Trends in industry-university relationships

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1. Introduction

Since World War II, United States universities have been the envy of the world, conducting cutting-edge basic research that has created and transformed multiple industries. Through an initial concept presented by Senator Harley Kilgore and fully developed in Vannevar Bush's seminal report *Science, the Endless Frontier* (Kevles 1977), universities have served as the home of rigorous, relevant scientific research at all stages of maturity, from creative idea to robust technical solution. The National Science Foundation stemmed from this call, serving as the key pillar in the national approach to funding basic research.

The national scientific infrastructure grew rapidly in the post-Sputnik era, with rapid university effort focused on training faculty and aligning research with perceived Cold War needs. The economic downturn of the 1970s created new imperatives for universities as innovation began to be viewed as an engine for economic growth. This inspired the creation of multiple programs to accelerate the flow of knowledge and people between universities and industry.

The modern NSF portfolio of programs includes the Engineering Research Centers (ERCs), the Science and Technology Centers (STCs), the Industry/University Collaborative Research Centers (I/UCRCs), Grant Opportunities for Academic Liaison with Industry (GOALI), and others with varying degree of engagement directly with the university. However, while these programs have not have not changed substantially in funding nor substance since the 1980s, the industrial and university environments have evolved together and separately, slowing unwinding university-industry alignment.

It is common today to discuss "ecosystems," borrowing a term from ecology to discuss an environment where distinct players contribute to and benefit from the presence of the others. In the university-industry environment, select factors have begun to inhibit this relationship. It is to everyone's advantage to restore balance.

This report was commissioned to synthesize external data and interviews with key opinion leaders to describe the evolution of these relationships. It highlights some of the key policy and operational issues driving challenges in keeping industry-university centers not only relevant, but instrumental in supporting the national research agenda.

2. Selected trends

In the last thirty years, the industrial and academic environments have experienced many profound changes. The role of scientific investigation in the economic fabric of the United States has changed substantially as the products of a research environment (captured memorably in one interview as "people, papers, and patents") have been valued in different ways by the general marketplace. These changes are driven by and provide feedback to the sources funding research and development (R&D). While R&D is often considered as a single entity, disentangling “R” and “D” is important to understanding the distribution of activities between academia and industry.

A separate trend that will be explored is distinguishing between invention (creating a method or process based on a novel scientific or engineering discovery), innovation (creating value from a new method or process), and entrepreneurship (creating a sustainable business from a new method or process). The current focus on entrepreneurship in engineering schools has accelerated since the financial downturn of 2008. The impacts of this trend on industry-university relationships, and indeed on the very definition of industry, will be discussed.

2.1. Funding research and development

The American Association for the Advancement of Science (AAAS) reports that in the last thirty years, national funding of R&D has increased from roughly $200 B in 1985 to $450 B in 2014[1] (Figure 1). Since 1985, federal funding has varied between roughly $100 B and $130 B.

The strong increase in R&D funding stems from industrial sources, with a slight uptick in “other” sources such as foundations and non-profits. While federal funding drove research in the early Cold War, industrial spending accelerated and now outpaces federal investment approximately 2:1.

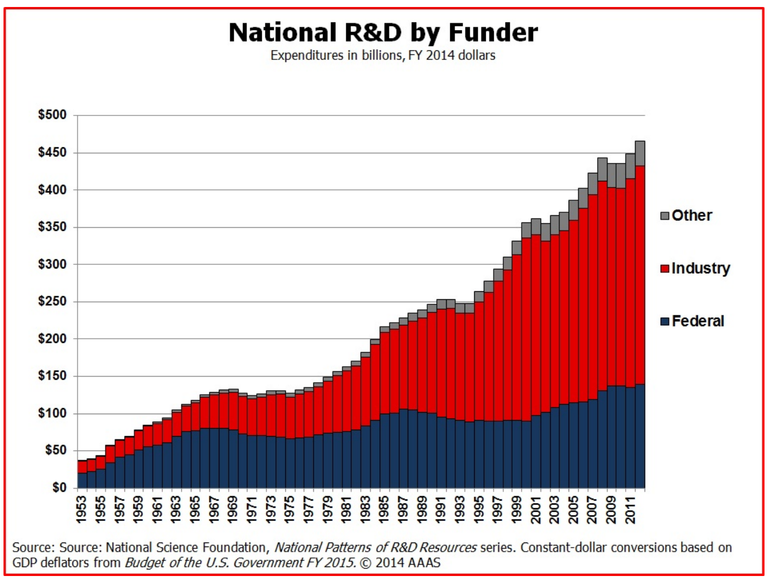

Figure 1: National research and development expenditures (American Association for the Advancement of Science, 2014).

The federal funding described in Figure 1 supports work in universities and in industry alike, but the nature of the work differs. Figure 2 indicates that federal agencies have consistently

[1] Funding levels expressed in constant FY 2014 dollars.

supported basic research in universities and development research in industry. Federally funded industrial development research has experienced wide swings over the last fifty years. Interestingly, intermediate applied research funding appears to be shared between the two types of institutions.

The ambiguity of the appropriate home for applied research may partially explain the lack of clarity regarding the hand-off, and thus the slow progress toward the marketplace for potentially transformative technologies.

