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Building an innovation hub: A case study of the transformation of university roles in regional technological and economic development

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ABSTRACT

Universities have assumed an expanded role in science and technology-based economic development that has become of interest to catch-up regions as well as to leading innovation locales. This paper examines how the role of the university has evolved from performing conventional research and education functions to serving as an innovation-promoting knowledge hub though the case of Georgia Institute of Technology (Georgia Tech). This case is discussed in the context of state efforts to shift the region from an agricultural to an industrial to an innovation-driven economy. Central to the transformation of Georgia Tech as a knowledge hub is the emergence of new institutional leadership, programs, organizational forms and boundary-spanning roles that meditate among academic, educational, entrepreneurial, venture capital, industrial, and public spheres. Comparisons between Georgia Tech's experiences and those of university roles in selected other catch-up regions in the southern United States highlight the importance to the case of networked approaches, capacity building, technology-based entrepreneurial development, and local innovation system leadership. Insights on the transformation of universities and the challenges of fostering a similar transformation in regional economies are offered.

1. Introduction

Albeit often gradually, the roles that universities undertake in society change and evolve over time. "The medieval university looked backwards; it professed to be a storehouse of old knowledge... The modern university looks forward, and is a factory of new knowledge." So wrote the English biologist Thomas Henry Huxley in 1892 (Huxley, 1892), remarking on the transformation that industrial society had stimulated in long-established functions of universities.

In this paper, we examine the case of one university and how it has undergone a further transformation, from that of a knowledge factory to a knowledge hub, to advance technological innovation and economic development in its region. One of the hallmarks of a knowledge hub is that it serves as a boundary-spanning organization that accumulates mediating functions for the exchange of tacit as well as codified knowledge between academia and local business and financial communities. The case of Georgia Tech illustrates how one university has benefited from university leadership and the accumulation of boundary-spanning programs. These programs seek to develop new technology-oriented business capabilities among academic faculty, startup ventures, mature companies, and industry clusters. Evaluations of these programs suggest that their explicit elements are most likely to be measured

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and reported, even though tacit knowledge sharing is what is most valued by participants and stakeholders. After comparing the approaches to leveraging universities in other rising innovation regions in the US South, we then explore the implications for university transformation in stimulating an innovation-based regional economy.

2. Role of intermediaries in the innovation process

The earliest models of universities highlighted their roles as "accumulators" of knowledge—a function that was largely separated from the rest of society. This was signified, for example, in medieval universities (such as Oxford and Cambridge), where scholars and students housed in residential colleges lived and learned apart from the public at large, leading at times to "town v. gown" clashes (Brockliss, 2000).

Beginning in the nineteenth century, the rise of a more active role was heralded for universities. The pursuit of scientific research based on rational inquiry and experimentation grew, as seen in the formation of Berlin's Humboldt University, which then became a model for other universities. Universities also assumed roles in conducting research and training in technical disciplines (as well as purely academic ones) and in educating students to meet the needs of industry (Graham and Diamond, 1997; Noll, 1998; Mowery et al., 2004). Examples here include the development of "red brick" universities and local technical institutions in the industrial cities of Britain, and state land-grant universities and private technological institutes in the US, all of which stressed the value of practical subjects and the application of research.[1]

University institutions continued to expand on both sides of the Atlantic in the twentieth century. Following World War II, government and industry funding for university research was greatly expanded, with support (particularly from government) provided both for basic science and applied technology development. In the 25-year period, 1954–1979, US university R&D expenditures grew at an average rate of 8.1% per year in real terms, significantly higher than the annual rate of growth of 5.3% for the economy as a whole. In the subsequent 25-year period through to 2004, the average rate of growth of university R&D in the US slowed to 5.0% annually in real terms, although this was still a higher rate than for the overall US economy (3.9%). In 2004, US academic R&D totaled $42 billion or about 14% of all US R&D, up from about 10% in the 1970s.[2] Enrollment in all types of higher education in the US increased from 6.9 million students in 1967 to 15.7 million in 2001.[3] Moreover, the decades immediately following World War II have been viewed as an era in which industrial mass production was preeminent in the US and other advanced economies (Piore and Sabel, 1984). The features of linear organization, scale economies, and dedicated systems that characterize mass production have at least some analogies in the growth and orientation of universities in the mid-to-late twentieth century, particularly for high-enrollment campus institutions. In rudimentary terms, such "knowledge factories" developed inputs (e.g., students and research funding) into outputs (prospective employees and research papers) in batches, with set methods, raising comparisons with assembly-line production.

Training students and conducting research to produce new knowledge remains the "bread and butter" of the modern university. However, we suggest (see Fig. 1) that a third model of the university has emerged in recent decades—one in which the university functions as a "knowledge hub" that seeks to animate indigenous development, new capabilities, and innovation, especially within its region (Shapira and Youtie, 2004; see also Newlands, 2003). In this model, universities become even more deeply embedded in innovation systems, seeking to actively foster interactions and spillovers to link research with application and commercialization, and taking on roles of catalyzing and animating economic and social development. Processes of the creation, acquisition, diffusion, and deployment of knowledge are at the core of these functions, hence the terminology of knowledge hub. The university, of course, always has been an institution of knowledge, but in this third mode, the institution seeks actively to use knowledge to promote indigenous development and new capabilities in its region and beyond.

There are multiple forces influencing this transition and evolution in university roles. They include the underlying shifts in advanced economies away from traditional mass production and linear transfer relationships to post-industrial, knowledge-driven, open, and more interactive innovation systems (Florida, 1995; OECD, 1996; Chesbrough, 2003). These shifts challenge universities to reorganize research (for example, to address new developments in technology which require interdisciplinarity and collaboration), to evolve educational missions and methods (to meet demands for new qualities in human capital development), and to reconsider the ways in which they develop and exchange knowledge (including their knowledge-based interactions and networks with industries and communities). Related to these shifts are new expectations by government about the performance and contribution of universities. In the US, state governments (which operate large public university systems and fund teaching) increasingly request that their institutions foster economic development and innovation within their localities. Federal policy encourages university technology transfer (including through the Bayh-Dole or University and Small Business Patent Procedures Act of 1980 and other legislation), while federal agencies, which fund most university research, also increasingly look for economic and

[1] A prominent example is the incorporation of the Massachusetts Institute of Technology by the Massachusetts legislature in 1861, as a "... a school of industrial science [aiding] the advancement, development and practical application of science in connection with arts, agriculture, manufactures, and commerce" (Acts of General Court of The Commonwealth of Massachusetts, 1861, Chapter 183, Section 1, available at http://web.mit.edu/corporation/charter.html).

[2] *Source*: National Science Foundation (2006). Authors' calculations of constant dollar compound annual growth rates in R&D spending based on data in Appendix Table 4-4.

[3] National Science Foundation (2006), Appendix Table 2-3.

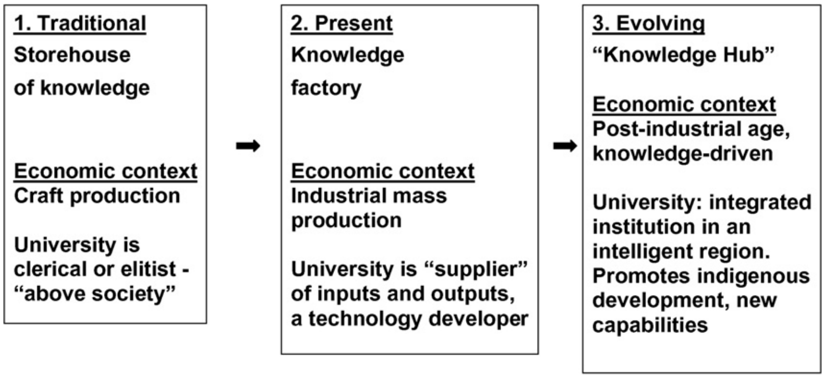

Fig. 1. Evolving University Contexts and Missions. *Source*: Adapted from Shapira and Youtie (2004).

social returns on their R&D investments. Similar trends to promote the linkage of universities to technology transfer, innovation and local development are seen in Europe, Japan, and other advanced economies. The examples of Massachusetts Institute of Technology and Stanford University (both private institutions, although each receiving significant public R&D funding) in stimulating regional high-technology development are often highlighted for emulation. Other new approaches to integrating universities with regional and community development have been advanced which seek to foster broader impacts on localities beyond high-technology startups, including addressing opportunities for diverse populations and targeting research to current economic, social, and environmental problems (Forrant, 2001; Crow, 2002). Efforts to imbue these new design attributes into universities are not unproblematic: besides issues of institutional inertia and resistance to change within the ranks of academia, concerns have been raised about the balance of public vs. private interests in university research and technology transfer, and indeed whether unrealistically high expectations are being raised about the ability of universities to generate economic transformation (Mowery, 2005; Fischer, 2007). Nonetheless, it does seem that university leaders, government policy makers, business groups, and other stakeholders in the US and elsewhere are actively promoting new university innovation roles and knowledge relationships.

