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Redefining university roles in regional economies: a case study of university–industry relations and academic organization in nanotechnology

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Abstract The emerging field of nanotechnology has created a new frontier for the convergence of university and industrial research. In the United States, major federal investments provided a massive boom for this field over the decade. This paper reports on a case study of how the University at Albany came to establish the first college of nanotechnology in the US, as part of a larger R&D complex oriented towards building a regional nanoelectronics cluster. The case points to the role of entrepreneurs in mobilizing ideas and resources to advance novel organizational forms. This study demonstrates how a mode of technology transfer based on research facilities was deliberately used to build a nanotechnology complex at Albany, highlighting the enabling role of state S&T policies in supporting university engagements in regional economic development.

Keywords Nanotechnology · Academic organization · Technology transfer · State policy · Regional economic development · Emerging fields

American universities are increasingly expected to play active roles in promoting technological innovation to reinvigorate regional economies. This expectation has been assimilated by university administrators and state policy makers. Most states seek to induce technology-based economic development, involving universities in their initiatives to grow high technology clusters (Geiger and Sá 2008). Some states have made substantial commitments to university research and infrastructure in fields with clear technological promise and economic potential. Universities make their own investments in these areas of research, seeking to be at the forefront of such critical fields and to secure external support and resources. Biotechnology epitomizes these 'science-based technologies', areas of fundamental investigation where research discoveries can lead to valuable innovations. As the biotechnology industry expanded over the past three decades, close relationships developed among university and industrial scientists, who participate in common research networks in the joint pursue of discovery and intellectual property (Powell and

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Owen-Smith 2002). The field in many ways shaped contemporary technology transfer practice, as it provided a paradigm driven towards the patenting and commercialization of academic research that was widely adopted by universities.

Increasingly important for various industries, the emerging field of nanotechnology has created a new frontier for the convergence of academic and industrial research. Broadly, nanotechnology is an extension of and builds upon R&D in advanced materials, semiconductors, electronics, and the life sciences (Mody 2004). The US National Nanotechnology Initiative defines nanotechnology as 'the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale' (http://www.nano.gov/html/facts/whatIsNano.html). These and other definitions point to the manipulation of matter as a central thrust, and collapse the boundaries between science and technology.[1] Heralded for its expected future impacts on industrial manufacturing, nanotechnology has already enabled more than 1,000 exiting consumer products by one estimation (The Project on Emerging Nanotechnologies 2010). Promoted by major S&T policy initiatives across the globe, nanotechnology received a massive boom in the United States during the 2000s from the federal government (McCray 2005; Johnson 2004). Nanotechnology policy has induced the convergence of several academic disciplines around research problems at the nano-scale with clear impacts on industrial technology. Further, it has promoted close university–industry ties and the prompt commercialization of research discoveries (McCray 2005).

Nanotechnology remains an emerging field in academia, despite considerably hype about the implications of 'nano' in industry and the economy (Mody 2004; Stephan et al. 2007). Accommodating this new field, or recombination of other fields, into the academic structure of universities is not easy. Costly facilities such as clean rooms, scientific instruments, and research infrastructure are required. Beyond capital constraints, nanotechnology present an organizational challenge: how to integrate interdisciplinary teams of scientists and engineers into coherent academic programs? As an inchoate field, nanotechnology still lacks widely shared norms of academic organization that can be easily replicated. While many research universities boast research centers and institutes in the field, few have organized academic programs, in most cases attached to more traditional disciplines and departments (Stephan et al. 2007).

The conceptual point of departure of this study is that emerging science-based technologies such as nanotechnology provide opportunities for entrepreneurs in academia to advance new organizational forms, including models of university–industry collaboration. Having established the first college of nanotechnology in the United States, the University at Albany is an auspicious site for investigating the introduction of novel structures and strategies. Part of the State University of New York (SUNY) system, Albany is a relatively young institution. It developed out of the state impetus to develop state universities, gaining university status in 1962. Albany has evolved to become a mid-range research university, which ranked 59th in R&D expenditures in the 2007 survey of the National Science Foundation (National Science Foundation 2008). Within the SUNY system, the

[1] In another popular definition, Bushan (2006, p. 1) proposes that 'nanotechnology encompasses the production and application of physical, chemical, and biological systems at scales ranging from individual atoms or molecules to submicron dimensions, as well as the integration of the resulting nanostructures into larger systems'.

Albany campus trails its counterpart in Buffalo in terms of sponsored research, and it has a smaller presence in graduate education than both Buffalo and Stony Brook.

