Contributions of Academic Research to Industrial Performance in Five Industry Sectors

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ABSTRACT. Results are presented of a National Academy of Engineering consensus study that documents the contributions of academic research to the growth and competitiveness of five industries − aerospace; financial services; medical devices; network systems and communications; and transportation, distribution, and logistics services. Academic research has made substantial contributions in varying degrees to all five industries. These have ranged from graduates trained in modern research techniques, to fundamental concepts and "key ideas" out of basic and applied research, to the development of tools, prototypes, and marketable products, processes, and services. In network systems, there is a history of university involvement in serving as test beds for new networking concepts and in spawning firms. The academic medical center provides a distinctive environment for testing and incremental improvement of medical devices and for conducting essential clinical trials. In financial services, academic economics and mathematics research contributions have been important, in spite of the lack of a well-developed R & D infrastructure for the industry. Challenges and opportunities for enhancing academic research contributions are presented in the areas of regulatory research and innovation, service sector innovation, information technology, intellectual property rights, and the role and identity of the university.

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1. Introduction

In 1998, the National Academy of Engineering (NAE) launched a study to document and assess the contributions of academic research to the performance of U.S. industry in five industry sectors (National Academy of Engineering, forthcoming). A 15-member consensus study committee, chaired by Jerome Grossman, Chairman and CEO, Lion Gate Management Corp., was appointed to execute the project. Committee members included experts from both industry and universities, many of whom were members of the NAE. Five industry groups were selected for study: aerospace (AERO); financial services (FS); medical devices and equipment (MDE); network systems and communications (NSC); and transportation, distribution, and logistics services (TDL). Using a common framework for analysis developed by the NAE committee, all five industry panels of five or six members each prepared or commissioned case studies of specific knowledge technology transfers; conducted informal e-mail or letter surveys of academic, industrial, and other experts; and convened major fact-finding workshops throughout calendar 1998.

The five industries represent a diversity of research fields and industry structures. All five are important industries in terms of sales and employment, technological intensity, expected growth rates, or other metrics (see Figure 1). Two of the industry groups, MDE and NSC, were recognized as having a strong recent tradition of extensive collaboration with academic research. The other three groups, AERO, TDL, and FS, are generally perceived as having much more

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Aerospace (AERO): Includes five subsectors ranging from the more mature large-scale airframe, jet engine, and launch vehicle businesses to emerging businesses, such as unmanned aerial vehicles (UAVs) and space-based information systems; all of aerospace accounted for roughly $148 billion in sales and 577,000 people employed in 1997; commercial satellite communications systems accounted for another $20 billion in sales and 87,000 employed in 1998.

Network Systems and Communications (NSC): Includes computing and communications equipment, software, and services (basically all information technology (IT) minus semiconductors); roughly one-half trillion dollars in sales and over 4million people employed in 1998.

Medical Devices and Equipment (MDE): Includes all Food and Drug Administration (FDA) Category 3 and some Category 2 devices and equipment; roughly $50 billion in sales and 270,000 people employed in 1997; as well as medical information systems which accounted for roughly $12 billion in sales in 1996.

Financial Services (FS): Includes all services associated with the packaging and description of financial securities, and the implementation of financial transactions; roughly $560 billion dollars in gross domestic product and more than five million people employed in 1996/1997.

Transportation, Distribution and Logistics (TDL): Focusing on integrated logistics services. Costs associated with the nation's business logistics system – inventory carrying costs, and transportation and administrative costs associated with moving freight and people – were $898 billion or roughly 11 percent of Gross Domestic Product in 1998; in 1997 employment in transportation occupations alone was 4.5 million.

SOURCES: Delaney (1999); Dorenfest (1997); McGraw-Hill & U.S. Department of Commerce (2000); U.S. Bureau of the Census (1999); U.S. Department of Transportation (1999).

Figure 1. Industry Definitions*

Aerospace (AERO): Although there are some innovative areas, most innovation in the larger subsectors is directed towards incremental improvements and cost reductions over a longer period of time than in the other industries. Heavy government support for R&D has been reduced in recent years.

