 2001), 14-17.

<sup>40</sup> Roger L. Geiger, *Knowledge and Money: Research Universities and the Paradox of the Marketplace* (Stanford: Stanford University Press, 2004).

<sup>41</sup> Irwin Feller, Catherine P. Ailes, J. David Roessner, "Impacts of Research Universities on Technological Innovation in Industry: Evidence from Engineering Research Centers," *Research Policy*, 31 (2002): 457-474.

<sup>42</sup> Michael D. Santoro and Alok K. Chakrabarti, "Corporate Strategic Objectives for Establishing Relationships with University Research Centers," *IEEE Transactions on Engineering Management*, 48,2 (May 2001): 157-63. Gifts in kind (e.g. equipment) are frequently used for relationship building.

<sup>43</sup> Cohen, et al., "Links and Impacts," 16-17; interviews, corporate research project.

<sup>44</sup> ERCs are proposed by universities according to NSF guidelines. Industry partners pay a nominal membership fee to participate, and may commission additional research projects. This formula appeals principally to large corporations with R&D labs. The 2007 RFP for a third generations of ERCs explicitly added participation of small companies to the stipulated criteria:

<sup>45</sup> The following draws on the evaluation of ERCs in 1995-1996 reported in Feller, et al., "Impacts of Research Universities." See also, D. Fennel Evans and Matthew V. Tirrell, "Research Teams at Universities: the Center for Interfacial Engineering" in Chemical Sciences Roundtable, *Research Teams*, 42-49.

<sup>46</sup> Feller, et al., "Impacts of Research Universities," p. 471.

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- 47 Evans and Tirrell, “Research Teams,” 49.
- 48 Santoro and Chakrabarti, “Corporate Strategic Objectives.”
- 49 Charles Concannon, “University R&D Collaboration,” presentation to SSTI Annual Conference, Oklahoma City, (November 1, 2006).
- 50 See [www.intel-research.net](http://www.intel-research.net). These labs also represent a significant shift in research strategy at the corporation toward more basic research and co-publication with academic researchers. This strategy seems to have survived a corporate revamping in 2005.
- 51 Eric Brewer, quoted in “Intel Research Berkeley Collaborating to Change the World,” [http://:www.intel.com/research/labs/htm](http://www.intel.com/research/labs/htm).
- 52 Interview by author.
- 53 Sachi Hatakenaka, *University-Industry Partnerships in MIT, Cambridge, and Tokyo: Storytelling across Boundaries* (New York: Routledge Falmer, 2004), 98-117; <http://web.mit.edu/newsoffice/nr/2000/alliance.html>. The corporate partners were, Amgen, Merck, Ford, NTT, Merrill Lynch, DuPont, Microsoft, and Hewlett-Packard.
- 54 Charles M. Vest, *The American Research University from World War II to the World Wide Web* (Berkeley: University of California Press, 2007), 45-6.
- 55 Hatakenaka, *University-Industry Partnerships*, quote p. 108; Vest, *American Research University*, 45.
- 56 Alan P. Rudy, et al., *Universities in the Age of Corporate Science: the UC Berkeley-Novartis Controversy*, (Philadelphia: Temple University Press, 2007); Robert M. Price and Laurie Goldman, “The Novartis Agreement: an Appraisal,” *Administrative Review*, UC Berkeley, (October 4, 2002). My thanks to Robert Price for providing this document.
- 57 Geiger, “Patterns of Industry Sponsored Research.”
- 58 Magnotta and Tao, “Open for Business.”
- 59 Vest, *American Research University*, 44.
- 60 Frank R. Baumgartner, et al., *A Strategic Energy Initiative for Penn State: Report of the 2006 Energy Task Force*, Pennsylvania State University (September 2006).