While there are historical parallels, particularly with the establishment of technology-oriented institutes by industrialists and government in the late nineteenth century, there are essential differences in orientation and mechanisms that reflect today's post-industrial knowledge-driven context and efforts to foster institutions that are motivators of innovation. One important feature of the third model of the university is the attention paid not only to the formal or codified knowledge (that which can be written down, peer reviewed or examined), but also to developing and transferring tacit and embodied knowledge. In the recent literature on technological and economic development, much has been written about the role of tacit knowledge in the attainment of competitive advantage, particularly by businesses and localities (Maskell and Malmberg, 1999). Tacit knowledge confers context-based and hard-to-replicate capabilities to an organization or collection of organizations in a geographic setting. It is often compared with codified or explicit knowledge which can be more readily conveyed through formal training, documents, databases, and other computerized information technologies. Of course, too sharp a contrast between tacit and explicit knowledge can be misleading because there are interrelationships between them (Amin and Cohendet, 2000). Using codified knowledge well invariably requires related tacit knowledge. Similarly, accumulations and applications of tacit knowledge, particularly those related to science and technology, invariably draw on codified knowledge.

Our conjecture is that in an increasingly knowledge-based environment, high-performing institutions are those which have capabilities not only to develop, acquire and use codified knowledge, but also to effectively advance, distribute and recombine tacit knowledge. In the case of universities, we propose that institutional transition from the second mode ("knowledge factory") to the third mode ("knowledge hub") is associated with increased attention and weight to tacit knowledge especially in technology transfer and regional interactions. This does not mean that second mode institutions do not develop and use both kinds of knowledge—they surely do. Rather, in the third mode, there is a more conscious and deliberate recognition of the role of tacit knowledge, and strategies are put into place to operationalize this recognition and to add value to the organized knowledge that the institution creates. Such strategies may include the attraction or development of particular kinds of human capital and talent, the embodiment of a significant emphasis on tacit knowledge in technology transfer programs, and the engagement of relational knowledge enablers that seek out tacit knowledge and link it with other individuals and organizations to exploit it, thus integrating the university in new relationships that foster innovation within the region (see also Gertler, 2003).

We further suggest that one of the critical ways through which third mode universities facilitate the value-added exchange of knowledge is through the creation and accumulation of boundary-spanning roles. A boundary-spanning activity typically involves communication of knowledge across boundaries within and external to an organization. Internal boundaries within universities include those among intra-organizational units such as academic departments, R&D laboratories and centers, service and extension programs, and administrative branches. External boundaries are defined by the multiple sectors and actors operating in economic, governmental, educational and community spheres. Boundaries can inhibit the transfer of knowledge by blocking its transmission or at least reducing the speed of communication, introducing misrepresentation, omitting certain knowledge, limiting scanning capabilities, and fostering inward looking biases. While boundaries do have positive aspects in regulating behavior and establishing frameworks for relationships, knowledge-oriented development is likely to be accelerated when negative boundary hindrances are overcome. This is seen in the emergence of spanning roles such as scanning, brokerage, liaison, and meditation, to facilitate the transfer of knowledge (Guston, 2001; Tushman, 2002; Aldrich and Herker, 1977). These roles may be filled by boundary-spanning individuals. Academic "star scientists" can serve as boundary spanners who distribute research knowledge and specialized information about new breakthroughs that can be commercialized by private-sector firms (Zucker and Darby, 1996). Similarly, academic leaders (such as university presidents), industry executives and government agency heads may fulfill boundary-spanning roles based on their interactions in scientific, technological, business, and public policy councils and boards. Additionally, organizations may carry out boundary-spanning roles. Guston (2001) notes that such organizations can address knowledge exchange problems across boundaries by creating new communication methods and tools, garnering participation from representatives on different sides of a boundary, or developing expertise in delegated areas along the lines of principal-agent theory. The US agricultural extension program, which involves universities and federal and state government agencies, is a long-established boundary-spanning mechanism active in translating and transferring scientific discoveries to farmers (Carr and Wilkinson, 2005). In their "triple helix" model, Etzkowitz and Leydesdorff (2000) highlight the importance of innovation-fostering hybrid organizations at the interface of university, industry, and governmental segments.

In the linear model in which knowledge transfer was formerly conceived, the research commercialization process was segmented and fewer boundary-spanning organizations may have been needed. Current models portray technology transfer as a more complex and iterative activity, involving feedback loops across multiple dimensions. This more complex model creates the need for organizations that can take a more panoptic view and perform discursive networking functions across boundaries. The development of the technology transfer office has been highlighted as a boundary-spanning organization between the research and entrepreneurial and industrial communities. It houses technology transfer specialists with the capabilities to determine which results are patentable and how to market these discoveries to industry, and it develops policies and practices to enhance incentives for faculty participation in commercialization activities (Guston, 1999; Siegel et al., 2004). Significantly, as Siegel et al. observe in their study of new university technology transfer activities, boundary-spanning occurs through a combination of adjustments in organizational forms (such as the technology transfer office), organizational practices (including intellectual property management), and behavior (for instance, the willingness of faculty to engage with industry, which in turn is influenced by actual and perceived incentives and barriers).

However, there are limits to the extent to which organizations or individuals can fulfill boundary-spanning requirements. Tushman (1977) finds that the accumulation of more boundary roles *per se* may not always be productive. Likewise, although boundary organizations tend to be less likely to suffer from myopia because they have multiple stakeholders, the breadth of their knowledge spanning can still be limited, especially in places without a long tradition of diverse knowledge constituencies. Moreover, there is a risk of limited long-term stability despite the ability of boundary-spanning organizations and elites to draw on multiple constituencies on both sides of the boundary for independence and survival.

Despite these limitations, we maintain that the ability to facilitate the exchange of tacit as well as codified knowledge through boundary spanning is a fundamental characteristic of third mode universities. Given the varieties of knowledge and the multiplicity of interests and stakeholders to be addressed, there are multiple ways through which universities can do this. Luger and Goldstein (1997) suggest that universities can have multidimensional impacts on their regional economies through research and knowledge creation, education and human capital formation, know-how transfer to improve existing industry, technological innovation to commercialize and spinoff technologies, infrastructure development, knowledge-flow improvements, leadership to address regional problems, and the creation of a favorable regional milieu. In essence, the university has embodied the role of a boundary-spanning organization in the fulfillment of its knowledge-hub function.

While many universities now seek to make a transition to some variant of the knowledge-hub model and thus have a greater impact in regional innovation, there is diversity in the ways in which this is pursued and the results achieved. Some have observed the growth of entrepreneurial universities that actively engage in the development of their region through commercialization of research, spinoffs of new companies, and work with regional economic development agencies (Slaughter and Leslie, 1997; Shane, 2004). Building on Jaffe's (1989) work which showed that university R&D positively impacts industry R&D and patents, Audretsch and Feldman (1996) found that knowledge spillovers from university research, industry R&D, and skilled labor were associated with a clustering of localized innovative activity. Zucker and Darby (1997) demonstrated that biotechnology firms seek to locate near "star scientists" at universities to facilitate knowledge transfer to their R&D units. University leadership itself is also a factor. Breznitz et al. (2008) argue that events following the arrival of the new president at Yale University in the early 1990s had a substantial influence on the development of a biotechnology cluster around the university.

