How States Augment the Capabilities of Technology-Pioneering Firms

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Abstract

State governments offer a variety of programs to assist technology intensive entrepreneurial firms yet we have a limited understanding of how firms use these programs. The paper provides a framework for categorizing state technology programs and uses detailed case studies to examine how these programs augment firms' capabilities. We conclude that firms made extensive use of state programs that provide access to university intellectual property and research facilities. In addition, firms participated in programs that provided incentives for faculty to conduct joint research with industry. Finally, state venture capital programs, though small relative to federal R&D grants or venture capital, appear to nurture firm's development.

Keywords: economic development, state governments, entrepreneurship, start-up companies, public-private R&D partnerships, university R&D

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Introduction

A fundamental question about economic institutions is how best to organize scientific and technological resources for commercial innovation and economic growth. While innovation is a complex process predicated on the actions of private firms, governments and public research institutions provide the scientific and technical infrastructure and other resources critical to firms' success in their early-stage innovation efforts. Relative to other nation advanced economies, the U.S. system of innovation has become heavily dependent on new firms to develop new products and services from recent scientific and technical advances (Audretsch 1995; Klepper and Simons 2000).

Despite their potential, these new, small firms face formidable technical challenges complicated by a lack of internal scientific and financial resources (Kelley 1993). When located in a resource-rich institutional environment, innovative small firms have a greater chance of finding and utilizing the technical capabilities needed to augment their internal capabilities for innovation (Feldman 1994; Powell, Koput and Smith-Doerr 1996; Zucker and Darby 1998). Moreover, since the conditions for nurturing small, technology-intensive firms are location-specific, state governments may play an important role in support of local entrepreneurs (Malecki 1997).

Another characteristic of the U.S. system of innovation is federalism, which distributes authority and fiscal resources between the national government and fifty individual state governments (Osborne 1988). State governments have developed a range of programs to support the innovative activities of small firms. In addition to research support and access to university facilities and scientists, states provide a myriad of specialized programs ranging from business planning services to marketing and personnel training assistance (Schachtel and Feldman 2001). Together, states spent more than $400 million on these programs in 1995 (SSTI 1998).

State programs target small-size firms. Yet only certain types of small firms are likely to be innovation leaders. Moreover, evaluations of state technology and economic development programs typically focus on a specific program in isolation, not as a part of a larger system. Thus, we have a limited understanding of how this type of small, technology-intensive firm use state resources and subsequently how state programs affect the development of the firms and their technologies.

This paper provides a framework for examining the role state programs play in the development of what we define as *technology pioneering firms.* To differentiate this type of firm from the universe of small firms that might use state programs we identify a technology pioneer as a new company that is formed for the explicit purpose of commercializing new technologies. The technology pioneer focuses its innovative effort on the exploitation of recent advances in science and technology. If successful, these firms have the potential to transform existing industries or to create entirely new industries.

Our data are limited to in-depth case studies of four technology-pioneering companies. At the time of our investigation, all four had already achieved national recognition for their technologies. All four are award winners in the highly selective national competitions of the Advanced Technology Program (ATP) of the National Institute for Standards and Technology (NIST)[1]. Moreover, as described in the following section, because of their original location in certain states, the selected cases illustrate the range of services that states may provide. We then identify common elements in program structures among the states and differences between them. Finally, we offer our observations and conclusions concerning the role of state resources in the development of technology pioneering firms.

Methodology and Data

Rather than focus on a specific state program or type of program, we shift the unit of analysis to the firm. The ideal evaluation of the effects of government programs on the development of technology pioneering firms would require data on both program participation and firm performance over time (see Bartik 1991). Unfortunately, such data do not exist. A first step is to conduct in-depth case studies of a small number of companies to discern the programs that are important to firms and the role that the program played in the development of the technology and the development of the business.

The analysis uses the pool of ATP award winners as a point of departure for two reasons. First, the program is a highly selective national program with peer review on both the technical merit of the project and potential of the entity to successfully develop the product. Only twelve percent of the projects are funded in any given year and winning an ATP award signifies a threshold of technological sophistication. Second, the ATP maintains detailed records on firms that have been awarded and continues to collect information for six years after the funded project has been completed, thus providing a unique resource to study the innovation process. Few other federal programs have similar archival information on firms; or, if they do, the data is not available for scholarly use.