This study explored how and why nanotechnology became a major institutional thrust at Albany, where unlike other universities this emerging field became embedded in a unique academic unit. A case study strategy was used to pursue these questions, employing multiple, complementary sources of evidence (Yin 2003). The study involved archival research and documentary analysis, in addition to personal interviews with administrators and researchers during a site visit in 2006. Documentation analyzed includes institutional records, New York State policy documents, nanotechnology policy reports, nano-science publications, news articles and campus reports, and among other relevant materials.[2] Analysis of the case data revealed a long and complex history leading to the creation of the college that spans decades. Examining critical junctures in that history is the main task of this paper.

The story of Albany's college of nanotechnology provides insight into the role of entrepreneurs in mobilizing ideas and resources to shape organizational models for research, education, and technology transfer. It demonstrates how a mode of collaborations with industry based on research facilities was deliberately used to build a nanotechnology complex at the university, oriented towards building a regional nanoelectronics cluster. That model is substantively different from the standard approach to technology transfer inspired by the life sciences, based on the licensing of academic patents by technology transfer offices (Mowery et al 2004; Geiger and Sá 2008). Moreover, Albany's case brings to the forefront the role of state S&T policies in supporting university engagements in regional economies as a crucial enabler of such pursuit.

Below, key concepts in this research are framed: entrepreneurs, organizational forms, and emerging fields. The case is presented in the four following sections. Discussion of the main findings and implications conclude the paper.

Conceptual framework

The study of entrepreneurs is commonly traced back to Schumpeter (1934), who famously cast them as innovators leading 'creative destruction' in the economy. According to Schumpeter, entrepreneurs recombined existing resources to create new products, methods of production, sources of inputs, markets, and business organizations. Since Schumpeter's days, attention to the role of entrepreneurs has only increased. Scholars from different fields have expanded the notion of entrepreneurship to cover a wide range of meanings, activities, and social settings (Hwang and Powell 2005; Pozen 2008). There are 'policy entrepreneurs' in politics, 'social entrepreneurs' in civic issues, 'intrapreneurs' in firms (Pozen 2008), and of course, 'academic entrepreneurs' in universities (Bercovitz and Feldman 2008). Even within research focused on higher education, entrepreneurs and entrepreneurship are understood in a variety of ways, reflecting the multiple framings and applications of the concepts across the social sciences (Mars and Rios-Aguilar 2010).[3]

[2] Content analysis of field notes, documentary data, and interview data followed standard protocols for identifying themes and corroborating evidence through triangulation (Weber 1996; Strauss 1987).

[3] In a recent review of papers in higher education journals, Mars and Rios-Aguilar (2010) found that academic entrepreneurs have been more often understood as university professors who engage in commercialization activities, and entrepreneurship tends to refer generally to market-oriented behavior.

This paper refers to entrepreneurs in universities more broadly as consequential agents in organizational change. In the pursuit of their interests, campus actors may have an impact on the structures, strategies, and trajectories of their universities. Entrepreneurship is seen not as a discrete set of standard responses to the environment, but as involving the creation of "new organizational models and policies that change the direction and flow of organizational activity" (Hwang and Powell 2005, p. 179). This approach is consistent with broader principles that have conceptually defined entrepreneurship in the Schumpeterian tradition: the introduction of innovative recombinations of ideas and resources to exploit opportunities and create value, within the context of the organization. Introducing new organizational forms is one expression of entrepreneurial action.

Similarly, there are multiple theoretical approaches to and definitions of organizational forms. They variously emphasize internal or external aspects, as well as objective or subjective dimensions of organizations (Aldrich and Ruef 2006). This paper draws on the work of organizational scholars who have defined organizational forms as the bundle of core organizational features involving goals, authority relations, technologies, and client markets (Rao and Singh 1999). Put more simply, organizational forms may be viewed as organizational structures and associated organizational strategies (Ingram 1996, 85). As some have pointed out, those elements of structure and strategy embody subjective beliefs and values shared in the organizational field (Haveman and Rao 1997; Greenwood and Hinings 1996).

Organizational fields are commonly understood as collectives of organizations that constitute identifiable realms of activity. They include "key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar products and services" (DiMaggio and Powell 1983, 148). Fields evolve through the reproduction of behaviors that create, sustain, and change those constitutive elements. In mature fields, norms, practices, and patterns of inter-organizational relationships are well established. They are widely known and shared among organizational actors, whether one speaks of commonly accepted industry recipes, enforced standards of operation, or taken-for-granted hierarchies among organizations. In such fields, prescriptions about organizational forms tend to be highly elaborated and diffused among field participants. Mature academic fields are institutionalized in the university departmental organization, and count on a social structure of professional associations, journals, conferences, grant programs in research funding agencies, and other sources of support and recognition (Abbott 2001). There is a pecking order of distinction among university departments/schools in the field, as well as among the other elements of the social structure. The 'top' schools tend to set configurations of academic program and be widely emulated.