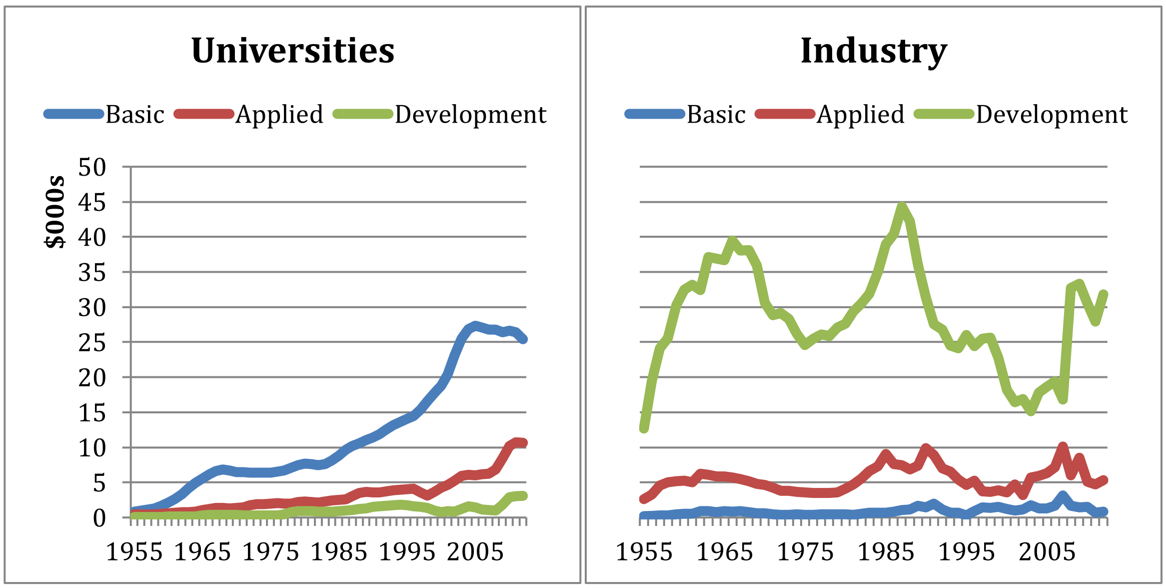

Figure 2. Character of federal research spending. All amounts in $M, expressed in 2015 dollars. (Data from the American Association for the Advancement of Science.)

A recent report from the National Bureau of Economic Research echoes the finding that industrial research is in effect more concentrated on "D" than on "R", indicating that corporations now value technical capabilities more than basic research (Arora, Belenzon and Patacconi 2015). Two key reasons are suggested for this change. First, global competition has accelerated, shortening the time frame in which research needs to migrate to the marketplace to generate a return; this effectively converts basic research into an unaffordable luxury, viewed as an expense rather than an investment. In parallel, the corporate world has, moved toward the "core competency" model popularized in the 1990s, narrowing a company's scope of work and limiting the potential cross-cutting nature of basic research.

Corporate acquisitions may effectively displace R&D; an inverse correlation between these activities has been observed historically (Blonigen and Taylor 2000). An interesting recent study indicated that public companies conducting more R&D underperform public markets over multiple time scales (Hessedahl 2014). In fact, this was suggested as a recent trend in the health care industry (Fisher 2015), particularly as new drug discovery tools reduce the cost of the effort and enable smaller enterprises to enter that business.

Another important trend is the nearly fixed nature of state and local support of university research. Figure 3 illustrates how federal research funding has grown fastest, with industrial funding keeping pace.

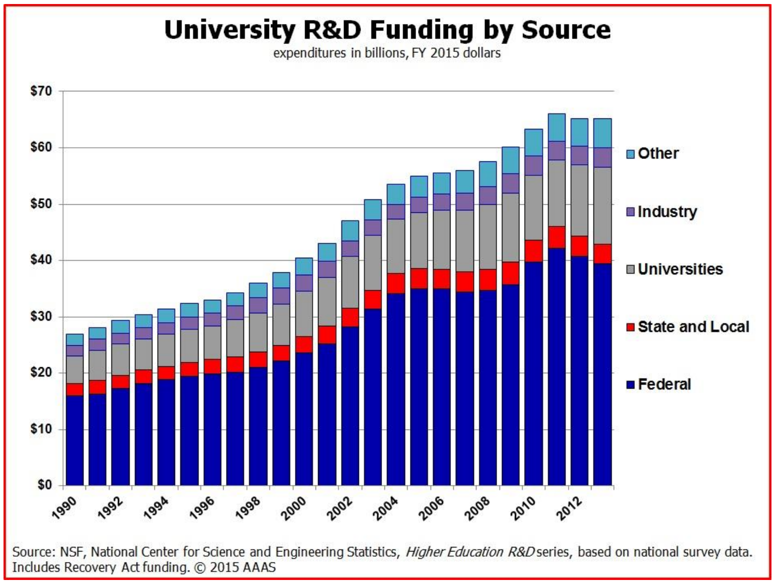

Figure 3. University R&D funding by source (American Association for the Advancement of Science, 2015).

The tepid growth in state and local funding is troubling, particularly if universities are viewed as spurring regional innovation. While federal support of research is of course in the national interest, state support is critical to ensure a sustained community and ongoing economic impact. This concern will be discussed further below.

Figures 1 and 3 suggest that the dramatic increase in industrial R&D funding is directed toward internal efforts rather than academia. This contradicts apocryphal stories regarding the end of corporate R&D, although it is likely directed to "D."

Summary and impact

The funding of R&D has evolved as follows:

- Federal funding to universities has been steered principally, but not entirely, to basic research. Recent federal funding to universities includes modest levels for development stages, and the level of applied research funding mirrors that of industry.
- Industrial research funding has doubled in the last thirty years and is not invested in

universities. Instead, it appears that industry funding is maintained internally and used primarily for its own development efforts. Industry investment in universities has apparently doubled, plateauing in recent years.