Network Systems and Communications (NSC): Well developed innovation system fostering rapid creation and implementation of new innovations, facilitated by a research culture and an industry structure that promotes innovation. Major growth segments currently unfettered by excessive regulation. Heavily market and technology driven. Substantial R&D support.

Medical Devices and Equipment (MDE): Well-developed innovation system benefiting from broad public interest and support, including nonprofit organizations. Probably the most regulated of the five industries and affected by government policy towards health care payments. Substantial R&D support.

Financial Services (FS): A nascent, organized innovation system is slowly beginning to emerge, driven by rapid improvements and changes in information systems and technology. R&D activity, overall, is rudimentary and not broadly supported. The needed R&D mix may be less technological and more business, organizational, and social science oriented, although all sectors could benefit from some of this focus.

Transportation, Distribution and Logistics (TDL): This services oriented industry has a less well established innovation system more akin to FS than to MDE or NSC. Although the transportation system has lacked a focus on R&D and technology-driven innovation, developments in integrated logistics are establishing new R&D and innovation linkages. However, support for R&D in integrated logistics is modest.

SOURCE: National Academy of Engineering (forthcoming).

* Drawing on Lundvall's (1992) definition of national innovation systems, we define an industry's system of innovation as being "constituted by elements (people, capital, organizations, *et al.*) and relationships that interact in the production, diffusion and use of new, and economically useful, knowledge" within a given industry.

Figure 2. Innovation systems * for five industries

limited and less systematic interaction with the academic research enterprise. All five industries have generally demonstrated an impressive capacity for innovation over the past decade. However, only the three industries heavily involved in manufacturing, NSC, MDE, and AERO, have longstanding, well-developed R&D functions. By contrast, the two predominantly service industries, FS and TDL, have only recently begun to develop an R&D ethos (see Figure 2).

2. Comparative assessment and findings

University-industry research interaction varies from sector to sector

Each of the industry sectors provides a distinctive environment and set of somewhat different challenges for university researchers. As a result, the nature of the university-industry research interaction varies from sector to sector. In network systems, there is a history of university involvement in infrastructure building, with universities serving as test beds for new networking concepts and capabilities. There is also a strong national research culture in NSC that fosters innovation by supporting the movement of ideas and people across a broad range of diverse research structures. In medical devices, the academic medical center provides a unique environment for testing and incremental improvement of devices, and for conducting essential clinical trials to obtain regulatory approval in an atmosphere of close industry-university collaboration. In aerospace, the mature, highly concentrated airframe, propulsion, and launch vehicle subsectors have a fairly narrow focus with respect to academic research per se, using consultancies and contract research to extract better process methodologies and tools. In the TDL and FS industries there remains a sizeable cultural gap between industry and both academic research and R&D in general. As result, neither has developed interfaces with academic research comparable to MDE or NSC.

The contributions of academic research

Academic research has made substantive contributions in varying degrees to the performance of all five industries. The breadth of research contributions have ranged from graduates trained in modern research techniques, to fundamental concepts and key ideas out of basic and applied research, to the development of tools, prototypes, and marketable products, processes, and services. The disciplinary sources of these contributions have spanned the fields of engineering, the natural and computer sciences, mathematics, as well as the social, behavioral, management, and policy sciences.

Research-trained graduates. University-based research provides a training ground for future entrants into the industrial workforce. Integration of research and education helps create an outward flow of human resources from the university that results in an educated industrial work force as well as new spin-out companies and start-ups. A rising tide of entrepreneurship in universities is making it possible for some research-trained students to participate in commercially relevant activity while at the university. Demand for research-trained graduates is particularly high in the MDE and NSC industries. In FS and TDL, demand for graduates with research training is concentrated in a very small number of leading companies and the consulting and software companies that serve the industries. Startups are a strong force that attracts students, graduates, and faculty in several of the industries. University graduates sometimes embark on a startup prior to graduation, based on ideas formulated or prototyped while students.