In contrast, emerging fields are less structured social arenas, where there is greater uncertainty about field composition and the rules of the game (Maguire et al. 2004). The roles of organizations, their interrelationships, and the means to obtain material and symbolic resources are not as developed as in mature fields. In the absence of established channels for resource acquisition, entrepreneurs need to meet the needs of actors who provide necessary support. Emergent fields provide entrepreneurs from different positions in the social hierarchy with opportunities to advance organizational arrangements that are favorable to them (DiMaggio 1988; Hardy 1994; Fligstein 1997). Without clearly recognized standard-setters exerting isomorphic pressures, there is greater room for new organizational forms to be introduced. Emerging academic fields do not enjoy a secure foothold across universities, with permanent academic structures, professorial appointments, degree programs, and accepted understandings about the field's location in academia. Promoters of new scientific fields seek to establish robust social networks, resource bases, and legitimacy (Frickel and Gross 2005). Competing with other aspiring fields for intellectual territory and resources, participants in emerging fields need to establish shared identities and research directions. While those are in the making, the field may manifest in disparate ways across campuses, and participants lack common assumptions about academic organization.

Thin films and entrepreneurial science

The trajectory of what become a major nanotechnology complex at the University at Albany started well before the field was thrust into public debate in the late 1990s-early 2000s. In the 1980s, the university became more influential in the state legislature, as New York and other states were reorienting their investments in high technology programs (Plosila 2004). The Albany area had experienced the economic decline of traditional manufacturing that assailed the American rust belt, and as other states, it viewed science and technology as a potential solution. States started to view investments in university research as a means to upgrade and diversify local industries. Albany developed new institutional relationships that created the conditions for the rise of research initiatives linking universities and local industry.

Albany's president Vincent O'Leary partnered with Rensselaer Polytechnic Institute president George Low in the early 1980s as they sought state assistance to jointly exploit an industrial site in Troy. Low had been particularly active in positioning RPI as a catalyst of new high tech business and a partner of large corporations based in the state, currying considerable support from the state government (Leslie 2001). The partnership among the neighboring universities increased their influence in the state legislature. It also led to cross-campus research collaborations in applied physics, which ultimately resulted in the creation of the Joint Laboratories for Advanced Materials (JLAM) in 1987.

The Joint Laboratories for Advanced Materials brought together scientists working on complementary research programs in the area of thin films materials and process research on the two campuses. One of the center's founders was physics professor James W. Corbett, who throughout this career bridged industry and academia, as well as the two universities around the Hudson River. A specialist in semiconductor and solid-state physics, Corbett worked for General Electric for 13 years before joining the Albany faculty in the late 1960s. While still at GE, he had a stint as an adjunct faculty at RPI (Saxon 1994). Another key participant in JLAM was a younger physics professor, Alain E. Kaloyeros, who came to Albany in 1988 after obtaining his Ph.D. in experimental physics at the University of Illinois. A Lebanese-Greek émigré, Kaloyeros co-directed JLAM for a decade, forging useful connections with industry. The center attracted a range of corporate partners, including Motorola, Intel, Air Products, IBM, and SEMATECH (Fury and Kaloyeros 1993, p. 61).

In 1993, Kaloyeros led a research team that obtained support from New York's Center for Advanced Technology (CAT) program, one of the first of its kind in the nation.[4] The program provided sustained support for university research teams to create research "centers of excellence" that worked with industry in high technology fields. To achieve

[4] Interestingly, the CAT program originated from RPI's lobbying efforts to secure support from the state for research that would aid the local economy. Political bargaining resulted in the program, which could distribute state resources geographically (Etzkowitz 1997, p. 418). For a detailed account of Low's efforts, see Leslie (2001).

that, CATs received one million dollars per year from the state for 10 years, contingent on equivalent matching funds from industrial partners. The Center for Advanced Thin Film Technology brought together several Albany researchers in the areas of microelectronics and optoelectronics, and specialized in computer chip interconnects. This was a crucial technological area for firms in the semiconductors industry such as neighboring IBM, a historically large employer in the state. The center was quickly successful. With support from corporate sponsors, it built a pilot manufacturing facility for semiconductors in 1996, "NanoFab 200." Equipped with the latest wafer manufacturing technology, it could produce the 200 mm wafers utilized by the industry.

Kaloyeros and his colleagues engendered close collaborations with industrial partners. He had strong ideas about the links between academic science and industrial innovation. Working closely with corporate researchers, Kaloyeros decried the gap between the cultures of academia and industry. With an IBM collaborator, he professed, "While it is always the hope that [fundamental research] will result some tangible success—commercial, humanitarian, or notoriety—such success has been secondary to the academic legitimacy of proposing a project to address an unknown, and to educate in the process" (Fury and Kaloyeros 1993, p. 59). Beyond the low regard for more applied research projects in academia, they viewed the normative and professional separation between basic and applied science as part of the problem: "application of the results of that research was the province of those employed in areas of applied research and product/process development." This separation, in their estimation, created a "gap in technology continuity in microelectronics" (ibid.).