Most states have programs to support new enterprise technology development. Schachtel and Feldman (2001) provide taxonomy of state technology programs and find that ten states – California, Connecticut, Georgia, Illinois, Maryland, Massachusetts, New Jersey, New York, and Pennsylvania – offer the broadest spectrum of programs. With such a complete array of technical and business assistance programs, theoretically, these states are providing needed resources to new firms at each of the early stages of its technical and business development. This includes support for efforts to develop a new technology from its initial conceptualization through to the manufacturing stage. The selection of our four test cases was limited to firms that were located in one of these states in order to place the firm in an environment where all possible choices of program activity type were available. This allows us to consider the use of state resources as indicative of the preferences and needs of the archetypal technology pioneer.

To carry out the research, we required the cooperation of each company and each state agency that provided assistance. Our selection of cases was assisted by the recommendations of state technology program officers who cooperated with us in this study. Primary sources of information and data include interviews with company principals, ATP program managers, and officials from the economic development agencies in the state. Our test cases are: AviGenics (Georgia), CuraGen (Connecticut), SAGE (New Jersey) and HT Medical (Maryland).

Company Profiles

The youngest company studied was ***AviGenics, Inc***., founded in 1996 by the team of Dr. Robert Ivarie, Professor of Genetics at the University of Georgia, and Mr. George Murphy, a serial entrepreneur[2] in heath care and biotechnology. The company has 21 employees located in facilities on the campus of the University of Georgia.

AviGenics specializes in developing a technique, avian transgenesis, which may be used to produce eggs enriched with pharmaceutically valuable proteins. These proteins can then be used as raw materials for further processing by biopharmaceutical companies. One such application is to alter eggs so they contain large quantities of human serum albumin (HSA), a protein that is used in saline intravenous solutions in hospitals. If AviGenics is successful, egg-laying hens could produce HSA at a fraction of the current cost of extracting this protein from human blood plasma.

Although there are several companies racing to produce commercially useful quantities of protein in the eggs of transgenic chickens, AviGenics has a number of advantages over its competitors. First, the firm enjoys a first-mover advantage, since it was the first to enter this field. Second, it also has a technical advantage over its competitors. The company has an exclusive right to use a patented technique developed by the founder, Dr. Ivarie. His invention is a new method for injecting genetic material into a chicken egg. Compared to other techniques for manipulating chicken embryos, the advantage of the Ivarie method is that it achieves a much higher survival rate for the developing embryos. Third, AviGenics has a locational advantage, since Georgia has a high concentration of poultry producers, and AviGenics has already formed a partnership with a major poultry producing firm in the state.

Avian transgenesis has the potential to open up a new, high-profit market for the poultry industry as a new source for raw materials needed by the pharmaceutical industry. Since Georgia is one of the largest centers of poultry production in the nation, the state is well positioned to capture a significant share of the downstream economic benefits from AviGenics' success.

CuraGen is a Connecticut-based company developing genomic and bio-informatics systems that accelerate the discovery of new therapeutic products. Jonathan Rothberg, a researcher at the Yale

University School of Medicine, and Gregory Went, a post-doctoral candidate at Cornell University, founded the company in 1991. By the end of decade, the company had developed a portfolio of fully-integrated genomics technologies, processes and information systems designed to rapidly generate comprehensive information about gene sequences, gene expression, biological pathways and the potential drugs that affect these pathways. As of March 2000, the company held nine US patents on its technologies, with 10 additional patent applications pending.[3]

CuraGen is now using this technology as a platform for developing novel genomic-based biopharmaceutical products. Its proprietary system has provided the basis for the company to form research and discovery partnerships with a number of leading bio-pharmaceutical firms. In 1999, the company earned $15 million from contracts with other companies for R&D activities. In addition to these collaborations, CuraGen is also pursuing its own internal product discovery and development program covering such disease areas as obesity and diabetes, cancer, autoimmune diseases, and central nervous system disorders.