- State support for R&D has not kept pace with neither industry nor federal investment.

The difference between public and corporate trends may stem partially from the role of intellectual property in today's economy, discussed further below.

2.2. Generating value through intellectual property

One measure of the value of federally funded research is the contribution to the national economy; by one measure, an estimated 30% of the NASDAQ exchange's value stems from university-based, federally-funded research (Sherer 2012). This value is realized principally through the intellectual property (IP) generated through research.

The economic importance of IP, and more generally intangible assets, has grown significantly in the last thirty years. Intangible assets have increased as a proportion of the S&P 500 market capitalization from approximately 17% in 1975 to about 84% in 2015 (Ocean Tomo 2015); in other words, the vast majority of an S&P 500 company's market capitalization is captured not in its tangible assets (cash, property, etc.), but rather in its intangible asset base. Although difficult to validate for privately held startup companies, this fraction could be even higher for startups with minimal portfolios of tangible, readily valued assets. Venture-backed startups were reported to hold an average of 6 patents or applications, while startups without venture capital had none (Graham, et al. 2009).

IP not only generates firm value, but the associated jobs generate an estimated 30% increase in average wages (US Chamber of Commerce 2014). These observations jointly motivate public investment in forming companies with strong IP foundations.

However, patents comprise one form of intellectual property, and only select corporate inventive activities are protected by patents (Fontana 2013). Nonetheless, patents remain key indicators. Although patent counts and citation rates contain significant information on the market value of firms (Trajtenberg 1990), (Hall, Jaffe and Trajtenberg 2005), the direct relationship between economic value and technology novelty remains unclear (Strumsky and Lobo 2015). Links between patent activity and innovation vary strongly with company size (Brouwer and Kleinknecht 1999) and industry (Arora, Ceccagnoli and Cohen 2008) (Fontana 2013) (Pérez-Cano and Villén-Altamirano 2013).

Interestingly, patent renewal rates apparently increase when backed by government loans with a high degree of focus on commercialization (Svensson 2013), suggesting that market orientation in government finance leads to patents with greater commercial potential.

Global competition has accelerated patent filings. However, United States companies and universities fare differently when ranked for patent counts (not economic value) in their respective peer groups. Only two of the top ten companies filing international patents under the Patent Cooperation Treaty (Qualcomm and Hewlett-Packard) were from the United States, whereas eight of the top ten universities are American[2] (World Intellectual Property Organization 2016). These data suggest that American universities still demonstrate invention strength in the global marketplace. The link of these inventions to innovation will be discussed further below.

Summary and impact

Intellectual property has risen in importance as an asset for many stakeholders:

- IP represents a large fraction of public market capitalization and generates increased wages in associated jobs. Patents are an important form of IP, with patent counts and citation rates linked to firm value.
- Links between patent activity and innovation vary with company size and industry, but patent renewals increase when backed by government loans a commercialization focus.
- The role of IP in the public and private capital markets makes it an important element of any corporate interactions.

Questions remain regarding these trends in light of the issues regarding reverse engineering, cybersecurity threats, and other activities that threaten intellectual property protection; however, currently IP remains an important element of firm and economic value.

2.3. Translating research via entrepreneurship

Many top universities, such as Stanford, Harvard, Johns Hopkins, and the University of Southern California, have had technology transfer offices since the 1970s. These offices rose in stature when the Bayh-Dole Act of 1980 gave universities the rights to technologies developed with federal funds, creating new incentives for institutions and faculty alike to commercialize their work. Prior to that legislation, rights remained with the federal government, and thus any potential royalties would be paid to the federal government and viewed effectively as a tax.

The Bayh-Dole Act enabled the development of new university spinoffs (i.e., companies formed to license a technology[3]). Interest in university technology grew dramatically in the 1990s after a group from the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC) developed the Mosaic web browser (NCSA 2016)

[2] In descending order: University of California system, Massachusetts Institute of Technology, Johns Hopkins University, University of Texas system, Harvard University, University of Michigan, University of Florida, and Stanford University.

[3] *Spinoffs* are contrasted with *startups*, general new ventures that may or may not have licenses to university-developed IP.

commercialized by the newly-formed Netscape Communications, whose initial public offering[4] in 1995 effectively launched the first so-called "dot-com boom." Although Netscape did not license the technology from UIUC, the tremendous success of the company highlighted the potential value of technologies and technical talent harbored inside universities.

Further interest in university technologies skyrocketed nearly a decade later, when Google's initial public offering in 2003 returned over $330 million to Stanford University. This return was generated via Stanford's equity interest in the nascent venture rather than through a conventional royalty agreement[5], triggering a new era in negotiated deals with spinoff companies as other universities sought to replicate the extraordinary return. Between 1980 and 2014, nearly 5,000 companies were launched and nearly 4,000 jobs were created (Association of University Technology Managers 2014).

This environment has created a new set of concerns for universities as they determine the *raison d'etre* of their technology transfer offices. Replicating the Stanford/Google experience is extremely difficult because of the equilibrium in the startup marketplace; the return was so high precisely because success is so rare. If universities become much more effective in producing successful exits (i.e., acquisition and/or initial public offerings) for investors, the returns would presumably decrease along with the risk level. A national infrastructure of technology transfer cannot be predicated on an assumption that all universities generate the same high returns. Most new companies do not experience dramatic growth; many remain "small businesses" rather than "young big companies."

However, it is certainly reasonable to assume that commercializing previously untapped assets will deliver modest returns, and thus ongoing growth of the technology transfer ecosystem is an important way to capitalize on the significant value of IP. Many university technology transfer offices do not generate sufficient licensing income to pay for themselves; however, at top tier universities, licensing incomes can be significant (in the range of tens of millions of dollars).