There are also examples where universities have expanded efforts to foster knowledge flows and technology transfer, but have not had a great impact on their regional economies. This is often the case of universities in small communities which lack the critical mass of industry to absorb university research outputs, but it is also true in urban universities. For example, Feldman (1994) did not find an anticipated high level of spillover from Johns Hopkins University into the Baltimore economy. And even though public universities have a mission focused on spurring local economic development, Hegde (2005) found that public universities were less likely than private universities to have localized citations of their patents.

In addition, there is the issue of the constellation of research institutions to consider. In the US, the leading regions for innovation are often those with multiple nodes of research strength including universities, government laboratories, non-profit research organizations, and private-sector R&D units. However, in other regions, there may be only a single dominant university and a lack of other kinds of research and industrial partners with advanced capabilities with whom the university can interact. Local regions in economic catch-up positions and which lack multiple nodes of knowledge generation hope that their university will serve as an "anchor tenant" to attract other private-sector R&D facilities (Agrawal and Cockburn, 2002). However, there is also a risk – if a single university becomes all-prevailing – of an "Upas tree effect" where a dominant institution crowds out other players in the regional innovation system (Checkland, 1981).

In this paper, we examine the case of one university in the context of its region, focusing on the transformation of the university as a knowledge hub able to advance technology and economic development in its region. The university case is that of the Georgia Institute of Technology (Georgia Tech), a public university in Atlanta, Georgia. Georgia Tech's mission is "to provide the state of Georgia with the scientific and technological knowledge base, innovation, and workforce it needs to shape a prosperous and sustainable future and quality of life for its citizens" (Georgia Tech, 2002). Georgia Tech is not an "Ivy League" university, it does not have a large endowment, and it is in the South—not traditionally one of the leading areas for innovation in the United States. To the extent that Georgia Tech has secured resources and national and international recognition for research, education, and innovation impact, it has been through processes of strategic choice, institutional adaptation and development, and leadership. It is thus of interest to understand the Georgia Tech model, how the university evolved from a knowledge factory to a knowledge hub, how it has accumulated boundary-spanning functions, and what complementary actions facilitated this transformation. These elements are explored in the context of the US South and the emergence of contrasting models in other universities in the broader region. After discussing the regional context, we then focus on the Georgia Tech case and explore the implications for university transformation and their roles in stimulating an innovation-based regional economy.

3. Regional context: contrasting university models in the US South

In undertaking studies of universities and economic development, regional context is very important. Among the most well-known models of US regions where universities have had powerful influences on innovation and local economic development, are Silicon Valley (in Northern California) and Route 128 (Boston metropolitan region in Massachusetts). Silicon Valley and Boston both have multiple, well-established, top-ranked research universities and complementary assets for commercialization in their regions. Other regions – particularly those which are not yet well-established locations for research and commercialization – can and do observe these two prominent models, but they are unlikely to be able to replicate them. Rather, customization – if not the development of new approaches – relevant to particular regional contexts will be needed. Indeed, as observed by Saxenian (1996), there are important differences between the Silicon Valley and Boston in industry organization, networking, and culture, and these are reflected in the ways in which university–industry relationships have materialized in each of these two high-technology regions.

In the last decades, there have been many new efforts to leverage universities for regional economic development, including in the rapidly growing Sunbelt regions in the United States. The emergence of mediating universities in the Sunbelt is of interest because this region does not have a long tradition of alternative organizations to fulfill this mediating function. The southern region contains three prominent examples of innovative regional economic development: the Research Triangle (North Carolina), Austin (Texas), and Atlanta (Georgia). All three of these areas were – in the mid-20th century – catch-up regions relative to the nation as a whole. Each of these examples illustrates diverging approaches to the exploitation of key universities to stimulate knowledge-based development in the local region (see Table 1).

The Research Triangle has the longest history. The initiative was anchored around three universities in the Piedmont region of North Carolina (the University of North Carolina at Chapel Hill, Duke University in Durham, and North Carolina State University in Raleigh) and influenced by post-World War II ideas of new green-field high-technology research parks. No major metropolises were involved; rather multiple medium-sized cities formed the basis of the endeavor which was centered on what was then a predominantly rural area. As a result of a planned state-level effort by the leaders from government, business and the universities, the Research Triangle Park broke ground in 1959. In the 1960s, two R&D branch facilities – IBM and the National Institute of Environmental Health Sciences – located in the research park. From that point, the park grew as various information technology and biopharmaceutical firms set up branch facilities in the park. Smaller technology startups eventually emerged (Link, 1995, 2002).

In Austin, economic transformation was rooted in the successful recruitment of high-tech branch facilities and industry consortia. The Austin approach reflects planned

Table 1
Three models of university-leveraged technology development in the US Sunbelt

Regions	Research Triangle	Austin	Atlanta
Locational anchors	Medium-sized cities of Raleigh, Durham, and Chapel Hill	Austin metropolitan area	Atlanta metropolitan area
University-based leadership	University of North Carolina (Chapel Hill), Duke University, North Carolina State University	University of Texas	Georgia Tech, Georgia Research Alliance
Time frame	1950s and 1960s to present	1980s to present	1980s and 1990s to present
Economic development strategy	R&D branch facilities, spinoffs follow	R&D branch facilities and industry consortia, spinoffs follow	University spinoffs, capabilities build up
Planning	Top-down, state initiated approach using research park model	Bottom-up chamber initiated approach	Bottom-up university initiated approach
Key high-technology employers	IBM, EPA, Cisco, Burroughs Wellcome, GlaxcoSmithKline	Dell, Motorola, IBM, Advanced Micro Devices, Applied Materials	Scientific Atlanta, Lucent, CNN/Turner, BellSouth

bottom-up efforts of the local chamber of commerce in combination with city government and the University of Texas at Austin. Two major industry consortia – Microelectronics and Computer Technology Corporation (MCC) and Sematech – were recruited to Austin. In the same timeframe, Dell was formed and Austin attracted branch facilities of Advanced Micro Devices, and 3M among others. A high-tech incubator was established at University of Texas in 1989 that generated further technology-based entrepreneurial activity (Gibson et al., 2004; Gibson and Rogers, 1994; Henton et al., 1997, Smilor et al., 1988).

We will show that the Atlanta, Georgia, case represents yet a third approach of university transformation in the context of an already growing large metropolis. Although there are a few technology-based branch facilities in the city, the attraction of out-of-area R&D centers was not a major focus of this approach (although attraction of outside facilities has been the mainstay of economic development in the state of Georgia as a whole). Atlanta's is a story of university-initiated efforts and knowledge and human capital capacity building put forth in an effort to try and become a technology-based startup location. The following section describes this approach in detail.

4. Evolution of the role of Georgia Tech as a knowledge hub

At the close of the US Civil War in 1865, the state of Georgia was a poor and war-ravaged agricultural region with an economic base inherited from the pre-war plantation system. By 1929, the state was still poor, relative to the nation, with per capita income only 49% of the US average. Today, the state has emerged as among the fastest growing in the nation and a leader in the continuing expansion of the American Sunbelt region. More than 8.8 million people now live in Georgia (2004 estimates from the US Census Bureau). After a period of convergence over the past two decades, the state's per capita income is now 91% of the national average, although Georgia still ranked 29th relative to other US states as of 2004 (Bureau of Economic Analysis, 2005). Georgia has a growing high tech sector, particularly in knowledge-based services (e.g., telecommunications, software publishing, internet services) rather than manufacturing (AeA, 2005). Still, Georgia is not viewed as a traditional place for innovation. Its public educational (elementary and high school) performance has ranked among the lower two-fifths of states (Corporation for Enterprise Development, 2006). In addition, there is a gap between public/academic and private R&D. Georgia ranked 12th in academic R&D in 2002 relative to other US states, with $1 billion of work being conducted at the state's research universities. However, the state's ranking dropped to 22nd when considering its level of industrial R&D (National Science Foundation, 2003). There are also substantial differences between metropolitan Atlanta – the most developed region for innovative activities – and other parts of the state. For example, per capita income in Atlanta in 2004 is above the national average (104%), whereas the smaller metropolitan cities in the state are a little over 80% of the national average and rural Georgia is just under 70%. Although centers of research and industrial activity exist elsewhere (such as Athens), there is clearly a "research gap" between metropolitan Atlanta – particularly the Northern suburbs where successful technology parks have been created and where most of the high-tech firm reside – and the rest of the state.