Headquartered in New Haven, near Yale University, the company employs more than 300 people, twenty-five percent of whom hold doctorate degrees in fields such as molecular biology, chemistry, and medicine. Of our four cases, CuraGen is the first to have an initial public offering of stock (IPO). In 1998, the company went public with an initial market capitalization of more than $40 million. By the summer of 2000, CuraGen was the largest biotech employer in Connecticut.

SAGE (Sun Active Glass Electrochromics), Inc., was founded in 1990 to develop energy saving windows by John E. Van Dine, formerly director of process development at a New Jersey company. From its beginning in an incubator at Rutgers University, SAGE has focused on the development of electrochromic technology as coatings on glass to control the transmission of light, heat, and near infrared radiation. This technology can be applied to windows, large area information displays, eyewear and photographic and optical filters.

The company holds six US patents on its technology. It has succeeded in developing a prototype of its “Smart Windows” technology, now known as SAGEGLASS®, has demonstrated the performance characteristics and durability requirements demanded by the architectural glass industry, as evaluated by the National Renewable Energy Laboratory (NREL)[4]. Moreover, the technology is featured in exhibits at Disney's EPCOT center as a revolutionary new building technology.

In 1998, SAGE formed a partnership with VIRATEC® Thin Films, Inc., and VIRACON, wholly owned subsidiaries of Apogee Enterprises, which is headquartered in Minneapolis-St. Paul, Minnesota. This partnership provides the opportunity to scale-up SAGEGlASS® for manufacturing specialized architectural glass. To be close to its commercializing partners, SAGE Electrochromics migrated from New Jersey to Minnesota to be close to its commercializing partners. SAGE began marketing its technology in 2000. The company employs 20 people in VIRATEC's facilities in Faribault, Minnesota and remains privately held.

HT Medical Systems produces real-time interactive surgical simulation and robotics technology. Gregory Merril founded the firm, in 1987 in suburban Maryland near Washington, D.C. The company began under the name of High Techsplanations and specializes in developing multi-media educational videos for medical equipment producers. In 1992, the company changed its focus to interactive virtual reality systems for medical procedures with applications in training and potential in the delivery of remote medical care. The company's technology provides the first, real-time interactive simulation that incorporated a realistic tactile interactive experience.

While HT Medical holds no patents on its system, the company has established a reputation as a leading innovator in the development of virtual reality technology. *VR World*, a trade journal, evaluated the company's simulator as the best virtual reality application of 1995. Then, in 1996, HT Medical was a finalist for the Innovation of the Year Award of *Computer World*, a trade journal published by the Smithsonian Institute. Again, in 1998, the company's first commercial VR system, CathSim®, won a World Medal in the educational media category at the New York Festivals' International Interactive Multi-Media Awards. The company has three products on the market and employs 52 people. It is privately held and has received venture capital investments.

In sum, the companies selected provide insights into a variety of industries and applications. AviGenics and CuraGen are biotech companies: AviGenics works on animal applications and drug manufacturing while CuraGen focuses on bioinformatics. HT Medical works on medical applications but through the use of computer technology and robotics. SAGE is developing advance material technology for the building industry but with potential application to other industries such as optics. All four companies are still working to develop their technologies, and none has yet to achieve profitability. During the course of their development, all four have made use of state technology programs.

How States Augment the Capabilities of Start-up Companies

States offer a wide array of programs to assist technology intensive start-up companies.[5] Some states began providing business assistance programs in the 1930s. From an early focus on efforts to stabilize local economies, state programs evolved in the 1960's and began to provide assistance designed to attract relocating firms and branch plants. During the last two decades, a new generation of programs was initiated by states that focused on supporting the growth of firms that were pioneering the development of new technologies.

Table 1 provides an overview of the types of programs that were used by the firms that we studied. All four of our case-study companies used some form of university-based technology assistance programs. As indicated in Table 1, university-based technology assistance programs fell into three categories: technology transfer programs, applied research grants, and the provision of facilities, subsidized space and shared resources. All four companies we studied accessed the laboratories and specialized equipment of universities and also engaged in joint research activities with university faculty members. With respect to the transfer of technology from the university to the firm, we find two cases where our technology pioneers were awarded licenses for university-owned intellectual property.