Basic, long-term research contributions. Contributions of basic, long-term academic research have figured prominently in all five industries. Portfolio theory, linear programming, derivative pricing theory, and prospect theory, all of academic origin, have laid the foundation for whole new families of financial products and services. Likewise, academic contributions to linear and integer programming and queuing theory are the building blocks of information management and decision support technologies at the heart of the integrated logistics revolution in TDL. Medical devices such as magnetic resonance imaging machines and fiber optic laparoscopes are built on fundamental academic research contributions from a variety of fields, including physics, mathematics, electrical engineering, computer science, and materials science as well as the life sciences. In NSC, the history of the Internet shows a 30-year trajectory of academic and industrial R&D to build a revolutionary communications technology with universities making significant contributions in areas such as packet switching and Internet protocols (TCP/IP). Fundamental academic research contributions have also figured largely in the development of digital subscriber line technology (VDSL), 3rd-generation wireless transmission (CDMA), computer graphics, data bases, search engines, generalized processor sharing, parallel processing, traffic management and stable broadcast networking. In aerospace, basic research contributions include the theoretical basis for unmanned aerial vehicle (UAV) flight controls, Shannon's information theory, electromagnetic antenna theory, linearized unsteady flow analysis, composite laminate theory, improved understanding of fiber-matrix interactions in composite materials, superplasticity, and real-time decision systems using artificial intelligence.

Applied research contributions. Academia has also been an important source of applied research contributions to the five industries, with academic researchers and the academic research infrastructure directly implicated in the development of industrial tools, prototypes, products, and production processes, as well as the delivery of products and services. More specifically:

Aerospace. Contributions to tools development include advanced nonintrusive instrumentation, flow visualization techniques, and computational fluid dynamics. Applied research contributions to specific technologies have been made in the areas of heat transfer, combustion cooling, and aeromechanics; low Reynolds number airfoil design; Internet by satellite, including protocols and computational tools for data integration; and folding-wing design for small UAVs.

Medical devices and equipment. A wide range of medical therapeutic and diagnostic devices have been developed through involvement of academic researchers and academic medical centers in R& D, prototype testing, evaluation, and clinical trials. Devices and equipment include magnetic resonance imaging equipment; whole body cat scanners; flexible endoscopy; lasers for a broad range of medical applications, ranging from gastrointestinal surgery to eye surgery; cardiac assist devices; organ and joint replacements; ultrasound and minimally invasive surgical techniques; and new developments in tissue engineering.

Financial services. Applied contributions include new financial instruments (index funds, derivatives), financial information and research tools (risk/credit metrics, financial risk management software), models for pricing derivatives and securities, and advances in cryptography for specific financial services applications.

Integrated logistics services. Contributions include optimization modeling for shippers, software applications/decision support systems for routing, production scheduling, logistics, and distribution management. Academic spin-off companies commercialized much of this software.

Network systems and communications. Applied research contributions involving university researchers include packet switching and the Internet TCP/IP protocol, both key elements in the development of the Internet. The Mosaic web browser interface was an important step in the rapid evolution of the worldwide web. University researchers and other university personnel have contributed in significant ways to routers, ATM switch developments, digital subscriber line technology (VDSL), 3rd-generation wireless transmission, computer graphics, search engines, traffic management, stable broadcast networking, the evolution of new networks, and standards development.

Key ideas and incremental advances. Academic research has been an important source of key ideas for all five industries – ideas that generate significant technological opportunities through fusion of knowledge of what's doable with knowledge of what needs to be done. In addition, academic research has fed the industries studied with a stream of smaller incremental advances relevant to industry products and processes, the cumulative impact of which has been significant.

Major technological opportunities or breakthroughs resulting from key ideas are often the product of a cumulative string of incremental advances involving the flow of ideas and people back and forth across the boundaries between universities and industry (National Research Council, 1999). Some examples of key ideas include packet switching, the TCP/IP Internet protocol, the web browser, routers; index funds and derivatives; decision support technologies; laproscopy, magnetic resonance imaging (MRI).