With an industrial focus and significant resources, industry-university centers can serve as the most effective university engine for generating commercial opportunities, albeit at the earliest stages given the funding profiles of Figure 2. Furthermore, the funnel from disclosure to patent, and on to license and then revenues, is long, with severe losses at each step (for instance, Stanford files patents for approximately half of its disclosures, yet only three of its licenses to date could be categorized as "home-runs" returning in excess of $100 M). A recent Association

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[4] Privately held companies generate returns to their investors when they "exit" through either an acquisition by another company or by an initial public offering (IPO). In 2014 venture-backed companies were approximately three times more likely to exit via acquisition (Wilmer Hale 2015).

[5] Key licensing deal economic components may include upfront and/or maintenance fees, and royalty payments, calculated frequently as a percentage of sales of products based on the IP. Licensing to spinoffs generates an additional form of consideration in the form of equity in the company.

of University Technology Managers (AUTM) survey reports that products follow initial patent filings after five to twelve years (Association of University Technology Managers 2013).

Despite the fact that entrepreneurship support may not be viewed as a sure bet nor as a sustainability model, it is also not optional. At the faculty level, it is well-known among university administrators that faculty retention has become increasingly linked to the strength of commercialization infrastructure and that perceived weaknesses in technology transfer can yield to expensive ($2-3 million) retention packages for dissatisfied faculty. In fact, many of the top-tier institutions view technology transfer as a mechanism to build relationships with faculty and graduate students alike, creating potential donors but principally supporting the university community. This opportunistic view has grown in popularity in the university technology transfer world.

With respect to graduate students, a challenge to creating companies is the foreign student population. Foreign students received 23% of science and engineering doctorates in 1966 (Freeman, Jin and Shen 2004). By 1991 foreign students obtained 25% of natural science doctorates, 40% in mathematics and computer sciences, and 45% of engineering doctorates (National Science Foundation 1993) and by 2011, foreign students were awarded 56% of doctorates in engineering, 51% in computer sciences, and 44% in physics (National Science Foundation 2014). Current immigration policies do not allow for this talented pool to stay in the United States and launch companies, thus impacting spinoff generation rates. However, new recognition of this problem has led to a recent US Citizenship and Immigration Services (USCIS) proposal of the new International Entrepreneur Rule, granting foreign entrepreneurs up to five years of parole to grow startups (US Citizenship and Immigration Services 2016). This proposed change could dramatically impact the technology commercialization path of many university-based startups.

Today, the number of university entrepreneurship centers[6] has increased from roughly 400 to 700 in the last year alone (La Salle 2016). Entrepreneurship centers may offer co-curricular experiences designed to enhance the classroom education, structured minors and other programs (Byers, et al. 2013) (Celis and Huang-Saad 2015). Business model education and a hands-on customer discovery process naturally align with the general educational trend toward project-based and experiential learning, as well as the growing population of auto-didacts who set their own learning pace by accessing free digital courses and other content.

In industry-university collaborations, entrepreneurship is most appropriately linked through education, which has historically has been technical with both hands-on and standard classroom

[6] The most recent wave of university startup interest was triggered by the success of Facebook, launched by Mark Zuckerberg in his Harvard dorm room in 2004. However, this is less relevant to the questions of industry-university research partnerships, as these consumer-facing companies are launched by modifying standard tools rather than discovering and exploiting new physical discoveries.

elements. Supplementing a traditional technical program with robust business model education would give centers a new level of relevance in steering research toward potential opportunities. NSF's Innovation Corps ("I-Corps") program[7] provides both a vehicle and a model for efficient business model development, with an intensive seven-week course supported by a $50,000 grant[8].

Summary and impact

In the last thirty years, university entrepreneurship in engineering programs has blossomed and the pace is only increasing:

- Enabled by the Bayh-Dole Act, technology transfer has expanded well beyond traditional licensing of the 1970s to spinoffs. Spinoff rates will be impacted by immigration policies that affect foreign graduate students.
- While entrepreneurship support offers potential economic benefits to the university, it provides straightforward and important contributions as educational and faculty retention tools. This education can be effective for both large and small company engagement.

2.4. Offering value propositions to industry

Understanding the value propositions for the industry-university collaborations requires identifying the relevant stakeholders besides the academic partner. In particular, "industry" can mean startups, mid-sized companies, and large corporations. The local community may also benefit from an industry-university partnership, particularly in the form of a center.

Large corporations. The value proposition to a large corporation considering participation in an academically-based center may be difficult to articulate. Unlike small companies lacking major laboratory facilities and infrastructure, a large corporation does not have these concerns. While access to people is often the most important perceived driver, this can be obtained directly through sponsored research arrangements managed more efficiently. Large corporations may perceive the indirect cost structure as high relative to an internal project that can be managed with shared resources. Indeed, centers are often viewed as operating as multiple independent projects rather than as a coordinated effort.

The advent of electronic communication tools unavailable thirty years ago has obviated the need for centers to link university and industrial researchers. Simple tools such as web sites,

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[7] Disclaimer: The author serves as the Director of one of the seven national I-Corps Nodes.

[8] I-Corps teams comprise a Principal Investigator (PI), typically a faculty member; an Entrepreneurial Lead (EL), typically a graduate student or post-doctoral researcher; and an Industry Mentor (IM), drawn from the business community. During the seven-week course, the team conducts 100 interviews with potential customers and partners while developing and refining a business model. This intensive engagement between the academic team and the business world mimics that of a startup.