The regional context, in sum, is thus one of significant long-term modernization in the state, substantial population in-migration, and several bright spots of technology development, yet also lagging performance in other sectors and areas. In the progress that has been achieved to date in the state, and in strategies designed to address outstanding developmental issues and new technological opportunities in future years, Georgia Tech is a central player.

Georgia Tech was initially founded in 1885 to promote economic development and industrialization in Georgia. Its founders originally envisioned it as a trade school focused on the pragmatic educational and training needs of its new industrial base. Georgia Tech's traditional mission as a technical institute to train specialists for business and industry began to show signs of change during World War II as needs for research and more advanced education emerged. In 1948, the school's name was officially changed to the Georgia Institute of Technology (a reflection of efforts to follow the models of great national engineering universities such as MIT). The institute awarded its first doctoral degree in 1950, encouraged research activity (which rose to roughly $2 million in annual funding in the late 1950s), and set up a

Table 2
Timeline of Georgia Tech's evolution in regional technological development

Year	Event
1885	Georgia School of Technology is established by the Georgia legislature
1888	Georgia School of Technology opens for classes
1919	An Engineering Experiment Station (EES) is authorized at Georgia Tech to assist industry
1931	University System of Georgia, which includes Georgia Tech, is created
1934	EES begins engineering research projects
1938	Industrial Development Council (now the Georgia Tech Research Corporation) formed to conduct contract research
1948	Name is change to the Georgia Institute of Technology
1950	Georgia Tech awards its first Doctor of Philosophy degree
1960	Georgia assembly creates an Industrial Extension Service
1969	College of Management is established; Bioengineering Center established in conjunction with Emory
1972	Joseph M. Pettit, former Dean of Engineering at Stanford, becomes the 8th President of Georgia Tech
1981	The Advanced Technology Development Center (ATDC) is established; the Microelectronics Research Center (MiRC) is established
1984	EES becomes GTRI. Georgia Tech Research Corporation (GTRC) is established
1987	John P. Crecine becomes the 9th President of Georgia Tech. The Georgia Tech/Emory University Biomedical Technology Research Center is established
1988	Crecine proposes a restructuring of Georgia Tech
1990	Ivan Allen College established (with new schools in policy, international affairs, and other areas)
1991	Georgia Tech Lorraine in Metz, France is opened
1993	IES programs and ATDC are reorganized into the Economic Development Institute (EDI)
1994	G. Wayne Clough takes office as Tech's 10th president
1996	Georgia Tech hosts the Olympic Village and competitive venues
1998	Georgia Tech and Emory offer a joint biomedical engineering degree
1999	Georgia Tech campuses in Savannah and Singapore established
2000	Technology Square is announced, Georgia Tech and Emory announce a joint Ph.D. program in Biomedical Engineering
2001	Clough named to the President's Council of Advisors on Science and Technology (PCAST)
2002	Georgia Tech is ranked first in Innovation U. for economic development and university–industry technology transfer
2003	Technology Square opens—anchoring a new midtown research, commercialization, educational and living cluster
2004	Clough co-directs the Council on Competitiveness's National Innovation Initiative and is appointed to the National Science Board
2005	Georgia Tech ranked among the top 20 technological universities in the world[a]
2006	Georgia Tech ranked among top-10 public universities in the United States[b]

Source: Georgia Tech Fact Book, 2004, supplemented by additional sources including: [a]Times Higher Education Supplement, October 7, 2005. [b]US News and World Report, America's Best Colleges, 2006.

private non-profit corporation to support contractual needs associated with research (McMath, 1985; Combes, 2002). (See Table 2 for a timeline of Georgia Tech's evolving role in technological development.)

The role of leadership and boundary-spanning activities in Georgia Tech's development can be seen through the activities of the university's three most recent presidents. Joseph M. Pettit, former dean of engineering at Stanford, took office in 1972 as the eighth president of Georgia Tech. A number of strategic initiatives were instituted during his administration to bring Georgia Tech into the modern technological era, many of which were patterned after programs at Stanford. These included the creation of the Advanced Technology Development Center (a high tech incubator to support spinoffs of scientific and technological research at Georgia Tech), the Georgia Tech Research Institute (GTRI) to focus applied research (comparable with the Stanford Research Institute), and the Microelectronics Research Center (MiRC) at Georgia Tech to support interdisciplinary work in the growing field of microelectronics with the state's first university-based clean room. Extramural research awards increased 11-fold during the Pettit era, much faster than national R&D trends for universities (see Fig. 2).

In 1987, John P. Crecine, previously the senior vice president and provost at Carnegie Mellon, took over as the ninth president of Georgia Tech. His appointment was significant at Georgia Tech in that he was not an engineer—he was trained in industrial management. Crecine shepherded Georgia Tech through a strategic transition to a broad-based technological university through restructuring of colleges (which resulted in a separate College of Computing and a new Ivan Allen College of liberal arts "at the nexus of science, technology, the humanities, and social sciences"; Rosser, 2005), involvement of the university in Atlanta's successful 1996 Olympic bid, promotion of multidisciplinary research institutes, formation of the first international campus, and creation of a new organization that combined the university's economic development outreach and technology incubation programs. Research awards more than doubled to $163 million annually at the close of Crecine's tenure.

G. Wayne Clough, a civil engineer, assumed the presidency of Georgia Tech in 1994. His tenure has seen significant expansion in terms of the campus infrastructure, academic programs, research, and influence in federal and state policy circles. New research and academic buildings have changed the face of Georgia Tech; these include the Technology Square development which transformed a decaying business district across a freeway adjacent to the university into 2 million ft^2 of first-class space for teaching, research, conferences, technology transfer assistance, and government (the state's economic development agencies relocated to this part of the Georgia Tech campus), business, and retail activities. The institute has expanded its academic presence with a new regional campus in coastal Savannah, Georgia, internet-based degree programs, joint degree programs with the medical school at Emory University, and international campus-based programs, including

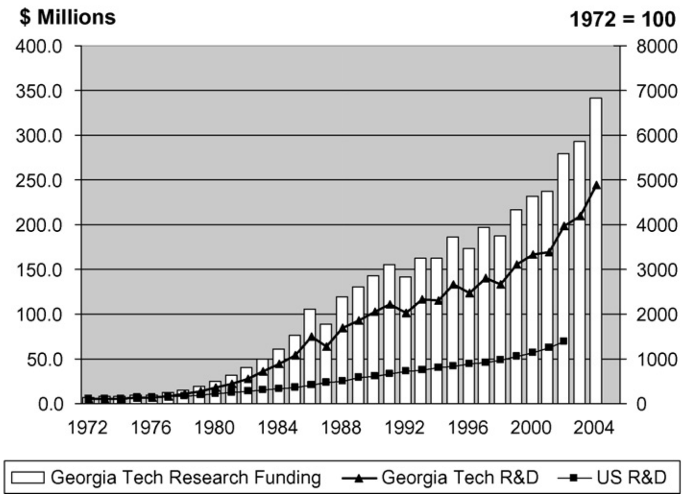

Fig. 2. R&D Expenditures at Universities and Colleges in the US (1972–2002) and Georgia Tech (1972–2004). The scale on the left represents Georgia Tech externally sponsored R&D expenditures, in millions of $; the scale on the right represents US R&D expenditures and Georgia R&D expenditures, normalized to 1972 = 100. *Note*, data is in current dollars, not adjusted for inflation. *Sources*: National Science Foundation/Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2003; Extramural Research Support, Georgia Tech Fact Book, various years; Combes (2002).

in France, Singapore, and China. Research awards grew exponentially to more than $400 million annually. Clough has also carved a new role in federal science and technology policy with his appointment to the President's Council on Science and Technology (PCAST) and the National Science Board, engagement with the National Academy of Engineering, leadership of the National Innovation Initiative of the Council on Competitiveness in 2004, and chairmanship of policy task forces at the state and local levels.