The Center for Advanced Thin Films Technology sought to close that gap. Growing success in enlisting corporate partners made the center outgrow the shared spaces it used at the university. In 1997, the move to a new facility on the northwest edge of the campus, the modern looking Center for Environmental Sciences and Technology Management. Erected in part with state support, the building was designed to accommodate university and industrial researchers close proximity.[5] It provided a more congenial home for the aspirations of the group to cultivate long-term relations with firms. By the decade's end, Kaloyeros and colleagues had established a presence on campus with the growing university–industry center, and were poised to exploit the fin-de-siècle transformations in the research policy environment.

The rise of nanotechnology

Policy entrepreneurs well versed in the workings of the federal agencies articulated the rise of a major federal program in nanotechnology from the mid- to late 1990s. The federal government had long made investments in nanotechnology research, but those were scattered across multiple agencies an amounted no more than $155 million by the turn of the century. Mihail Roco and other proponents captured the attention of Congress by aptly building upon the reorientation of science policy towards economic competitiveness, the perceived threat posed European and Japanese technological programs, and optimistic visions of the role of nanotechnology in shaping the future of manufacturing. Those factors fueled a sense of urgency that was aptly exploited by the nano-advocates. Indeed, when president Bill Clinton announced the National Nanotechnology Initiative (NNI) in 2000, it

[5] CESTM was erected with a $10 million state economic development grant, complemented by $2 million from a federal grant and $1.4 million from private sources.

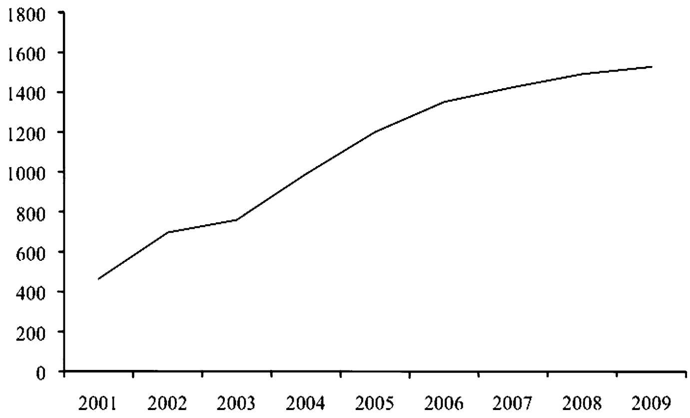

Fig. 1 Budget of national nanotechnology initiative (in $ millions). *Source*: NNI 2009

was hailed as a step to spur the technologies for the 'next industrial revolution' (McCray 2005).

The NNI was initially backed by a congressional appropriation of nearly 500 million dollars, and was signed into law in 2003 by president George W. Bush with the passage of twenty-first century Nanotechnology Research and Development Act (Public Law 108-153). The initiative soon elevated federal investments in 'nano-scale science and engineering' to more than a billion dollars, disbursed through 13 federal agencies (see Fig. 1). New York made its own provisions to capture a share of federal R&D dollars for the field. The administration of governor George E. Pataki (1995–2007) established the New York State Office of Science, Technology, and Academic Research (NYSTAR) in 1999, with a $130 million budget. Nanotechnology quickly became a priority area for NYSTAR, alongside biotechnology, biomedicine, and computer and information technology. The agency funded university research and infrastructure in these fields through various programs.[6]

The New York State Office of Science, Technology, and Academic Research proved to be a bonanza for universities in the state. Somewhat typically of state S&T programs, 'pork barrel' politics[7] played a role in the allocation of funding. All research universities received some support, but the state capital's campus was particularly rewarded. The University at Albany was the recipient of some of the single largest appropriations.[8] Starting in 2000, a series of grants from NYSTAR allowed the Center for Advanced Thin Film Technology to expand its activities to realize the promise of nanotechnology for the electronics and semiconductor industries. With great demand for increasingly small and powerful computer chips, famously proposed by Moore's Law, firms in those industries have a direct stake in nano-science and engineering that allows increasing miniaturization of materials and components.

[6] Those include the "Centers of Excellence", "STAR Centers" (Strategically Targeted Academic Research), and "Gen*NY*sis" (Generating Employment through New York State Science).

[7] In the US context, the term 'pork barrel' refers, in a derogatory manner, to the allocation of government funds to please special interests in the districts of politicians requesting them.

[8] One analysis shows Albany to be the biggest beneficiary of pork-barrel funds in S&T as well as in other areas (Garder and Rosenberg 2006).