LinkedIn, and email have accelerated the development of one-on-one relationships, effectively empowering individual faculty members and corporate researchers so that they do not need a center to create collaborations. In some cases, centers may serve as passive vehicles for large companies to maintain a connection with universities, particularly with personnel, without being closely integrated in the project management. In parallel, engineers in these same companies may manage their own relationships directly with faculty.

The importance of patents impacts the decision of a corporation to engage with a university. In fact, representatives of several Fortune 500 companies shared anonymously that "if it's important, we'll do it ourselves." Thus, work that is outsourced to universities is deemed to be of lower priority or in areas that are not core to the central R&D. This suggests that commercial opportunities stemming from center-based research will be difficult to realize through a corporate partner unless the intellectual property rights are favorable to the company.

Naturally, these large companies are potentially an important channel for university teams to identify and satisfy marketplace needs. However, it is not clear that the center is the most attractive way for a major corporation to engage with university faculty. University faculty are easy to find. New focused collaborations can be launched efficiently with select, small group of investigators pursuing more focused research objectives and subject to clear IP ownership policies. Just as it is now much more efficient to manage a small company than it was thirty years ago, it is also more efficient to run a "mini-center" to create effective collaborations.

A potential value proposition that is typically not linked directly to centers is the changing demographics of the work force in established industries. For instance, in the oil and gas industry an estimated 71% of the workforce is 50 years old or older, and as many as half the skilled energy workers may retire in the next 5-7 years. This transformation is referred to as the "Great Crew Change" (Aviles 2015). A similar exodus has been projected but not yet realized in the aerospace and defense industries (Hedden and Sands 2015).

These companies have real needs to become the so-called "employer of choice." For instance, with the rapidly growing automation of the manufacturing world, computer scientists have great value to traditional industrial companies. However, this path is not as commonly sought by these increasingly desirable graduates. A relationship with a university that creates a mechanism for developing and recruiting talent would have great benefit to these organizations, particularly if it simultaneously helps improve diversity in the workforce.

Indeed, many large companies cite the ability to recruit talented students as a major benefit of any funded project, including center participation. A center potentially provides a forum for graduate students trained to participate in collaborations with appropriate communication skills, although many faculty members certainly create environments that teach these skills without the benefit or overhead of a center.

A final consideration in developing partnerships between large companies and universities is the perceived "impedance mismatch" in collaboration operation. These simple collaboration issues should not be mistaken for a bent toward agile development models, which are project-specific and thus poorly aligned with the opportunistic nature of basic research. Instead, centers seeking to be competitive in today's economy should have communication capabilities equivalent to those in industry, specifically:

- Besides the universal use of email, university-industry partners should use standard digital collaboration tools to manage projects for virtual teams, often used in industry but rarely in academia. Modern information systems allow for distributed information and task management via on-demand and cloud technologies. The failure to rely on these tools and depend instead on traditional collaboration management is perceived to add to the cost of center operation without adding value.
- International collaboration has blossomed for corporate partners due to improvements both in real-time communication and global capability development. Domestic center-based collaborations therefore have increased competition from other industrial opportunities to source and nurture innovation, particularly because international partners may offer competitive cost structures.

These simple considerations have profound impact on the cost and operations of a center and the value propositions to a potential industry partner. While scientific and multi-disciplinary convergence acts as a strategic driver encouraging center-style interactions, the use of outdated project management tactics make other options, such as international collaborations and smaller efforts managed independently, more attractive.

Mid-sized and startup companies. Mid-sized and startup companies may benefit differently from engagement with centers. If smaller companies lack facilities and have poor access to students, the centers can provide a pathway to specialized facilities and promising graduate students. The companies may also access faculty who can potentially serve as consultants or advisors. Many existing centers appear to offer tiered membership structures such that the fee is lower for a startup than a large company. However, advertising a tiered offering is not a guarantee of significant membership, and interviews revealed decision factors of startups considering membership in centers.

These benefits appear to be greatest when the companies had a pre-existing relationship with the key faculty member. For instance, a startup resulting from the laboratory of a center principal investigator (PI) may enjoy a continued relationship with the research group, serving as a potential employer for graduate students. Startups that are new to the community and do not stem from the university may not perceive the same benefits. University spinoffs do not have the same challenges for university IP managers because their interests are already aligned through their license agreement.

These benefits also appear to be easier to realize when the center membership fee is organized in a flexible fashion. For instance, recognition of in-kind contributions allows a startup to offer its product back to the technical community, accelerating the testing and validation process. High cash fees are often viewed as inhibitory to a smaller company. Companies may also seek other vendors of laboratory research facilities if the university relationship is perceived to be difficult (for instance, inconvenient access).

This set of companies may be of increasing importance. One analysis indicates that in 1985, firms employing more than 10,000 people accounted for 73% of non-federally funded R&D, whereas by 1998, this share had dropped to 54% (Arora, Belenzon and Patacconi 2015). Evidently research is conducted more frequently in companies smaller than the large corporations; in other words, the share of corporate research at small and mid-size firms is growing.

An important factor in the university-industry ecosystem is the Small Business Innovation Research (SBIR) program, a competitive national program that encourages domestic small businesses to engage in federal research with the potential for commercialization (Small Business Innovation Research Program 2015). The program was founded in 1982, motivated by an influential study suggesting that small businesses were more than twice as innovative as large ones (Edwards and Gordon 1982). The program has grown steadily since inception, now administered individually by eleven federal agencies. In 2009, Congress recognized the importance and potential of SBIR, mandating that its budget increase from 2.5% of an agency's R&D budget to 3.2% between 2014 and 2017 (US Congress 2009); the current aggregated budget is approximately $2 B.