Cross-sector technology flows and indirect research contributions. The growing importance of cross-sector technology flows to performance in the industries studied underscores the importance of academic research contributions that are indirect, i.e., derived from research more closely associated with areas outside of a given industry. For example, information technology has become a driver of innovation and performance in all five industries. Advances in information systems are critical to the technical and market performance of commercial aircraft and their components. Similarly, advances in medical devices, although occurring in the medical/life sciences sector, benefit strongly from developments in the mathematical and physical sciences and engineering. Computer-related technologies such as intelligent sensors, computer-aided diagnosis, and robotics flow into medical devices from other industry sectors.

Social science and multidisciplinary contributions. Academic research contributions to the five industries are not solely technological. Much activity comes from outside schools of engineering and science, from the social, behavioral, management, and policy sciences. The sector studies underscore the growing importance of integrating natural science and engineering research more effectively with the social, behavioral, management, and policy sciences. In NSC, academic business schools have long been concerned with how information technology can be exploited for business benefits and have developed a number of research approaches and techniques to inform this area, including decision support systems, information technology (IT) and strategic advantage, computer-supported cooperative work, productivity research, and software development methodologies. In FS, there is the Nobel Prize winning work in economics by Markowitz and Sharpe on portfolio theory, by Scholes and Merton on pricing derivative securities, and by Koopmans and Kantrovich on linear pricing models. In MDE, clinical research studies, which underpin the acceptance or rejection of new medical devices, require a variety of disciplines. Regulatory and consumer research in the social sciences and psychology are becoming increasingly important in several industries.

Multiple, mutually reinforcing pathways of contribution. The pathways that link academic research to each of the five industries are numerous, diverse, and often mutually reinforcing. These pathways include direct hires of students, graduates, and faculty by industry, temporary researcher exchanges, faculty consultancies, industry-sponsored research contracts and grants, various institutional mechanisms at universities (research centers, consortia, industrial liaison programs, etc.), technology licensing, spin-off companies, publications, conferences, and short-courses.

Assessing impact

In recent years, researchers have employed various approaches to the quantitative assessment of the impact of academic research on industrial performance. Narin and colleagues (1997) have documented a sizable increase in the citation linkages between U.S. patents (one proxy for industrial performance) and scientific research papers over a recent six-year period. Others researchers have surveyed university researchers and industrial personnel to obtain information on the extent and relative importance of various academic research contributions to industry (Cohen *et al.*, 1998; Morgan *et al.*, 1997). Still others have attempted to quantify the economic impacts of specific research universities or university technology licensing activity more broadly.[1] For example, using economic impact models, the Association of University Technology Managers (1999) estimated that $33 billion of U.S. economic activity supporting 280,000 jobs in 1998 was attributable to the results of academic licensing of technology. Moreover, several economists have attempted to calculate the private returns (returns to investing firms) and the social returns (returns to both firms and consumers) from university research.[2] Others have used regression analyses with production functions to evaluate the impact of academic research on industrial patenting, manufacturing productivity and other measures of industrial performance (Adams, 1990; Jaffe, 1989).

Nevertheless, the measurement of academic research impact remains a very young and inexact science. The task of isolating, tracking, and measuring over time the contributions of a given body of academic research to the performance of particular firms, industries, and regional economies is complex and difficult (Feller, 1997). We found existing quantitative research to be of limited use to the industry-specific assessments of our study. Therefore we relied on informed opinion and expert judgment to assess qualitatively the impact of academic research on industrial performance on the five sectors of interest.

Based upon E-mail surveys, workshop discussions, and panel and committee deliberations, the impact of academic research on performance in the NSC, MDE, and FS industries has been large. Its impact on performance in the AERO and TFL industries has been only moderate to date. More specifically:

Medical devices and equipment. The impact of academic research on performance in this sector has been large. Driving this result, in addition to science- and technology-based research and innovation in universities, is the unique role that academic medical centers play in going beyond education and training to facilitate a high degree of codependency and interaction with industry in product introduction and modification. Although the impact has been strong, it could be greater if there were a more systematic approach to educational partnerships between industry and university. Such partnerships might include the sharing of large, expensive medical research facilities, and joint research and training activity.