At the turn of the century, Albany became a "focus center" on chip development of the National Interconnect Focus Center program, along with RPI, Stanford, MIT and the Georgia Institute of Technology. This program was organized by the Semiconductor Industry Association (SIA), the Defense Advanced Research Projects Agency, and semiconductor equipment suppliers. New York State provided $5 million over 5 years to back the center (State of New York 2001).

Funding from NYSTAR enable the expansion of the Center for Environmental Sciences and Technology Management, to house a new pilot manufacturing facility equipped with 300 mm wafer integration technology. Semiconductor companies were at the time making the transition towards this new technology platform, which was more efficient than the previous generation 200 mm facilities, but also costly to build and maintain. Significantly, industrial manufacturing plants tend to be located near leading research institutions. The political appeal of state investments on the universities' R&D infrastructure was thus obvious—they "helped attract semiconductor and other hi-tech manufacturing to the State" (State of New York 2000, n.p.).

In 2001, a partnership between the state and IBM created the NYSTAR Center of Excellence in Nanoelectronics at Albany. The multinational had over the years relocated an increasing number of plants overseas. Keen to retain the R&D and manufacturing operations of the Big Blue, political leaders in the state backed Albany's growing infrastructure for nanotechnology as an anchor for the company's operations. The university counted on the support of key state politicians at the time: Senate Majority Leader Joseph Bruno, Speaker of the House Sheldon Silver, and Governor Pataki. With $50 million from the state and $100 million from IBM, Albany's research infrastructure was considerably strengthened. A second "Nanofab" with another 300 mm wafer integration facility was erected in the sprawling complex of buildings in the northwest of the Albany campus.

Albany nanotech and the first college of nanotechnology

The conglomerate of research programs and facilities growing around the Center for Environmental Sciences and Technology Management became identified as Albany Nanotech. More than a research park, Albany Nanotech was a self-styled agent in the promotion of a regional nanotechnology cluster. With Kaloyeros at the helm, it started recruiting industrial partners aggressively. In 2002, SEMATECH International North, an international R&D consortium, was lured to Albany—a major coup that put Albany Nanotech on the map of the industry. Other consortia and joint ventures soon followed.[9] The visible hand of the state enabled many of these achievements, through direct subsidies for new partners to locate in the state capital.[10]

As explained by one administrator, Albany Nanotech's mission "is to accelerate change."[11] Rather than simply dealing with firms on discrete projects, or even nurturing long-term relationships with individual corporations, they seek to establish broadly based inter-organizational partnerships. They perceive that greater rewards lie in engineering ties with various firms in the

[9] They include the International Venture for Nanolithography, the Center for Advanced Interconnect Science and Technology, and the Institute for Nanoelectronics Discovery and Exploration. They involve investments of $500+ million, $500 million, and $435 million, respectively (CNSE Backgrounder 2007, pp. 2–9).

[10] For example, to land SEMATECH and the first Tokyo Electron R&D laboratory outside of Japan, the state footed a $310 million bill.

[11] Quoted from an interviewee on the Albany campus (05/06/2006).

same product value chain, whose R&D goals and technologies are complementary and interdependent. Contiguous clean room facilities are made available for industrial partners to work side by side to develop different components that feed into larger technology platforms—in close proximity to the academic scientists and students in the complex.

Early in 2004, former New York State Governor George Pataki disclosed an auspicious initiative: "we will work with the University at Albany to create a new College of Nanotechnology—the first of its kind in the country—to provide our industry with the high quality workforce it needs to grow in New York State" (Pataki 2004). More than the first college in the field, The College of Nanoscale Science and Engineering (CNSE) is expected to be an influential agent in the creation of a regional nanoelectronics cluster, following the trail blazed in previous years by Albany Nanotech. Its internal organization is reminiscent of industrial R&D labs: faculty members are not assigned to academic departments, but to flexible faculty 'constellations' in nanoscience, nanoengineering, nanobioscience, and 'nanoeconomics'.[12] Many of the senior faculty and administrators have had some experience working in non-academic settings, including in a few cases long tenures at industrial laboratories and start-up companies.[13]

Kaloyeros is the college's 'Chief Administrative Officer', and also Vice-President for University-wide Economic Innovation and Outreach. The CAO title is not accidental—one college official claims that it makes communication with corporate partners easier.[14] The concern with resonating with executives in the private sector is not unfounded: CNSE obtains about 80% of its revenues from industry. Even as industry-sponsored research declined nationally in the early 2000s, the amount of corporate-sponsored investigation performed at Albany skyrocketed, as shown in the Fig. 2. Moreover, in sheer numbers, the complex has developed a substantial industrial footprint on campus. By 2008, it housed over 2,000 corporate R&D personnel.