The SBIR program functions as public venture capital, financing high-risk companies that experience other barriers to funding, discussed below. Its role in the innovation ecosystem is complex. While government venture capital has been shown to have no direct impact on invention and innovation, it does boost the impact of independent venture capital firms (Bertoni and Tykvová 2015). In the case of the NASA SBIR program, its role in supporting invention has been demonstrated (Giga, et al. 2016), but with less clarity regarding its role in innovation, and suggesting that the education programs influencing value creation can be effective.

SBIR-funded companies are natural partners for universities. One-third of respondents to an NRC SBIR Phase II survey reported university involvement, with 27% of those reporting the use of university faculty as contractors and 17% using universities as subcontractors (Wessner 2008).

Summary and impact

As centers evaluate the opportunities to partner with "industry", it is critical to define this term more precisely.

- Large corporations form a critical backbone to the national engineering environment, but they do not need organized center structures to recruit academic research partners. Large companies seeking to engage with universities concern themselves greatly with patent policy and IP rights.

- Small companies may realize value through ongoing relationship with the university, but this is highest when the relationship between the principals precedes the center. In-kind subscription models for membership allows small, cash-restricted startups to continue to engage with the scientific community at large.
- The SBIR program is an important source of funding to nurture startups in their ongoing relationships with the universities, and government venture capital may stimulate private capital as well.
- A major value to companies of all sizes is access to potential employees, viewed (rightly) as a critical competitive advantage. This output is likely the most important of all the potential products of a cutting-edge collaborative research activity.

2.5. Attracting venture capital

One important potential benefit of these centers is the ability to link university faculty with venture capitalists. Although the venture capital industry long predated the internet, tax reform of the late 1970s spurred steady growth of the industry in the 1980s (Gompers 1994) and thus it was well positioned to exploit the rapid growth of the information age infrastructure. It grew with and fueled the development of the commercial internet, and venture capital expanded from roughly $20 B in 1995 to nearly $50 B today (Pricewaterhouse Coopers 2016). Although venture capital represents less than 1% of the United States economy, its outsized importance stems from its ability to finance risky innovation in both technologies and business models, and thus it is a natural partner for early-stage university spinoffs.

Venture capital does not finance technologies uniformly. In concert with the growth of the distributed internet, the operational costs to launch a software company declined by an estimated factor of 100 between 2000 and 2010 (Andreesen 2011). As a result of this dramatic increase in capital efficiency, the private capital markets have skewed strongly toward software.

Table 2 shows the changing national venture capital landscape in five-year increments since 1995 (PricewaterhouseCoopers and National Venture Capital Association 2016) and indicates that while capital was invested in software and electronics (selected as an example of a manufacturing technology) at a 10:1 ratio twenty years ago, today the ratio is closer to 50:1. Similarly, software attracts capital at a rate of roughly 7:1 compared to industrial opportunities, compared with roughly 2:1 twenty years ago. In addition, the average investment in a software company has increased from $3 M to $13 M, compared with $3 M to $6 M in electronics. While an average industrial deal is similarly sized at $12 M, there are simply not as many of them. Biotechnology has seen rapid growth as well, generating deal sizes that tripled from $5 M to the largest shown here, $16 M today. Relative to software, biotechnology deals face additional challenges from the long path to market, the enormous capital requirements, and the regulatory considerations.

Table 1. Venture funding for select industries on a national basis. "Number" specifies the quantity of venture deals in a given quarter, and "funds" represent total invested capital. (PricewaterhouseCoopers and National Venture Capital Association 2016)

	Electronics/ Instrumentation		Industrial/ Energy		Biotechnology		Software	
	Number	**Funds**	**Number**	**Funds**	**Number**	**Funds**	**Number**	**Funds**
1995	48	$137 M	130	$ 542 M	175	$831 M	436	$1,183 M
2000	75	$781 M	253	$ 2,625 M	361	$4,290 M	2,177	$25,453 M
2005	87	$445 M	157	$ 1,101 M	421	$4,027 M	960	$5,353 M
2010	73	$395 M	299	$ 3,275 M	507	$3,984 M	1,092	$5,255 M
2015	67	$402 M	265	$ 3,222 M	482	$7,717 M	1,811	$23,671 M

Summary and impact

- The venture capital industry has expanded by a factor of 2.5 in the last twenty years, driving the development of the information age infrastructure.
- The software industry has grown tremendously in the last twenty years, and it has become increasingly difficult to attract venture capital to manufacturing-oriented technologies outside the biotechnology space.
- Biotechnology is also growing rapidly, indicating an appetite of the capital markets for platform technologies that can underpin industrial transformation.

2.6. Crossing disciplinary boundaries

Historically, scientific progress in academia has depended on demonstrating sustained depth in a narrow field of research. Disciplinary boundaries made it easy to align research fields with traditional course structures, enabling university administrators to efficiently manage teaching and research organizations. Academic promotion processes recognized faculty members with greater success in obtaining their own independent grants rather than those who participated in larger initiatives where their contributions were not fully recognized. Interdisciplinary research has experienced cycles, with faculty maintaining a "stick to your knitting" attitude during funding lulls.

The nature of scientific discovery today forces increased multi-disciplinary collaboration and demands greater expertise in systems-level approaches. New national research priorities have recently been defined (American Institute of Physics 2016) that call for these skills.