The successes of these three university administrations in developing university capabilities owes much to the leadership of the individual presidents, but also reflects other contributing factors. Bottom-up initiatives, from faculty, research groups and centers and unit leaders, have often been powerful in sparking new programs and directions. Examples include initiatives in interdisciplinary education (for example, in developing programs in the management of technology), numerous research collaborations within and external to the campus, business and economic development services, and international expansions. Particularly important in this regard has been the evolutionary fostering of an experimental culture within the institution, where faculty can seek and obtain support for new ideas, usually from external sponsors, although many times with some internal seed funding. Additionally, there has long been a favorable attitude in the state towards Georgia Tech, including from elected officials, who generally have been willing to provide increasing levels of basic educational and special project funding. Certainly, the institution invariably desires more funding than the state will allocate, particularly for teaching, faculty salaries, and building projects, seeks to protect its "turf" especially in engineering and other technological subjects from claims for resources to offer comparable programs by other universities in the state system, and chafes at the regulations and constraints that typically come with state support. Nonetheless, the state of Georgia has established a remarkably consistent and close relationship with Georgia Tech (and, of course, one of the primary responsibilities of every institute president is to maintain this rapport). However, when coupled with the research support received from federal and other sponsors, this leads to an array of expectations of the institute. Georgia Tech is expected to be world class, performing at frontiers of research and graduate education alongside peer universities such as MIT or Caltech. At the same time, unlike its private peers, the institute is expected to be the local primary provider for home state undergraduate students seeking technological education and to actively serve the technological and innovation needs of state businesses and communities. To address such multiple expectations not simply in discrete ways but by seeking symbiosis between them is, we suggest, one of the facets of transition to a knowledge hub.

5. Examples of university-centered knowledge-hub initiatives

In this section, we discuss a series of programs and initiatives that illustrate, using the Georgia Tech case, how a knowledge-hub institution can combine together activities with multiple goals in a variety of boundary-spanning organizational forms to foster advanced research, education, and innovation. Significantly, all of these initiatives coalesce both formal and tacit knowledge generation and exchange processes, with key mediation and brokerage roles played by organizations within or associated with the university. We highlight six boundary-spanning initiatives. Two of these – the Georgia Research Alliance and the Yamacraw Initiative – represent statewide efforts to create and expand knowledge pools, with Georgia Tech

Table 3
Knowledge orientation and boundary mediation target of state university-centered innovation programs

University-centered innovation programs in Georgia (selected)	Knowledge orientation	Boundary mediation target
Georgia Research Alliance	Eminent scholars conduct research which is codified through academic outputs such as publications. They also are tasked with technology transfer duties that use entrepreneurial tacit knowledge	Research universities and private sector and government
Yamacraw Initiative	Initiative-supported research in broadband chip design is codified through publication of papers and intellectual property contracts with member contracts. Tacit interactions occur between the university and large and small company members	Research universities and private industry startups and established firms in a targeted sector
ATDC	Practices and service offerings are explicit. ATDC also has a tacit role in connecting entrepreneurs and venture organizations	Academic researchers, entrepreneurs, venture capital community
VentureLab	Tacit relational knowledge uncovers commercializable research in the university, which can become codified through intellectual property processes	Academic researchers and venture capitalists
Traditional Industries Program	Closes innovation gaps through codifying research in targeted areas, which is transferred in tacit ways to industry sponsors	Academic researchers and established industry in targeted sectors
Centers of Innovation	Closes innovation gaps through tacit relational knowledge linking remote assets in a less developed region and the university	Mid-sized cities (policy makers, entrepreneurs, existing industries) and research universities
Industrial Extension Service	The manufacturing specialist serves as a knowledge enabler, transferring know-how which is new to the company (though not to the specialist or the world). Upon joining the national MEP system, this practice has become increasingly codified	University expertise and SMEs

playing substantial roles. The other four are designed to foster commercialization of state-of-the-art and off-the-shelf knowledge into the regional economy. The knowledge orientation and boundary mediation targets are summarized in Table 3.

5.1. New scientific entrepreneurs: the Georgia Research Alliance

The Georgia Research Alliance (GRA) was formed in 1990 as a collaborative research initiative among six major research universities in the state of Georgia, including Georgia Tech (Lambright, 2000). There is collaboration in establishing high-level research and technological strategies, in encouraging technology transfer, and in funding plans. GRA has several key programmatic elements. Most well-known is the Eminent Scholars program, which recruits leading researchers in targeted areas based in part on a GRA supplementary endowment to be used for facilities, equipment, and other non-salary expenses. GRA also has made selected investments in key aspects of Georgia's technology transfer infrastructure. GRA has supported investments to expand the Georgia Tech Advanced Technology Development Center (ATDC) incubator program throughout the state to convert GRA's research investments at member universities into commercial applications. It has sponsored expansion of VentureLab, also established at Georgia Tech, to provide early assistance to faculty research with startup potential. And it supported the creation of two seed funds managed by ATDC. Since its inception, the state of Georgia has invested some $400 million in GRA. The program reports that these moneys have leveraged $2 billion in new federal and private-sector sponsored research, added 120 leading researchers, and assisted in the formation of 100 high-technology spin-out companies (see case study of GRA in OECD, 2007a, pp. 323–328).

GRA programs mediate research universities, private-sector spinoffs, and industrial recruitment activities of the state government. The GRA's approach recognizes the importance not only of knowledge upgrading (i.e. creating new knowledge pools in strategic emerging areas) but also of the varieties of knowledge necessary for successful research commercialization. Highly regarded scholars with dual missions of research and technology transfer are embedded in local institutions that hitherto did not have deeply rooted traditions of attracting such researchers. These academics integrate their work into the university through typical academic practices, being expected to produce codified knowledge in the form of publications, conference papers, and other academic outputs. However, the GRA scholars also have a technology transfer mission that is less well routinized. This involves translating research into commercial value, working with partner companies, and interacting with venture specialists, licensing professionals, and the broader business community. Such activities on the entrepreneurial side of the GRA Eminent Scholar program frequently require a high level of tacit knowledge exchange.

5.2. Targeted technology clusters: the Yamacraw Initiative

Yamacraw was a state initiative launched as a 5-year project in 1999 to make Georgia a world leader in the design and commercialization of high-capacity broadband communications systems, devices, and system-on-a-chip technologies. Again, Georgia Tech emerged as a central player in the program. The basic elements of the initiative included: (1) corporate membership in the Yamacraw design center; (2) an industry-relevant research program; (3) development of a large and growing pool of graduates in relevant degree programs, based on the recruitment of new university system faculty and state-of-the-art curriculum development; (4) an early-stage seed fund for investing in chip design startups; (5) a marketing program to build Georgia's high-tech image in the area; and (6) a new building to house the program. When a new governor was elected, the initiative was reconfigured as the Georgia Electronic Design Center and moved under the auspices of the GRA. Forty corporate and federal agency members and research partners work with the center and it conducts about $10 million in research a year. The educational curriculum component, which resulted in more than 400 students receiving specialized training in the area a year, has been absorbed by the universities that were part of the original Yamacraw Initiative. An assessment of the program in 2002 found that Georgia Tech was the prominent producer of research in this field. Concern about the dominance of university research and lack of significant corporate research was raised as a potential limitation of employment growth in the area (Shapira et al., 2003). However, two companies – Pirelli and Samsung – set up embedded laboratories in the facility in 2005.

By networking researchers, established firms, and startups, the Yamacraw Initiative focused attention to collaborative research and commercialization opportunities in broadband and mixed signal (analog and digital) communications that might previously have been overlooked if they were in separate centers and departments. The use of intellectual property contracts with established partner companies represents a codification of the new knowledge created by the project. However, an underlying goal of the initiative has also been to foster innovative economic development through the creation of firms in these fields that engage in tacit knowledge exchanges with the university. In essence, Yamacraw sought to create a learning region of firms in the targeted communications sector in the metropolitan Atlanta area. There are some early signs of progress, through startups, the attraction of established firms, and the formation of university–industry alliances, although it is acknowledged that this is a long-term transformational goal that will take more time to come to fruition.