Network systems and communications. The impact of academic research in this sector has been large. The strong flow of researchers, ideas, and entrepreneurial activity between universities and industry coupled with government support for research and testbeds for infrastructure development have been instrumental in the creation of new industries and E-commerce. At present, the impact of university research may be moderating somewhat as emphasis in the industry shifts to deployment and maintenance of large-scale operational systems and economical provision of services. Research relevant to operational networks is expensive and university researchers are in high industrial demand. On the other hand, emphasis on support of research by the federal government in information technology is continuing. Of particular interest is whether research that bridges the gap between engineering and the physical sciences on one hand, and management and the social sciences on the other, can contribute to the growing service sector emphasis of the industry.

Financial services. The impact of academic research in this sector has been large, especially in the area of novel financial products and services. The financial instruments, investment management, and decision support tools created in academia or through public private-sector partnerships have been critical to the success of the financial services industry, as manifest in new products, business lines, and gains in transactional efficiency. Furthermore, a significant component of what the financial services sector is engaged in today would not be possible without the fundamental mathematical tools developed or adapted to financial problems by academics, including research on linear programming models in economics, portfolio theory, and pricing derivative securities. Much of this technology transfer has occurred through faculty consulting and the launching of start-up companies based on academic research. What is interesting about the large impact of university research on financial services is that it seems to have happened in spite of the lack of a well-developed, organized R&D system targeted towards financial services problems and issues.

Aerospace. The impact of academic research on performance in the mature and largest subsectors of the aerospace industry has been relatively modest in recent years. This situation has resulted in part because of the shift in focus by the industry from competition and performance enhancement to production processes, as well as the fall-off in government research funding. On the other hand, there has been a large impact in the small, nascent unmanned aerial vehicle (UAV) subsector, which relies on universities for research and innovation, functioning more like elements in the start-up phases of the NSC sector.

Transportation, distribution, and logistics services. The impact of academic research on performance in the transportation, distribution, and logistics industry as a whole has been relatively modest to date. One factor contributing to this somewhat limited impact in the decision sciences/technology area is too much "push" on the academic side and not enough "pull" from industry. Academic research with the greatest impact on practice in the TDL industry has been basic research in such areas as linear and integer programming and queuing theory, some of it done in the 1950s, without any logistics applications in mind. Applied work in these fields has also made important contributions, for instance, in the area of large-scale optimization modeling, decomposition methods, network optimization, and other areas of operations research (OR). As in FS, faculty consulting and faculty led start-up companies have been significant vectors for technology transfer to the TDL industry in these areas of research. These successes notwithstanding, there is a large gap between technologies that offer the tremendous potential of impact and the ones that are actually having an impact now.

Opportunities for future research impact

In this section, we focus on five major opportunities or challenges that are likely to have significant effects on the extent to which university-based research will impact industrial performance in two or more of the five industries.

The services challenge. The sector studies underscore a broad services challenge to the nation's academic research enterprise. Services industries account for roughly 80 percent of the U.S. GNP, employ a large and growing share of the nation's science and engineering (S&E) workforce, and are the primary consumers of information technology. In most manufacturing industries, service functions such as logistics, distribution, and product maintenance have become leading sources of competitive advantage. The rate of innovation and productivity growth of the nation's services infrastructure – finance, transportation, communication, health care, and so forth – have an enormous impact on the productivity and performance of all other segments of the nation's economy. Moreover, as the studies of FS, TDL, and NSC document, services are major drivers of innovation in the economy. Nevertheless, these studies also confirm that the U.S. academic research enterprise, while seemingly well positioned to meet the service challenge with its broad disciplinary base and potential for cross-disciplinary research and training, is not well focused and organized at present to meet the needs of service businesses. Among the challenges are the need for research regarding the adaptation and application of systems and industrial engineering concepts, methodologies, quality control processes to service functions, and the need for integrating technological research with social science, management, and policy research.