Specifically, as we generate new understanding of the basic building blocks of biological systems, the level of control that we enjoy for novel materials will extend to the life sciences and integration of life and physical sciences will accelerate. Indeed, Stanford reports that 10% of the inventions disclosed last year could not be categorized as either life or physical sciences exclusively (Stanford University 2015). We should expect more discovery along the interfaces bordering the life sciences, with a small subset including the computational treatment of biological systems; biomimetic structures drawing from nature; new cost-effective use of biological catalysis for material synthesis; and many other applications.

Another important merger of disciplines is the technology evolution of the last 100 years, viewed perhaps as transitioning from atoms to bits to combined systems (“ABC”). The distributed architecture of controls via the cloud and similar systems will enable a new set of technologies. Sectors will overlap in the ensuing industrial transformation; one example is the convergence between internet companies and auto manufacturers as so-called “connected cars” mature. The ongoing “internet of things” revolution will require combined competence in both mechanical and electrical engineering; sensor and communications technologies; and many other combinations. A single corporate “core competency” will be obsolete if it is not paired with another dynamic operation; indeed, firm value and industries will rise under combined competencies. As manufacturing and industrial deals are increasingly viewed as platform and integration opportunities, capital will flow toward them. Academia should respond to this industry and indeed can drive this viewpoint and research direction.

Industrial engagement with academia is critical to creating a workforce with technical depth and breadth. Systems approaches will become more valuable and education must provide rich experiences in synthesis and integration to develop a relevant workforce. Industry-academia interactions will be critical in maintaining a national competitive advantage in sectors under transformation.

2.7. Partnering with states in regional economic development

Centers can potentially serve as anchors for regional growth. This is linked to the discussion of entrepreneurship because interactions between entrepreneurs and regional resources have been widely acknowledged to contribute to the development of industrial clusters (Feldman, Francis and Bercovitz 2005). Local communities have additional interest in supporting entrepreneurship because new companies have been linked to creation of an average of 1.5 million jobs per year and nearly all the net job creation in the United States (Ewing Marion Kauffman Foundation 2015).

States have long varied in their approaches to R&D, with the 2013 highest spend on extramural performers (including universities) invested in California, Ohio, Texas, and New York (National Science Foundation 2015). Research and development investment strategies extend to other approaches to innovation support and have been studied by other countries as well (Harris 2010).

Many forward-thinking states, such as South Carolina, and Virginia, have created their own center-like initiatives to support regional growth (National Governors Association 2013). The Oregon Nanoscience and Microtechnologies Institute leveraged Portland's historical strength in the semiconductor industry to create a new state-wide cluster, including gap funding (via two programs offering $75,000, then $250,000) to support nascent materials science ventures.

The International Center for Automotive Research (ICAR) at Clemson University provides another interesting model for state-university-industry partnership. By clearly identifying research partners, equipment partners, etc., ICAR can easily create meaningful value propositions and productive relationships.

The Commonwealth Center for Advanced Manufacturing in Virginia demonstrates another model of a meaningful center with deep industry-academia relationships. The state of Virginia contributed approximately $40 M to launching the initiative, and all state universities participate in a separate entity to manage the activities.

In addition to providing key support with large infrastructure, state incentives are critical to supporting innovation at the team level. I-Corps enjoys higher faculty participation in states where the state supplements the NSF award with additional incentives. For instance, Michigan offers the I-Corps Node team an additional $400 k to train other state institutions in I-Corps methodologies. Furthermore, the state has another program ($8 M over three years) to directly support translational projects; nearly every project funded is an I-Corps team.

Georgia provides the VentureLab program at Georgia Tech with an annual budget of roughly $1.4 M to support spinoffs. VentureLab supports their teams from inception through to multiple funding rounds, which often include funding from the Georgia Research Alliance (GRA), founded in 1990 and leveraging $600 M total in state investments. GRA funds two phases to the professor's laboratory group, totaling as much of $200 k; Phases 3 and 4 are, respectively, a convertible note of up to $250 k and an equity investment from the GRA Venture Fund that can exceed $1 M.

The University of Texas system has allocated funds in multiple ways to support state innovation, including: $350 k over two years to support local I-Corps development; $175 k to launch an undergraduate I-Corps program; $175 k to pilot a support program for SBIR grant development; and $225 k to collaborate with MIT in establishing a Venture Mentor Service.

Summary and impact

State participation in R&D support is critical to developing a robust infrastructure:

- Select states have invested heavily in specific centers, creating their own core competencies and proactively choosing the sectors in which they choose to be competitive.
- Other states support innovation at the individual team level, providing translational funding directly to teams and to instructors to support business model education.

3. Summary

Thirty years ago, when multiple federal programs were launched to nurture academic-industrial engagement, industry was defined by large, multi-national companies. These companies recruited students, supported research, and engaged with the federal government on a large scale. The division of labor encouraged basic research in universities, development research in industry, and shared responsibilities for applied or intermediate research. While industrial R&D investment initially complemented federal research funds, it grew rapidly and now represents roughly 2/3 of the national total. These funds are used principally for advanced development, valued more highly by the capital markets, as companies acquire technologies rather than develop them internally.

Today the nation is at an inflection point in university-industry interactions, beginning with a redefinition of "industry." New models for engaging and creating new industrial players are emerging from our academic institutions. Students show consistent and deep interest in launching their own businesses, providing a new avenue for university technologies to reach the marketplace. This trend is fed by increased interest toward experiential, relevant learning. The venture capital world, having grown by more than double in the last twenty years and hungry for new opportunities, now aligns itself directly with many university entrepreneurship centers in search of elusive deal flow. Venture capital skews strongly toward software and biotechnology, creating new opportunities for universities but also new challenges in manufacturing, industrial, and related technologies.