5.3. Building technology-based entrepreneurship: the Advanced Technology Development Center

Established at Georgia Tech in 1980, ATDC was one of the nation's first technology incubators. It offers entrepreneurial services including space, guidance, and support for early-stage new technology companies. Entrepreneurs come from the universities and also from the business community in Atlanta and other Georgia cities. ATDC also supports corporate R&D units through a "landing party" offering. ATDC is a unit of Georgia Tech/Enterprise Innovation Institute. It has 12 associates and receives about $2 million a year in state funding. There are three locations in Atlanta – including the headquarters offices in Technology Square – and centers in Savannah and Warner Robins. Capital activity in member and graduate technology companies associated with ATDC totaled more than $160 million for 2004. More than 140 entrepreneurs participate in or graduated from the incubator program since 1986. Surveys of companies affiliated with the ATDC indicated that they generated more than $1.75 billion in revenues and more than 4900 high-tech jobs. ATDC management have reported that about four of every five ATDC graduates has been acquired by an out-of-area firm (and, in some cases, moved out of Georgia). Nonetheless, ATDC has added to the stock of high-technology establishments in the state and to the pool of experienced high-technology entrepreneurs (who, after selling their companies, may then startup new ventures).

At first glance ATDC appears to have an explicit knowledge orientation. It has a formal application and admittance process and offers a specified set of services such as business planning, management and human resource selection, and access to Georgia Tech facilities and researchers. However, its real value is in its role as a mediator of tacit relational knowledge of local entrepreneurial leaders and organizations and academic entrepreneurs. ATDC's networking activities (including "brown bag lunches" and CEO roundtables) and its many informal interactions have helped to foster an entrepreneurial community. Several venture organizations and leaders have co-located in the ATDC facilities to create an entrepreneurial community of practice.

5.4. Faculty research commercialization: VentureLab

VentureLab was created in 2001 out of ATDC's efforts to improve the success rates of finding and commercializing spinoffs from Georgia Tech faculty research. VentureLab specialists provide pre-incubator services to assist faculty members through the commercialization process, including developing intellectual property disclosures and making linkages with experienced private-sector technology entrepreneurs and venture capital resources. From 2001 to 2004, Georgia Tech reports that VentureLab worked with 100 ideas from 80 faculty members and generated eight new companies that were backed with $9 million in funding.

VentureLab uses tacit knowledge about research conducted within Georgia Tech to link researchers with commercializable opportunities. Some of these interactions will become codified through intellectual property documentation. However, the relational knowledge of VentureLab specialists is at the core of the program as it illustrates a bridging role between university researchers and the venture community through locating and exploiting knowledge that has traditionally been hard to uncover within the university. It also imparts advice and learning to the faculty member about what types of research activities are commercializable.

5.5. Innovation in traditional industries and Georgia Centers of Innovation

In 1994, the state created the Traditional Industries Program to complement the GRA's focus on high-tech industries. The Traditional Industries Program serves a mediating role between industry and university researchers, linking them to work on critical competitiveness problems of the pulp and paper, food processing, and textiles and carpet industries. In 2003, the Centers of Innovation program was created with a new focus to mediate the needs of mid-sized metropolitan areas and research universities (Shapira and Youtie, in press). The evolution of a focus on mid-sized metropolitan areas with 50,000–500,000 in population represents a novel recognition that these cities have some of the assets, however incomplete, to engage in innovation-based economic development. Innovation centers offer development and technology transfer capabilities technology transfer/commercialization, technology incubation (through Georgia Tech's ATDC network), joint industry–university research (involving local colleges as well as established research universities in Georgia), and corporate memberships as appropriate. The program started with five centers, the earliest being the Maritime Logistics Innovation Center. The program receives about \$1.5 million a year from the state fund designed to help areas negatively impacted as a result of the 1998 Master Settlement Agreement compensating states for Medicaid costs attributed to smoking. These two programs are administered through Georgia Tech's Enterprise Innovation Institute in partnership with other state organizations.

The Traditional Industries Program uses grant contracts to make more explicit research that typically has been conducted for other purposes (thus "hidden" from industry) in targeted areas of benefit to the food processing, pulp and paper, textiles, and other mature industries. The transfer of research results to industry sponsors embodies tacit aspects, but this facet has been relatively less important in the past (Roessner et al., 2001). In contrast, the Centers of Innovation program also deals with innovation gaps but in more tacit relational ways by linking complementary assets in a region with university researchers at Georgia Tech and other universities in the state.

5.6. Know-how transfer: the Georgia Tech Industrial Extension Service

In 1960, Georgia joined North Carolina as one of the first US states to have a state-funded Industrial Extension Service. The program, situated in Georgia Tech's Enterprise Innovation Institute, currently operates a network of full-time experienced manufacturing specialists across the state and has partnerships with regional economic development groups, state labor offices, private-sector consultants, trade associations, and other contacts. The statewide program provides a gateway to the Industrial Extension Service's "skill centers" in ISO 9000/quality, lean manufacturing, industrial marketing and product development and design, environmental and energy technology, and to sponsored programs such as the Trade Adjustment Assistance Center (US Department of Commerce), the Minority Business Development Center (US Department of Commerce), and the Procurement Assistance Center (US Defense Logistics Agency). In addition, the Industrial Extension Service engages researchers and faculty at Georgia Tech and regional government laboratories to address problems at local manufacturers. In 1994, Georgia joined the national Manufacturing Extension Partnership (MEP), administered by the National Institute of Standards and Technology (NIST) of the US Department of Commerce. Although the program has been subject to state and federal budget cuts in the 2000s, Georgia operates a \$7.5 million manufacturing extension program (about \$3 million of which comes from the state). From 2003 to 2005, the Georgia program served more than 500 manufacturers a year, which is at the median of all US MEP centers.

Whereas the Traditional Industries and Centers of Innovation programs emphasize R&D collaboration and transfer, the Industrial Extension Service focuses on a broader set of knowledge sharing and innovation activities. At the heart of the Industrial Extension Service is the manufacturing specialist who serves as a knowledge enabler, mediating the needs of manufacturers and knowledge sources within university and off-the-shelf industry practices. The specialist examines company problems through discussion and assessment with plant managers and employees and though in-site facility visits. The specialist has know-how which is new to the company (albeit not usually new to the world or new to the specialist) and draws on this know-how to suggest solutions. The Georgia Tech Industrial Extension Service operated in informal ways for many years. Upon joining the MEP system, however, the service transformed part of its tacit knowledge into codified systems, particularly in process improvement areas such as quality certification, because the MEP has encouraged delivery of a relatively consistent set of services across the nation.

5.7. Other supporting state policies

The initiatives described above have been complemented and supported by additional state policies. At the educational level, the University System of Georgia (USG) was set up in the early 1930s to link formerly separate state-sponsored institutions into a single governing organization and state lobbying entity. The USG includes 34 junior and senior colleges and universities, each with a somewhat distinctive mission. In 1993, the state of Georgia created the HOPE scholarship program with funds from the new Georgia Lottery to underwrite tuition, fees, and other expenses at postsecondary educational institutions in the state for students in good academic standing. The number of students receiving HOPE scholarships increased from 13,000 in 1994 to more than 18,000 at the end of the decade (Bugler and Henry, 1998). In 1995, the USG formed the Intellectual Capital Partnership Program (ICAPP) to provide expedited educational programs for companies with university-level workforce needs.

The Georgia Department of Economic Development (DEcD) coordinates the state's economic development programs oriented toward recruitment of out-of-state business and industry. In the late 1990s, DEcD set up an Office of Science and Technology to build a specialized team with the background and skills to recruit and support technology and life science companies.

No single body manages or coordinates these technology development activities. Partnerships and multiple interlocking relationships enable these organizations to work with other state and local organizations (as there is considerable private-sector technology-based association activity in the Atlanta area). In addition, the above organizations – ICAPP and DEcD – as well as private-sector technology associations such as the umbrella Technology Association of Georgia have offices on the Georgia Tech campus; thus there is a physical boundary spanning through co-location as well as an organizational and programmatic one. GRA board members and Georgia Tech administrators serve on the boards of directors of state and local economic development organizations. GRA executives previously managed Georgia Tech's economic development and technology transfer programs. The state's multi-actor environment makes it difficult to engage in top-down centralized planning in the science and technology area in Georgia; the networking of diverse initiatives with loose coordination is a more common mode, with universities playing a hub role. At the same time, the decentralization of these programs has allowed them to survive multiple changes of gubernatorial administrations (Youtie et al., 2000).

6. Assessment and evaluation

There are numerous other interesting and significant research, educational and innovation-promotion activities that could be added to the list of initiatives underway at Georgia Tech. However, given space constraints, the initiatives that we have described represent a sample from which to draw assessment and evaluation insights.