Table 1: Types of State Programs Available to Technology Pioneering Companies

University-based Technology Assistance Programs	
	Technology transfer programs
	Applied research grants
	Facilities and access to resources
Financial Assistance Programs	
	Public Venture Funds: Loan or equity programs
	Matching Funds for Federal Research Grants
Business Assistance Programs	

Access to external financial resources is a key determinant of success for technology-pioneers (Roberts and Hauptman, 1987). States provided two types of financial assistance: public venture capital funding and cost-share financing of research projects. Public venture capital provides long-term low-interest loans or equity investments to firms for the purpose of developing the business. Cost-sharing assistance programs help finance research projects of firms. When a small firm is awarded a cost-sharing grant by an R&D agency of the federal government, states may subsidize the cost-share requirement of that specific federal grant. Two companies that we studied, CuraGen and HT Medical, received public venture capital funds. CuraGen also relied on a state financing to provide the cost-share on its ATP-funded research projects.

The firms we studied made limited use of the services of state business development programs. Under this category, states provide an array of market development services, networking opportunities or business incubators. Two companies, HT Medical and AviGenics used business development programs provided through universities. While each of the four companies currently sells technology to other firms or is engaged in strategic alliances, none participated in state networking programs to make these connections. Although they are small, the pioneers have reputations – through publications, displays at conferences, technical awards for excellence, and prestigious national research awards– that attract the attention of potential customers or other firms as partners in the development of their technologies. For example, like other biotech firms, CuraGen and AviGenics enhanced their reputations through academic publications of research results and patents awarded for novel technologies (Gittelman and Kogut 2001, Zucker and Darby 1998).

The next three sections follow Table 1, considering, in turn, the ways our case study companies relied on the technical capabilities of universities, used state programs providing financing and lastly, were assisted by business development programs. Each section begins with a brief overview and description of the programs that comprise the category. We then describe the specific examples afforded by our case studies.

University-Based Technology Assistance Programs

Universities are a source of innovation that has proven especially important in the United States innovation system (Rosenberg and Nelson 1994). In 1998, an estimated $26.3 billion was spent on sponsored research and development (R&D) projects at U.S. academic institutions. Through the National Science Foundation (NSF) and other mission agencies, such as the National Institutes of Health (NIH), the federal government is the largest source of funding for university-based research. In 1998, the federal government was the funding source for 59% of all universities' research expenditures (National Science Board 2000). Industry sources, state governments, and non-profit foundations contributed about the same amounts to university research, each providing eight percent of annual research expenditures of universities.

State governments may be more important funding sources for universities, both public and private, than their contribution to sponsored research suggests. States fund capital improvements in university laboratories and research facilities. Some states also contribute to the operating costs of both public and private universities. These contributions are not included in the National Science Board's estimates of the states' contributions to universities' research expenditures.

In three of our four case studies, scientists and engineers with advanced degrees moving from universities to the firm provided an important means of transferring knowledge although this mechanism is difficult to capture. In the cases of CuraGen and AviGenics, university faculty and research scientists were the founders of these firms. In the case of SAGE, a recent engineering graduate brought critical knowledge to the firm and contributed to seven of the patents the company generated during the 1993-97 period. In addition, all four companies engaged in research collaborations through sponsored research projects with university faculty, and three of the four made use of the laboratories and specialized equipment at universities. In two cases, we found that the firm was licensing university-patented inventions. In each instance, state programs or state-provided resources were important.

University Technology Transfer Programs

The Bayh-Dole Act of 1980 established the rights of American research universities to retain ownership over intellectual property developed by university-based scientists working on research grants from the federal government. The main justification for the act was to facilitate the transfer of university-developed knowledge to for-profit enterprises that would develop and eventually commercialize the technologies. The passage of Bayh-Dole marks a new era of active university technology transfer (Mowery et al 1999). Universities have organized formal technology transfer operations to manage their intellectual property. These may take the form of a new administrative unit within the university or the formation of a legally independent organization. In several states, public universities are restricted by statute from engaging directly in any commercial activity such as receiving fees, royalties, or stock in a company in exchange for the use of university-held patents. As a consequence, these universities have established independent organizations to legally engage in such transactions. Whatever the organizational form, the technology transfer entities have responsibility for keeping track of inventions made by university-employed researchers, preparing patent applications, and negotiating licensing agreements with firms for the use of university-owned intellectual property.