The regulatory challenge. Regulation and regulatory change have had profound impacts on the direction and industrial receptivity of academic research contributions to several of the industries. In some cases academic research has helped shape the regulatory environment that these industries face. Economics research redefined the role of regulation from one of protecting the public interest to stepping in when markets fail to drive prices to marginal costs, spurring deregulation in a number of industries, including communications. The movement of technically trained S&Es into financial service regulatory bodies has enabled regulators to draw on advances in risk modeling, management assessment, and how this has in turn fostered innovation and technology use within the industry proper. Nevertheless, at present the academic research community does not devote sufficient time and resources to examining regulatory issues and problems of the five industries, even though it has the interdisciplinary expertise to do so. For example, in the medical devices arena, academic researchers could play a greater role in the ongoing considerations of the Food and Drug Administration's regulatory policies related to medical devices – possibly serving as convenors for industry, regulatory, and clinical panels to discuss appropriate evaluative requirements in bringing different types of product categories into widespread clinical use.

The intellectual property challenge. Although intellectual property constitutes only a small but growing fraction of the university research contribution to industrial performance, considerable time and attention is being devoted to negotiating intellectual property rights (IPR) among individual researchers, universities, and industry in the five industry sectors.

There is reason to believe that in most instances, the parties directly involved are able to work things out to their mutual satisfaction without outside intervention. Aerospace (specifically its mature subsector) was the only industry that saw IPR issues as a significant barrier to university-industry research collaboration. IPR has not figured prominently in FS to date where secrecy and first-mover advantages reign.

There have been many positive consequences of increased patenting activity by academic researchers, including new avenues for entrepreneurial energies of academic researchers to pursue, and new products, services, processes, and companies to show for it (Morgan *et al.*, forthcoming). At the same time, important questions remain for university researchers to examine about the long-term impact of universities' growing emphasis on intellectual property rights on university-industry interactions and the health of the academic research enterprise.

The information technology challenge. Information technology (IT) has become critical to the performance of all five industries and will only become more important in the future. The financial services sector is the largest user of IT services and has spurred developments in cryptography. IT is a key enabler in the development of integrated logistics, new medical devices and diagnostic equipment, and onboard aircraft and satellite systems. Industry challenges related to the development, diffusion, and effective application of advanced information technology present a major opportunity for academic research across a spectrum of disciplines – including mathematics, computer, physical and biological sciences, multiple engineering disciplines, as well as the social and behavioral sciences. Among the challenges are the need for greater engineering discipline; for improved techniques for building software to drive the business; for reducing infrastructure and business vulnerability, particularly to security and privacy breaches; and for an adequate supply of IT human capital.[3]

The university identity challenge. Several of the sector studies confirm that some universities have become increasingly entrepreneurial and deeply and directly engaged with private companies and economic growth during the past two decades. A significant and growing number of university researchers in engineering and natural science have added financial gain and entrepreneurship to their perceived university roles, along with teaching, research, and service. Sector studies point to the emergence of a new generation of institutional linkages and interactions between universities and industry in MDE, AERO, and NSC. Leading universities are making long-term deals with individual companies – joint research, joint clinical trials, and revenue sharing.

The issue arises as to whether the entrepreneurial university[4] and the new interest in financial gain are distorting the traditional values, goals, and the identity of the university with negative consequences. In order to recruit and retain the best and brightest entrepreneurial faculty and graduate students, some universities are finding that they must concede greater proprietary rights to them, and allow them more time to pursue research and business interests beyond academia. A challenge requiring attention from academic and industrial leaders as well as the research community is to find the right balance between the new university entrepreneurs as an essential cog in the national innovation system and the open knowledge creation and dissemination function of the university (Press and Washburn, 2000).