Beyond corporate support, CNSE has effectively tapped political support from New York State senators and congressmen to obtain federal earmarks for research centers. That was the case of the New York Center for National Competitiveness in Nanoscale Characterization, funded at $1 million by the Senate appropriations committee, which focuses on the metrology of nano-scale technologies. Support from a New York congressman resulted in funding from the U.S. House of Representatives for the NanoSensor StageGate Accelerator, oriented towards military applications of nanotechnology.

The preponderance of corporate ties implies in research less oriented towards long-range, exploratory investigation. CNSE has not been successful in obtaining some of the highly competitive, major awards from federal agencies.[15] A reputation survey conducted

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[12] Such arrangements to recruit and organize faculty into loose multidisciplinary structures are becoming more frequent among US research universities (Sá 2008a, b).

[13] James G. Ryan, a former professor of nanoscience and associate vice president of technology, had worked at IBM for 25 years before joining CNSE in 2005. He left CNSE in 2008 to become the founding dean of the Joint School of Nanoscience and Nanoengineering, affiliated to North Carolina A&T State University and The University of North Carolina at Greensboro. http://cnse.albany.edu/News/index.cfm?step=show_detail&NewsID=1361.

[14] Interview conducted on site (05/06/06).

[15] For example, the National Science Foundation has over the decade supported the prestigious 'Nano-Scale Science and Engineering Centers,' awarded through an exhaustive, multi-stage review process. Albany is absent of the list of recipients of those centers, as well as other NSF-supported centers focusing on nano, as well as nanotechnology centers supported by other federal agencies. Several of the NSF Materials Science and Engineering Research Centers focus on nano-scale research; other agencies funding nano-centers include the National Institutes of Health, the Department of Defense, and NASA.

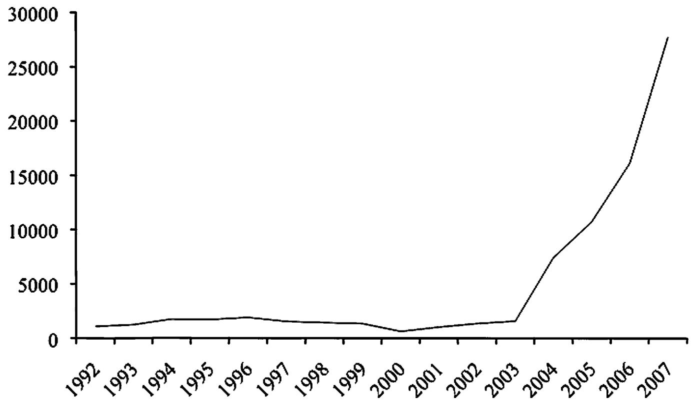

Fig. 2 Industry-funded R&D at SUNY-Albany. *Source*: National Science Foundation 2000, 2009

annually by a nanotechnology trade publication places Albany at the top as a singular school in the field, highlighting the facilities, educational programs, and commercialization activities of the complex. With six multidisciplinary graduate degree programs organized around the 'science' and 'engineering' of nanotechnology, CNSE is ahead of other institutions in the number of educational offerings. The lowest ratings, however, go to 'peer nano research.' (Small Times 2008, 2009). As much as such surveys are often methodologically problematic, this characterization of CNSE seems to reflect its priorities. Albany's complex is geared towards addressing complicated technological problems with near-term implication for industrial partners. Such work can be technically challenging and sophisticated, but may not be always aligned with the longer-term preoccupations of the academic community that drives fundamental research.

The role of research infrastructure in technology transfer

College of Nanoscale Science and Engineering-Albany Nanotech embodies the patterns of collaboration that have become common in the semiconductors industry. A more challenging competitive environment and growing costs of facilities used to develop new technologies drove companies to outsource much of their R&D efforts. With the vertical disintegration of corporate R&D and the rise of geographically dispersed clusters, innovation in semiconductors requires the cultivation of inter-organizational alliances. Saxenian (2006, p. 42) has argued that 'the coordinating functions of the corporate hierarchy … are being replaced by shifting collaborations between specialist producers that jointly design and produce a range of components and subsystems.' Industrial consortia have been a hallmark in the semiconductors industry for the pursuit of generic research.

Above all, Albany's R&D infrastructure for nanotechnology has been the cornerstone of university–industry collaboration. A growing presence of corporate partners located around CNSE evinces industrial interest in the infrastructure of the complex. A major challenge in technology transfer is for academic inventions to move beyond the 'proof of concept' stage towards the manufacturing of commercially viable products (Geiger and Sá 2008). There are innumerous obstacles in this process, including the technical aspects involved in scaling up production of the new technology in a cost-effective manner. The nanofabrication facilities at CNSE, compliant with industry standards, are intended to facilitate this transition.