Two of the companies, AviGenics and CuraGen, licensed intellectual property from universities. AviGenics illustrates the situation of a new for-profit enterprise formed with the assistance of the university for the specific purpose of exploiting the commercial potential of a patented invention.[6] CuraGen represents the case of a more established firm seeking to use a university's patented technology as a complement to its own inventions. In each case, an independent organization established by the university to hold the patents granted the licenses.

The University of Georgia Research Foundation, Inc., (UGARF) oversees contributions, and grants for sponsored research and assists with transferring technology developed through University of Georgia research to benefit the University and the public. Established in 1978 as a non-profit corporation, the UGARF administers the process of securing patents and copyrights on the inventions originating from university research, and arranges agreements with industry on licensing fees and royalties for the use of intellectual property.

As a university spin-off, AviGenics was formed to exploit the invention of its founder, Dr. Robert Ivarie, a Professor of Genetics at the University of Georgia. The underlying scientific research for this invention was conducted at the University of Georgia and the resulting patent was assigned to the University of Georgia Research Foundation (UGARF). The patent (#5,897,998) for the Ivarie method for injecting genetic material into the eggs of chickens provides AviGenics a technical and economic advantage over its competitors.

CuraGen licensed technology in 1997 from the University of Florida Research Foundation (UFRF), another independent technology transfer operation. The University of Florida established the UFRF in 1986 to support university-based research with potential commercial value. The foundation provides a means for the discoveries, inventions, processes, and work products of University faculty and staff to be transferred from the laboratory to the commercial domain. Recognizing that university-based research often requires further development in order for it to be exploited in the public domain, the Foundation has the option to assign university researchers' inventions and copyrights to industry through licensing agreements and through equity positions it holds in specific companies.

Information concerning the licensing agreement between CuraGen and the UFRF is confidential and we have no knowledge of the specific inventions and technologies transferred from the university to the company. However, CuraGen's scientists have collaborated and co-authored papers with university scientists at the College of Medicine of University of Florida since 1992. We therefore assume that these collaborators are the likely inventors. Until 1997, CuraGen operated a research facility in Aluchua, Florida, 18 miles away from the Gainesville campus of the University of Florida to facilitate collaboration.

In lieu of licensing fees for university-owned intellectual property, both the UFRF and the UGARF chose to take an equity position in the companies. For example, the University of Florida Research Foundation received $1 million in CuraGen stock in exchange for the use of the intellectual property. Equity investments provide a means for small firms to access technology while conserving cash (Feldman et al. forthcoming). If the company succeeds, the university will receive compensation based on the market value of the company's stock instead of traditional licensing fees.

Even when there is no patented technology involved, universities may retain rights to teaching materials developed by faculty. For example, in 1994, HT Medical began a fruitful and continuing collaboration with Plattsburgh State University of New York at the behest of Dr. Virginia Barker, then Dean of Professional Studies. HT Medical was granted access to the resources of the college in curriculum development and practicum teaching in the health professions. This material proved to be crucial to the development of a virtual reality intravenous training system on the CathSim® platform. Similar to the UFRF agreement, HT Medical's partnership with SUNY- Plattsburgh was funded, in part, by a not-for profit foundation, which provided $300,000 to the company between 1994 and 1997. In return, HT Medical agreed to award the Plattsburgh College Foundation a 5% royalty fee on all commercial sales of CathSim®.

Research Collaborations with University Faculty

States have undertaken a variety of programs to encourage research partnerships between university faculty and local firms. Since small firms have limited internal resources for their R&D activities, they rely heavily on external sources both for funding and for expertise. In each of our all four cases, the company participated in joint R&D projects with university faculty and these collaborations were supported, in part, by special funding programs of the individual states. None of the programs we examined provided direct funding to companies. Instead, the funding went to university faculty members who collaborated with the company. The structure and procedures of the state programs differ. These differences reflect an evolution of this type of program. The earliest programs were designed to encourage university researcher to assist companies in finding solutions to technical problems identified by the firm seeking assistance. Programs of more recent origin require the collaborators to submit a joint research proposal, which is subject to peer review. In addition, the company seeking to form the collaboration is required to provide matching funds or in-kind contributions. The case studies provide some illustrative examples.