3. Concluding remarks

The sector studies raise some concerns as to whether universities can keep pace with the rapidly changing research and associated human capital needs of today's industries, while continuing to jump-start new areas of basic, long-term research and generate the key ideas that will provide the foundation for tomorrow's industries. In NSC and MDE, where linkages to academic research have been very strong in recent decades, there is some concern about the ability of academic research to adapt to, to articulate, and to pursue new directions in basic and applied research and training. In FS and TDL, where the industry R&D ethos is quite nascent, there is concern about getting the academic research enterprise to take the research and training needs of the industries more seriously.

The adequacy of funding for basic, long-term research is particularly important. All five industry studies question whether the rate of investment in long-term academic research is adequate to meet emerging challenges and opportunities. Moreover, all five document that despite growing industry involvement with academic research, industry support for long-term academic research has not been sufficiently forthcoming and is unlikely to become so. The studies all reconfirm the critical role of federal funding for basic, long-term research. Furthermore, the studies indicate that a research portfolio balanced among various fields is desirable for fostering the important contributions that are made across disciplinary boundaries, e.g., from engineering and physics to the development of new medical devices.

Although industry financial support for long-term academic research has been minimal, the sector studies make clear that academic research, both basic and applied, has benefited greatly from interaction with companies. Indeed, industry has provided a large stimulus to fundamental long-term research in many fields, posing new questions to academic researchers and exposing gaps in knowledge through their innovative activities. While this may be particularly obvious in high-tech industries such as NSC and MDE, the FS and TDL studies demonstrate that even in industries where relatively little R&D is performed yet lots of technology is deployed, industry challenges can be an important stimulus to both basic and applied research. Clearly, opportunities for research interaction with industry that provide intellectual stimulus and the possibility of material gain to university-based researchers are becoming increasingly important to the recruitment and retention of top talent in many fields at research universities.

In conclusion, when we began this project in 1998, there was considerable skepticism about whether university research was contributing to industrial performance. We believe that skepticism has largely abated. A more recent concern is whether universities are becoming too much like industry. Our belief is that although some university-industry research interaction is highly desirable, the roles of universities and industry should be kept distinct and separate. As one NAE committee member put it: "Don't abandon mission: Academic research is good at some things, not so good at others. There is no contortion of the academic mission that would make it fit into the industrial model without doing great damage. 'The pillars of the temple should be close, but not too close.'"

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Notes

1. A 1997 study of MIT's economic impact concluded that the 4,000 plus companies founded by MIT graduates and faculty employed 1.1 million people and had annual world sales of $232 billion (BankBoston, 1997). Similarly, Stanford university estimated in the early 1990s that technology-based companies founded by its graduates and faculty accounted for roughly $31 billion in revenue in the San Francisco Bay area (Leone *et al.*, undated). One caution is that both MIT and Stanford may be counting some of the same people (e.g., B.S. from MIT, PhD from Stanford or vice versa). In another study, Pressman (2000) reports that 150 licensees with agreements to use MIT-owned patents have sold a total of $3 billion in licensed products. Over 500 of some 850 MIT patent license agreements since 1980 are still active.
2. Assessing seven industries, Mansfield (1991) estimated the annual social returns from academic research during the period 1975 through 1978 to be 28 percent. He also estimated that 1985 sales of new products based on academic research that were first commercialized in 1982–1985 totaled about $41 billion, or 5 percent of total sales for those industries. For a recent review of approaches to measuring the social return to R&D that is not specifically focused on academic research impacts on firms, see Jones and Williams (1998).
3. For a detailed consideration of the IT challenge, see National Research Council (2000).
4. Developments in at least one of the five industries, medical devices and equipment, indicate that the entrepreneurial university model is not without competition. New intermediaries, new research/innovation entities, are emerging beyond the university (companies/research boutiques fueled by venture/angel capital, and corporate acquisitions strategies) that make it increasingly difficult for universities to capitalize on their large and increasingly expensive installed research base (overhead costs, cost of recruiting and retaining new researchers, etc.). In short, the business of technology transfer and key idea generation is becoming highly competitive. Markets appear to be fostering alternative pathways for knowledge application and commercialization that bypass the licensing offices of universities.

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