Understanding the opportunities presented by these dynamics of the semiconductors industry, and the politics of state technology-driven economic development, was critical to the creation and growth of the Albany complex. In this scenario, being an agent in building a regional nanoeletronics cluster became a key source of resources and support for the enterprise. As new corporate research labs and manufacturing plants are opened on campus and surrounding areas, the complex has gained recognition for its mission. Albany Nanotech was mentioned when IBM decided to open a new factory in East Fishkill in 2002. When Advanced Micro Devices decided to build a new $3.2 billion factory in Saratoga County 4 years later, the university was also cited as a factor influencing this choice (Lohr 2006). Besides the university, however, massive subsidies by the state and local governments also influenced those decisions.[16] When SEMATECH International decided to move its headquarters to the Albany complex in 2007, promising employment opportunities and research funding for CNSE, a bill was passed in the state legislature allocating $300 million towards the purchase of equipment. Kaloyero's conspicuous role in attracting SEMATECH international to the state had rendered him public recognition, including friendly profiles in the national media (D'Errico 2002; Finn 2002; Engardio 2009). One senior administrator regards him in lofty terms as 'one of the main economic drivers for the development of upstate New York' (Redden 2007).

Indeed, large R&D facilities have been linked with the emergence of nanotechnology clusters (Mangematin 2006). Such infrastructure provides a distinctive pathway for technology transfer, based on the shared use of facilities and collaborative R&D. Nonetheless, the difficulties of building high tech clusters are well known, and the object of extensive academic research (e.g. Braunerhjelm and Feldman 2006). In a national analysis of the nascent nanotechnology clusters, Shapira and Youtie (2008) have argued that focusing investments in the research capacity of a single institution yields short-term benefits such as increased prominence for the region, and visibility for the institution. This has certainly been the case for both the Albany region and the university. Viewed from a national perspective, however, the Albany region is still an aspiring nanotechnology center. It is dominated by university-based research, which took off in the early- to mid-2000s, and patenting activity is not too intense. These features are consistent with the rise of Albany described above, and the ways it interacts with industry.[17] Shadowed by the considerable attention given by scholars and policymakers to technology transfer via the commercialization of academic inventions (Mowery and Sampat 2006), research facilities are an important element connecting university and industrial research.

Discussion

The Albany case provides a remarkable example of how entrepreneurial scientists can have a substantive organizational impact on their campuses. It is consistent with previous research suggesting that peripheral actors in organizational fields are more likely to adopt

[16] They pledged $1.56 billion to the IBM and AMD plants (Lohr 2006).

[17] Shapira and Youtie (2008, pp. 196–197) do caution, however, that this strategy "has the potential to crowd out other institutional actors who may be helpful in developing and energizing the regional cluster and who may exploit research avenues not favored by the dominant institution." Their analysis suggests that the most successful 'nanodistricts' have multiple centers of R&D and commercialization activities.

novel organizational models.[18] Albany lacked an engineering school, a usual academic home to nanotechnology programs because of the number of related research communities rooted in engineering fields such as electrical engineering, mechanical engineering, fluid dynamics, computer science, and materials science (Mody 2004). To date, even with the infrastructure and visibility of CNSE, its research is not considered top-notch by peers (Small Times 2009). Departing from a modest organizational base, Albany scientists had little to gain from seeking support and recognition through conventional channels such as federal research agencies. Embracing industrial partnerships and commercialization allowed CNSE to grow based on the exploitation of a unique niche. When Albany scientists decided to build nanofabrication facilities abiding to the latest industry standards, they were following a deliberate strategy to appease actual and potential corporate clients. The research infrastructure developed over the years provides a distinctive comparative advantage to CNSE in working with large, R&D-intensive firms.

Entrepreneurs in emerging fields need to devise new ways to meet the interests of relevant stakeholders who can provide necessary resources and support (e.g. Maguire et al. 2004). Linking research, technological innovation, and the promotion of a regional cluster was the strategy of Albany scientists to secure funding and recognition, building a coalition among state authorities and corporate partners. Albany scientists rejected conventional organizational configurations, whether by following the dictates of more prestigious institutions or the structural arrangements of more established disciplines. Rather, they pragmatically met the needs of corporations, and shaped organizational structures and strategies accordingly. In the absence of widely diffused norms about the nature, goals, and substance of nanotechnology programs and units in universities, CNSE advanced its approach as an innovation, in ways that resonate with the ideation of nanotechnology as a field. As Johnson (2004, p. 226) has argued,

> [n]anotechnology is a nearly perfect fit for what both companies and the government expect from science…. the development of the field is less stymied by the challenges it presents to traditional modes of doing science—e.g., transdisciplinarity, focus towards applications, ties to proprietary industrial research, blurring of science and engineering.