To develop a new tactical robotic arm for its VR system, HT Medical formed collaboration with a faculty member at the University of Maryland in 1994. The Maryland Industrial Partnerships (MIPs) program provided a grant of $35,000 to support the faculty member’s research. HT Medical turned to the MIPs program to identify a faculty with the special expertise in robotics that the company needed. MIPs matched the company with a particular faculty member at the University of Maryland and provided funding to the faculty for this research project. No joint patents or ongoing collaboration resulted from the MIPs’ grant.

In contrast to Maryland’s company-initiated program, other states require the joint research project to contribute to scientific advances of interest and importance to the participating faculty members. These programs even require proposed projects to be peer-reviewed and the participating faculty members must specify how the research project will contribute to scientific or technical advances in their fields. New Jersey’s Innovation Partnership (IP) program and Georgia’s Technology Development Program (TDP) are examples of this type of program.

New Jersey’s Innovation Partnership (IP) program requires that the firm and the participating faculty members work together to design the research project. The project is expected to address problems of academic interest to the university researcher as well as those of practical importance to the firm. If a project is approved for state funding, the company is expected to provide matching support to the university equal to the grant award. When small firms are partners, in-kind contributions are accepted in lieu of cash.

Beginning in 1993, SAGE partnered with professors in the Department of Ceramics and Materials Engineering at Rutgers University. This collaboration resulted in two successful IP grants totaling $125,000 in 1994 and 1995. Over the course of the life of this partnership (1993-1997), Rutgers' faculty contributed to the development of inventions that were subsequently patented by SAGE. SAGE enhanced its own internal research capabilities through its contact with the faculty by hiring a recent graduate to conduct research as an employee of the firm.

AviGenics' university collaborators received support from the Technology Development Program (TDP) of the Georgia Research Alliance (GRA), which was formed by a group of Atlanta businessmen in 1990. TDP capitalizes on GRA's extensive investments in university research infrastructure by providing financial support for university-industry collaborations. Similar to New Jersey's IP program, TDP finances university-based research projects that have successfully passed the program's peer review process and have succeeded in attracting matching support from a firm. Moreover, like Maryland and New Jersey's programs, the university partners, not the companies, are the recipients of these funds.

In 1998 and 1999, this program provided $110,000, to the University of Georgia for its joint research activities with AviGenics. TDP funds were used to support research in Dr. Ivarie's laboratory on the modification of the chicken genome via transgenesis procedures. Since 1998, AviGenics has spent approximately $250,000 per annum in sponsored research activities at the university, supporting two post-doctorate researchers, one laboratory technician, and one graduate student.

CuraGen also received financial support for its collaborations with university-based researchers through the Yankee Ingenuity Initiative (YII) program of Connecticut, which is operated under the auspices of Connecticut Innovations, Incorporated (CII). YII provides support to universities for sharing the resources and expertise of their faculty with industry partners. The state makes $1,000,000 available annually from the program to universities for such research collaborations.

Only projects and firms in certain technical fields are eligible for financing by any program operated by CII. In selecting priority technical areas, CII relies on the recommendations of the Connecticut Academy of Science. From time to time, these priorities change. During the period when CuraGen received funding from YII, CII was focusing on seven priority technical fields -- advanced marine applications, advanced materials, aerospace, applied optics and microelectronics, bioscience, energy and environmental systems, and information technology. At least one co-sponsoring business must be an established, independently owned Connecticut-based enterprise, and co-sponsoring businesses must also match state funds with cash or in-kind contributions. Similar to the state programs of New Jersey, Maryland and Georgia YII funds go directly to the educational institution. Unlike these other programs, YII funds can be awarded to any higher educational institution, public or private, in Connecticut.