A key driver behind the increased role of the venture capital community is the recognition of the importance of intellectual property, realized both in real economic return to the community and through its contribution to corporate valuations. University technology managers, positioned more prominently than ever before, now face significant trade-offs: traditional licensing models allow large companies to bring technologies to market, providing modest returns through typical royalty arrangements, while new models give universities high-risk, high-return opportunities to benefit from successful startup exits while simultaneously meeting strategic objectives of enhancing faculty retention and supporting the local ecosystem.

Industry-academic collaborations will continue as they provide rich channels for direct interactions between fundamental research and significant impact. However, the value propositions to large and small companies need to be evaluated separately and together. Industry cannot be viewed simply as a large check, but as a stakeholder that demands clearly articulated benefits. Compromises on intellectual property rights may be necessary to include the large corporations that may drive enormous technological transformations. Small company participation can be integral but requires creative funding structures, such as in-kind contributions, to ensure that the relationship doesn't develop at the expense of the company's sustainability.

Industrial and academic scientists can have deep and productive collaborations without the perceived inefficiencies attached to existing center structures. These relationships will continue – but outside the traditional centers. Academic researchers who demonstrate effective value to potential large industrial partners will attract funding directly in "mini-centers" with clear terms of engagement and a research agenda developed in partnership. Academic spinoffs will engage with a university primarily if the relationships predate the company and in limited fashion as the principal investigator typically already participates in the spinoff.

A center can provide a critical training ground for scientists and engineers to learn collaborative skills valuable in any scientific or technical environment. This "product" of a center – the trained workforce - cannot be overstated. It is particularly valuable in light of the melting of traditional disciplinary lines, creating new fields and new industrial opportunities as sector lines are redefined. Students trained in as these fields emerge will be well positioned to contribute substantially to an academic or commercial enterprise of any size as industries are transformed.

Generating jobs and creating rich ecosystems is a key concern of state governments, and efforts to address this have been uneven throughout the state legislatures. Some visionary states have created new programs and systems to support entrepreneurship, while others lag. A major challenge is a lack of long-term commitment and vacillations on innovation policy.

This is a tremendous opportunity for states to drive their own economic development by participating and partnering in this industrial realignment. States also can support innovation at the team level, funding education in customer discovery and translational research to deliver meaningful value to the marketplace. A competitive federal grant program would reward states that make meaningful investments; a pilot project could be launched immediately in 10-15 states that have already demonstrated commitment.

The opportunity is immense for federal and state governments alike to both benefit from and strongly support the interface of academic discovery and industrial transformation. However, one barrier to funding these efforts is the lack of understanding at the state level regarding the multiplier effect of federally-funded intellectual property development. Another challenge is insufficient distinction of the separate needs of small companies and large corporations, giving "industry-university engagement" starkly different meanings for each constituency; grouping them together will yield an average solution satisfying neither. A final challenge is understating the importance of the training elements and focusing strictly on the research output; these two will grow in concert.

The time is ripe for new federal-state partnerships to pilot a new demonstration project to identify value propositions, partner with the changing capital markets, understand the value of intellectual property, and create new economic value on a national scale. A visionary program that incentivizes states committed to linking university research with industry value would make a significant impact at all levels.

4. Methods

Interviews were conducted with:

Job function	Number of interviews
Executives from large companies (4,000+ employees) with responsibility for sourcing or managing technologies from universities; CTO Office or similar	5
CEOs/business development officers of small or mid-sized companies (20-300) who are members of ERCs	5
CEOs/business development officers of university spinoffs who are not members of ERCs	5
University personnel managing technology portfolios and state funding mechanisms	4

4.1. Large companies: Selected insights

"I don't want to pay twice for intellectual property. If I pay for the research, I don't want to pay royalties. I don't want to have that conversation over and over."

"We will not deal with universities that make it difficult to do deals over intellectual property."

"Our program with [unnamed university] is driven by the relationship that our CEO has with [unnamed faculty member], and that drives our funding."

"My international collaborations run much more efficiently because of the way we manage those tasks, using tools that don't seem to be common in universities."

"I can put people from around the world on planes to solve a major problem with 24 hours of notice. I just can't move that fast with a university."

"When we fund university research, most of the time we use it to evaluate and ultimately hire that graduate student."

"We don't need an annual conference to know what's going on, since we have hundreds of scientists and engineers who have that in their job description."

"We like the centers just to see what's going on but we still keep major research in-house."

"We belong to some centers but right now our bigger concern is workforce. We worry about interns and new graduates that don't need handholding and also addressing diversity. We are interested in just about any activity that addresses those issues."

"Our people just set up a collaboration directly with the university faculty without the whole center process."

4.2. Small companies that are members of ERCs: Selected insights

"We are members because [unnamed faculty member] was my advisor and I want to hire his graduates."

"We want the students to train on our software so they will buy it once they have jobs in industry."

"We like the annual conference because it puts us in front of potential customers."

"I wish they would take our software as an in-kind annual fee. We are moving to another ERC that does this."

"After years of trying with [unnamed agency], we finally got funded when we wrote grants with the university professional grant-writing people."

"We can't afford the fee that includes the data-sharing, so we have the lower level."

"We don't really interact with the large companies except with the one specific person who is interested in this field."

4.3. University spin-offs unaffiliated with ERCs: Selected insights

"The professor is on our Advisory Board so we talk to him all the time anyway and he helps us write our proposals."

"My board won't let me spend money on this."

"I don't see how that will raise my next round of funding."

"We already are in the university incubator so we have access to the facility."

4.4. State university personnel

Information from these interviews was paraphrased and inserted directly into the text.

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