Georgia Tech's innovation programs operate with a high level of tacit knowledge activity and involve linkages with multiple organizations. Formal knowledge aspects are also important. The GRA Eminent Scholars program emphasizes embodied knowledge through recruitment of foremost scholars and the expectation of high research performance in all the conventional ways (including through publications and awards); yet, critically, there is a vital tacit side. Eminent Scholars are also expected to provide leadership, serve as a catalyst to leverage university–industry relationships, and stimulate technological entrepreneurship. The Yamacraw Initiative seeks to advance leading-edge communications-related research, yet also make this relevant through a series of formal and tacit activities with the goal of creating a learning region of small and large firms in the sector. The Industrial Extension Service operates within a formal university-led organizational structure with statewide offices, is part of a national network, and deploys codified technology assistance tools and services. Yet, primarily, the service is based on the practical know-how of the manufacturing specialist and on the social capital that the specialist builds up over time with companies and local organizations. ATDC offers explicit services but most important is the tacit relational knowledge links it has with the venture community. VentureLab also uses tacit knowledge relationships to commercialize university research. The Traditional Industries Program and Centers of Innovation seek to close innovation gaps through combinations of tacit and explicit knowledge relationships.

Significantly, in a knowledge-hub environment, all of these initiatives involve multiple organizations, with the university serving as a platform that provides institutional stability, credibility, access to varieties of knowledge, an environment for interdisciplinary collaboration, and the ability to secure financial and human capital resources. The conventional vertical organization of the university – academic departments, administrative groups, and service units – is still present; but in the knowledge-hub, this is now crisscrossed by an internal and external matrix of lateral organizations and networks, providing numerous connections points and opportunities for decentralized nodes of activities. Staffing is also more varied. Again, the traditional academic organization of assistant, associate and full professors remains at the core of the institute's personnel structure, with the faculty charged with the undertaking of research, education and teaching, and service. But intermingled with this is a large cohort of full-time applied research staff (with a research faculty personnel structure), as well as flexible sets of incubator and technology-transfer professionals, industrially experienced field staff, educators and trainers, economic developers, and program managers. New faculty categories are also expanding, such as professors of practice (bringing in expertise from industry) in addition to the dual-role Eminent Scholars. On the student side, most graduate students have opportunities for hands-on research; undergraduate research and internship programs are expanding; and there are well-established programs of cooperative education (where undergraduates undergo a period of practical training). Traditional academic research and classroom teaching is not diminished (indeed, there are many efforts which seek to upgrade the quality of both). However, these developments signify how a knowledge-hub university embodies a wide range of human skills and capabilities, occupational classifications, and learning modes to populate and motivate the multiple missions.

What is the evidence that the kinds of initiatives undertaken by Georgia Tech are effective? Indeed, by what methods can these initiatives be assessed? Most of the available reviews emphasize the explicit elements of these programs. For example, the GRA and Yamacraw Initiative annual reports show the total number of dollars of research grant awards. Recently, GRA has engaged in a tracking of publications, patents, and prize winners. These measures are valued by university managers, but they do not represent the tacit aspects of the program, their entrepreneurship capabilities, and their potential for knowledge transfer with industry. Such program processes and outcomes are harder to quantify and are less frequently the subject of formal evaluations. Nonetheless, there is an important informal side to the evaluation of these innovation programs. Stakeholders associated with Georgia's innovation programs do engage in discursive learning over time involving state and university leaders, policy makers, and program managers. Initiatives that do not work well get deemphasized and resources are redistributed. Additionally, each program has its own executive and advisory structures and linkages which provide for accountability and regularized interactions with multiple external groups (Guston, 2001).

Two examples are illustrative. The Industrial Extension Service at Georgia Tech participates in an extensive national evaluation of its activities through the MEP program and also invests in a local evaluation. Most of the measurements emphasize the explicit elements of the program. The MEP's national survey of customers indicates that Georgia manufacturers had sales increases of $122 million, cost savings of $23.4 million, and jobs added or retained of more than 2500 from the second quarter of 2003 to the first quarter of 2005 as a result of the Industrial Extension Service. A survey of Georgia manufacturers conducted every 2–3 years recently found that Georgia Tech's clients had $10,000 in higher value-added per employee compared to nonclients and controlling for size, industry, location, and other attributes. At the same time, the survey found that the Georgia manufacturing base continues to face an innovation challenge. Fewer than 10% of Georgia manufacturers compete for customers through innovation or new technology compared with more than twice that amount competing through offering low prices. Yet innovative companies are much more profitable and pay on average $10,000 more in average wages (Youtie and Shapira, 2005). The Industrial Extension Service has taken some time to absorb these findings, although reallocations of resources to product innovation offerings and hiring of specialists with this type of know-how have occurred in recent years.

There have been several evaluations and audits of the ATDC program. Most have found the program to be effective and to have had an impact on the high-tech economy of the region and the state. A survey of 79 ATDC members and graduates from 1998 to 2003 and analysis of patent citations found that amount of funding obtained and backward linkages to university research are evidenced in successful graduating companies (Rothaermel and Thursby, 2005). Another survey comparing ATDC graduates to startup companies that applied but were not accepted to the incubator found that ATDC membership resulted in a positive impact on startup firms, although the biggest benefit was enhanced credibility and image rather than the use of particular incubator services. It was also pointed out that ATDC's being in a city with a growing high tech cluster makes it difficult to isolate program impacts, although ATDC was clearly found to have influenced the entrepreneurial infrastructure, networking linkages with finance and management, and the overall image of the city and state as a high tech locale (Culp and Shapira, 1997).

How has the emergence of Georgia Tech as a knowledge-hub university made an impact on its region and the state? Over the long-run, the state of Georgia's economic position has improved substantially in aggregate terms; as we have noted, the per capita income gap between Georgia and the nation narrowed very significantly during the twentieth century. Major problems of educational, income, and regional equity are still outstanding. Nonetheless, Georgia developed a modern industrial base, and has established a foundation for knowledge-intensive high-technology and services growth moving forward in the current century. Many federal and state policies contributed to this (Shapira, 2005). The development of Georgia Tech can be viewed as one of these state policies, and one that has attracted increasingly significant federal research investments. Georgia Tech has added significantly as a supplier of technological human capital in Georgia. In earlier periods, many of the institute's graduates had to look outside of the state for appropriate positions. Today, there are more opportunities for graduates, particularly in technological fields, within the state—mostly in the Atlanta metropolitan region. Moreover, Georgia – again led by Atlanta – has attracted more young qualified graduates than almost any other US region in the last decade (Cortright and Coletta, 2006). Georgia Tech's knowledge-hub activities have helped to create a regional climate which is attractive to companies, entrepreneurs, and talented people. In a study evaluating 164 universities in terms of their economic development influences on the local region, Georgia Tech has been independently identified as one of the leading "Innovation U's" (innovation universities) in the United States (Tornatzky et al., 2002). Aspects examined in this study included career services, entrepreneurial development, faculty culture and rewards, partnerships with economic development organizations, industrial extension and technical assistance, industry education and training, industry research partnerships, industry/university advisory boards and councils, leadership and policies, and technology transfer. The study notes that "The Georgia Tech culture, from president to academic units, is pervasively oriented toward outreach and engagement with the external world." According to Tornatsky et al., this has led to long-term results in support of regional innovation, industry research, economic development, high-tech startups, existing industry support, specialized training, and systems for entrepreneurial development.

7. Regional comparisons of university trajectories in the US South

We have proposed a broad path, through which universities may shift from a conventional focus on knowledge inputs and outputs to a new orientation as a knowledge-driven innovation hub. But we have also suggested that the specific ways in which any particular university pursues this transition will vary and will be significantly influenced by institutional and regional context. The Georgia Tech case exemplifies this, with a particular developmental strategy rooted in the framework of the US South and its relationship to a fast growing post-industrial metropolis. We saw that Georgia Tech began a strategic transition from a knowledge factory era “technical institute” to a knowledge-hub oriented “technological university” in the 1970s that is still underway.