CuraGen received grants from the National Institutes of Health and the Advanced Technology Program in 1994 and in 1996. CII supported CuraGen's research with YII grants totaling $235,399 to the company's university partners. On both occasions, the grants subsidized the research of Yale University scientists whose work focused on discovering the genetic basis of particular diseases.

Access to University Facilities and Resources

In order to carry out some part of their R&D program, technology-pioneering firms may require the use of expensive and specialized laboratory facilities, equipment, and technicians. For small and large firms alike, access to university facilities allows these firms to meet temporary or occasional needs for such specialized resources. Three of the four technology pioneering firms we studied – AviGenics, SAGE, and CuraGen – were able to use state-of-the-art laboratories at public universities for critical stages in their research and technology development programs. The University of Georgia, Rutgers University (the State University of New Jersey), and the University of California at Berkeley provided the specialized laboratory resources and staffing needed by these companies.

At the University of Georgia's main campus in Athens, AviGenics conducts research in Professor Averie's research laboratory in the Life Sciences Building, and also in laboratory facilities rented in the new Animal Science Complex. Alongside university research staff in Averie's laboratory, AviGenics' scientists conduct research on the modification of the chicken genome via transgenesis procedures. Both facilities were built with funds from the Georgia Research Alliance, a non-profit foundation. Since 1990, GRA has invested $200 million of state funds and $50 million from private sources to upgrade and modernize the research facilities at the various campuses of the University of Georgia system. This includes improvements in the laboratory facilities housed in the Life Sciences Building and the construction of the new Animal Science Complex on the Athens campus.

Similar to AviGenics, SAGE relied on a close collaborative relationship with the Malcolm G. McClaren Center for Ceramic Research (CCR) of Rutgers University. The CCR was established in 1982 as a National Science Foundation industry-university cooperative research center with the goal of developing the fundamental understanding required to realize the potential of advanced ceramic and composite materials in emerging applications. The Center is now housed in a new facility built in 1985. The construction costs were financed by the state, largely through the New Jersey Commission on Science and Technology (NJCST). Moreover, since the establishment of CCR, the Commission has provided an additional $8 million towards the purchase of state-of-the-art research equipment. The resources of the center are available to any company with a facility in New Jersey, regardless of the size of the firm.

In 1993, CCR provided SAGE its first real home with dedicated lab space and access to equipment. This began five-year collaboration between the company, the CCR and Rutgers faculty. By the end of 1994, SAGE established its headquarters in Piscataway, New Jersey. The chosen location was no accident, since the CCR is housed at the Busch Campus of Rutgers, which is also located in Piscataway. Through 1997, SAGE engineers worked with CCR staff and faculty on research projects funded by the federal government. Resources available at CCR for the material composition measurement were particularly helpful to SAGE in testing and calibrating its technology

Connecticut-based CuraGen utilized the specialized laboratory resources of a public university in another state. CuraGen scientists conducted research on the miniaturization of customized computer chips at UC-Berkeley's micro-fabrication laboratory. This collaboration with UC-Berkeley was instrumental in CuraGen's development of a complex "mini-lab" built into a single micro-chip.

Financial Assistance Programs

Bhide (1999) and Blanchflower, Oswald, and Stutzer (2001) find that at certain critical stages in the development of high-tech start-up company, access to external sources of capital is necessary for both the firm's survival and its growth. To launch major new R&D initiatives or to support substantial growth in the firm's R&D capabilities, each of our technology-pioneering companies raised substantial funds from external sources. In each case, a combination of funding sources were used, including private investments by individuals and other companies, the financial resources of joint venture partners, grants and contracts from agencies of the federal government, and two sources of state funding mechanisms – investments by public venture capital funds and matching grants for research projects funded by federal R&D agencies.

Like many new firms, our technology pioneers initially depended on their own financial resources or on individuals with whom the founders had personal contact. SAGE secured investment capital from private individuals in the first year of its operation. CuraGen initially depended on the financial resources of family and friends. While HT Medical, Inc. initially financed its R&D activities through revenues generated by the sale of educational videos and fees for its construction of interactive exhibits at medical conferences and conventions. AviGenics is the only case that had attracted substantial venture capital from private sources from its inception. The firm's initial capitalization of $1.2 million came from a number of private companies, and the largest contributor was, Crystal Farms, a Georgia-based poultry company.