State activism in promoting technology-based economic development was a crucial enabler of CNSE's creation and expansion. New York State government's commitment to nanotechnology at Albany was the culmination of an on-going relationship based on mutually reinforcing interests. The state's sizable investments in research facilities and infrastructure followed from the interest in retaining and attracting industrial jobs, a logic that was aptly exploited by the nano-entrepreneurs on the Albany campus. The growing nanotechnology complex continuously met the research needs of locally based firms who were important employers, and then reached out globally to recruit corporate partners. The state government supported and sanctioned such relations with continuous investments, subsidies, and official endorsement. The federal NNI legitimated and provided further stimuli to the on-going orientations and activities of the Albany researchers, although as shown above, it did not cause it. As it became widely recognized and subject of public

[18] In summary, that is because (1) marginal organizations are not beneficiaries of existing ideas and forms that sustain the status quo, and thus have an incentive to pursue alternatives; (2) they are less interconnected with central organizations in the field that sustain the status quo; and (3) they are more exposed to existing contradictions in the field. See Greenwood and Suddaby (2006, 29–30).

debate, nanotechnology allowed for a strategic and symbolic reframing of on-going research activities on semiconductors as part of a broader science and technology agenda.

Collaborations with industry were built not only on state dollars, but also on the ability of the Albany scientists to identify unfolding trends in corporate R&D. Large-scale research infrastructure has been linked to a mode of technology transfer based on formal and informal collaborations, stemming from the shared use of facilities (Mangematin and Peerbaye 2003). That model is different from, and at times conflicting with, the standard approach to technology transfer that has been widely diffused among US universities and beyond over the past generation, based on patenting and licensing. A strong patent model following the biotechnology paradigm can be a deterrent to forms of university–industry research collaboration that are more common in fields of engineering, advanced materials, and computer science (Geiger and Sá 2009). The object of collaboration in such fields usually involves incremental innovations in a technology platform developed over time through numerous technical advances. Expansive intellectual property claims on collaborative projects that are seen to intrude into previously developed technology are likely to refrain firms from collaborating with universities. Understanding this reality, CNSE adopted a strategy that is centered on broad-based partnerships and collaborative research, consistently with the practices and expectations of semiconductor companies.

The viability of Albany's approach in the long run relates to a number of further developments that go well beyond the campus. Support for nanotechnology research at the federal level has remained strong through the end of the 2000s, signaling to the continuing emphasis on the field. The approaches of other research universities have been more incremental, which begs the question of how nanotechnology will become structurally assimilated in the institutional fabric of prestigious institutions. Because of its multidisciplinary nature, nanotechnology may continue to be housed within parent disciplines that are more established on campuses, and in cross-disciplinary research institutes. Indeed, some have argued that the multidisciplinary character of the field may inhibit the appearance of nanotechnology departments and schools across institutions (Stephan et al. 2007). At this point, it is unclear whether Albany's college will enjoy a "first mover advantage" as it seeks to become established academically, or whether it will remain a singular unit tailored around a unique regional mandate. Above all, success in fulfilling its cluster-building role will certainly be determinant in securing continuing state support in the near future.

Conclusion

As the classic entrepreneur who recombines existing ideas and resources in novel ways to exploit opportunities, Albany scientists capitalized on shifts in science policy and politics, modes of corporate innovation, and expectations around the role of universities in fostering economic development to establish a major new organization on campus. Conceived as a 'new model' that breaks away from the traditional cultural clashes between academia and the corporate world, CNSE-Albany Nanotech is simultaneously an academic unit, a technology park, a regional development broker, and an industry-oriented campus development. This bundle of structures and strategies that make up the organizational form of the college embodies the ideas about the convergence of academic and industrial science that have been successfully promoted by 'nano-advocates' (Mody 2004; McCray 2005). With its multifarious roles, the complex also recombines known components of the growing technology transfer 'periphery' of universities into a novel form of academic organization, which brings to the forefront the role of research infrastructure and facilities that enable science and innovation.

This case raises broad implications for institutional decision-makers, as universities across the globe increasingly seek and are expected to play a role in regional economic development. It highlights that the conceptual and practical convergence among technology transfer experts and practitioners around the patent-driven model of the life sciences obfuscates important developments in other fields. Similar charges have been made among those critically examining the impacts of laws such as the Bayh-Dole Act in the United States, in light of how academic science influences industrial R&D (Mowery et al 2004). Recognizing the variety of ways in which university research may contribute to innovation widens the scope of alternatives open to institutional decision-makers who wish to advance an economic development mission. Pathways to move in that direction are multiple and relate to the nature of regional industry, their development strategies, and the dynamics of innovation of their sectors, in addition to regional policies for research and innovation.

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