In the Georgia Tech case, research and knowledge creation spread from a single research club to academic units, GTRI, a network of over 60 interdisciplinary centers that cut across traditional academic disciplines, and more than $400 million in extramural research. Educational and human capital formation moved from the technician-oriented curriculum to interdisciplinary programs in pioneering fields such as bioengineering, new instructional approaches, and campuses throughout Georgia and abroad. Know-how transfer of off-the-shelf technologies was realized in Georgia Tech’s offering one of the first industrial engineering services in the nation, joining of the national MEP network, showing client productivity in evaluations, but still working in an environment of a manufacturing base employing traditional low cost and branch plant oriented strategies to compete in the marketplace. The ATDC high tech incubator expanded from one of the first high tech incubators in the nation to support university-based spin-outs of commercializable research to a hub for creation of entrepreneurial infrastructure in seed capital funds and venture networks. New information technology and research infrastructure was developed and knowledge-flows encouraged through increased internationalization of global campuses and new engagement with private-sector firms in research centers and partnership programs. New infrastructure and milieus are evidenced in Technology Square that created a favorable regional setting in decaying midtown Atlanta by combining academic, research, and economic development programs with hotel, retail, and other private-sector activities. New leadership in the Pettit, Crecine, and Clough eras inspired these non-incremental transformations and moved Georgia Tech into the science and technology policy front to address national and regional problems.

It is useful to compare the Georgia Tech case with other notable efforts in the US Sunbelt to create knowledge-based development through leveraging universities. When contrasted with North Carolina’s Research Triangle and Austin, Texas, four major points emerge. First, the Georgia Tech case does not represent a top-down planned state-level initiative as was the case with Research Triangle Park. Nor does it reflect significant bottom-up urban-centered effort between the chamber, other local officials, and the university, as was the case with Austin in the 1980s. The Georgia Tech case embodies a multi-faceted networked statewide approach involving the institute, state-level programs such as the GRA, and local area venture organizations. State government, local government, and the chamber of commerce participate, to be sure, but through interlocking board memberships, task forces, program offerings, and other mechanisms rather than through a formal plan or department.

Second, the Research Triangle and Austin cases had initial strategies to attract external R&D facilities. And they were largely successful. Traditional economic development organizations in the state of Georgia also focus on recruitment, albeit mostly of routine manufacturing and services offices. In contrast, the Georgia Tech case, with a few exceptions, is a developmental case that largely underplays (although still supports) out-of-area R&D facility attraction. Georgia Tech represents an example of local capacity building of knowledge pools through the attraction of human capital. The GRA’s Eminent Scholar program and the leveraging of Atlanta as a growing-metropolitan area with substantial in-migration (including scientists, engineers, and information technologists) helped to extend the knowledge attracted to Georgia Tech in burgeoning disciplines by bringing in new capability.

Third, the Georgia Tech model places university-based startups at the core of its strategy rather than firm relocation. Not only did Georgia Tech generate more activity through university spinoffs into the ATDC, but it also created complementary assets in venture capital (through the starting and management of seed capital funds) and technology-based entrepreneurship networking. One of the downsides of this startup strategy is that many of ATDC’s graduates have been acquired by out-of-area facilities. Venture capitalists often desire that firms in which they invest be located nearby (Powell et al., 2002). Of course, this phenomenon is not limited to startup firms. Branch facilities, even ones that conduct R&D, can also be subject to closure, as the southern region has witnessed in recent years.

Fourth, Georgia Tech has leveraged its position as the dominant public technological university in the state. Emory University, a nearby private university with a major medical research function, has slightly more research funding depending on the year (although not more patents), and is increasingly teamed with Georgia Tech in biomedical and bioengineering research. The University of Georgia – the comprehensive state land-grant university – has also significantly increased its research position. But, this said, state policy makers and business and community-leaders in the state typically look to Georgia Tech for technology commercialization and innovation-based regional development. This stands in contrast to Research Triangle, which is a partnership of three universities. It also differs from Austin which, although dominated by University of Texas, has considerable private-sector R&D from industry consortia and company-specific R&D facilities. Research Triangle and Austin have universities that take on roles similar to those adopted at Georgia Tech, although they are situated in environments in which other organizations, government, or the private sector take on knowledge development roles not explicitly present in Georgia.

8. Concluding points

This paper has suggested an evolution in the roles of universities from knowledge storehouse (mode 1) to knowledge factory (mode 2) to knowledge hub (mode 3). (See Carayannis and Campbell, 2006; Harrison and Leitch, 2005; Hagen, 2002 regarding related uses of the mode 3 concept.) Of course, this is a highly abstracted simplification. Arguably there are variations and exceptions by country and institution. And we note that the university tends to accumulate roles, i.e. earlier roles do not necessarily disappear as new roles are added. While the details of our case derive from a US institution (which began life in mode 2, then more recently transitioned to mode 3), we do observe a general tendency across many advanced countries for universities to seek (or be pushed) towards greater linkages and relevance for innovation, particularly in regional contexts (OECD, 2007b). Some universities attempt to address these imperatives by “bolting-on” new activities, but without fundamental restructuring and reorientation. Others have more fully embraced innovation missions, and in the process, are pioneering a variety of new organizational and knowledge modes that we collectively term as knowledge hubs. In contrast to earlier modes, these knowledge-hub institutions not only accumulate and produce knowledge, but they also actively foster knowledge exchange, learning and innovation through new methods and the development of boundary-spanning activities.

We have explored this notion through a case study of the evolution of Georgia Tech as a knowledge hub. This focus on networked programmatic elements, capacity building, knowledge pool creation, and technology-based entrepreneurship has fostered the important transformation of Georgia Tech from a knowledge factory to an “animateur” of development. Georgia Tech has taken on a series of boundary-spanning roles that impart tacit as well as codified knowledge to other stakeholders. These are represented in the new policy leadership roles of Georgia Tech presidents, the Georgia Research Alliance’s support for eminent scholars to transfer knowledge to the private sector, the Yamacraw Initiative’s efforts directed toward telecommunications and mixed signal chip design, industrial extension’s transferal of know-how to SMEs, linkages developed by ATDC and VentureLab among entrepreneurs, academics, and venture capital finance, the Traditional Industry Program’s linking of researchers and mature firms, and the Centers of Innovation’s connections with mid-sized Georgia cities.

We saw that these knowledge transfer programs administered at Georgia Tech include both tacit and explicit elements. This dual nature can serve as a challenge to evaluation efforts. Moreover, the knowledge duality is compounded because these programs span diverse communities and thus may have different evaluation benchmarks. That said, most of the evaluations focus on the codified aspects of these programs, while most stakeholders tacitly believe these programs work (rather than being convinced by codified evaluations *per se*). Moreover, programs themselves discursively make changes based on learning over time rather than relying solely on codified knowledge in evaluations.

We note that university R&D, startups, and other knowledge-transfer programs are important, but by themselves may not be enough to turn around an innovation system. The importance of complementary assets (Teece, 1986) such as the need for venture capital and a good educational system suggest that there are limits to a university-based strategy. Georgia industry still ranks low in terms of private R&D activity, SBIR awards, and patenting. In areas targeted by the state for development, such as in the Yamacraw Initiative, Georgia Tech was by far the dominant knowledge producer. To address this issue of the dominant knowledge producer, the state could potentially look at strengthening other universities’ research roles or attracting new independent R&D facilities, both activities of which are evident in Research Triangle and Austin. But it can be a challenge to introduce additional research nodes where a dominant institution exists with respect to being able to build alternatives of sufficient scale and quality and with sufficient political support to make a difference. As a state, Georgia also needs to address fundamental problems and weaknesses outside of the research university sector, particularly those of K-12 public education, vocational training, incentives and capabilities for innovation in traditional and mature industries, lagging private R&D, and the quality of economic development strategies in smaller cities and towns. Many states and regions, in the US and elsewhere, face similar challenges. While there are no clear-cut technical or financial solutions to these and other critical economic, societal, and environmental problems, a common theme is the need to develop new capabilities, including the capability to pursue informed joint actions involving multiple stakeholders targeted towards implementing innovative regional and local approaches. A university knowledge hub has the design attributes to contribute in meaningful ways to the development of these capabilities. That does not mean that universities, even when acting as knowledge hubs, are enough to affect a broadly based transformation in a local economy. However, as the Georgia case shows, universities are more likely to be able to address the problems and opportunities of their regions if they pursue active institutional engagement to generate and share human capital, knowledge, leadership and other resources.

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