Public Venture Capital Programs

In the case of CuraGen and HT Medical, public venture capital funds provided a much-needed increase in the financial resources of the company. The state of Connecticut invested in CuraGen through its risk capital investment program, which is operated under the auspices of an independent, state-sponsored organization known as Connecticut Innovations, Incorporated (CII). Two different venture capital funds – the Maryland Health Care Product Development Corporation (MHCPDC) and the Enterprise Investment fund (EIF) – of the state of Maryland invested in HT Medical.

Connecticut Innovations, Inc. (CII) was established in 1989 by the state of Connecticut to support new venture development through a variety of financing mechanisms, including grants and equity investments. As discussed previously, this quasi-public organization targets firms and projects in certain technical fields. CII makes equity or near-equity[7] investments in emerging high technology. On an annual basis, this public venture capital fund invests between $8-10 million in high-tech start-up companies. On its investments, CII has realized annual compounded rates of return between 25-40%.

In 1994, CuraGen obtained $600,000 in working capital from CII's risk capital investment program. CII's terms permitted the debt to be converted to common stock in the company. Thus, in 1997, CII received nearly 400,000 shares of common stock in consideration of nearly $1.48 million, which represented the full payment of the initial note, including over $800,000 in accrued interest. One year later, at the close of CuraGen's initial public offering of stock, these shares were valued at $4,400,000.[8]

HT Medical Systems first tapped a state-funded source of capital in 1996. At that time, HT Medical Systems received $400,000 from MHCPDC, a non-profit quasi-public organization funded by Maryland's Department of Business and Economic Development and the U.S. Department of Defense's Technology Reinvestment Program. MCPDC funding was used to support HT Medical's commercialization of its VR technology. The second investment by the state occurred in 1996 and was provided through a different funding mechanism, the Enterprise Investment Fund (EIF). This program is also operated under the Department of Business and Economic Development. EIF invested $250,000 in HT Medical Systems.

As a matter of policy, MHCPDC targets companies involved in developing medical technologies of importance to national security and the national economy. Equity investments of MHCPDC range from $300,000 to $500,000, and must be matched by a private source. HT Medical received its matching investment of $400,000 from Cook, Inc., a medical device company located in Bloomington, Indiana. In return for its investment, MHCPDC expects to receive royalty fees, estimated to be 14% per year of the company's net profits. Combined with its equity stake in the company, the MHCPDC expects its investment to eventually yield an annual rate of return of 25%. The Enterprise Investment Fund targets emerging businesses in high technology fields, providing direct equity investments of up to $500,000. EIP has no matching requirements as a condition for making an investment in a particular company. EIP has similar terms as those of the MHDC.

Cost-sharing Programs

Cost-sharing programs may be important to new firms with limited financial resources, since these state funds reduce the cost to the firm of federally-funded research projects. Only one company, CuraGen, used the resources of a state program in meeting its cost share requirements associated with certain federal R&D grants. In Connecticut, the Federal Technology Partnership Program (FTP) is one of several financing programs operated under the umbrella of the CII. This program provides funds to small companies to match the cost share requirements associated with certain R&D programs of the federal government.

CII offered assistance to CuraGen by providing funding to the company to meet its' cost-sharing match requirements on its ATP awards. CuraGen received two grants totaling $687,500 from Connecticut's Federal Technology Partnership Program (FTP) in 1995. CII also provides Phase III financing of up to $50,000 for SBIR grant recipients. These funds may be used for the development of a marketing plan, beta site testing, promotional literature, and other marketing expenses. Phase II SBIR applications are evaluated for the likelihood that the product under development will reach the marketplace in the commercialization stage (i.e., phase III). CII commits to provide Phase III support to Connecticut companies' commercialization efforts in the hope of making the project more competitive in the national competition for Phase II SBIR funds. In 1995, the FTP provided CuraGen $50,000 for the commercialization of its Phase II SBIR-supported technology.

Business Assistance Programs

States provide business incubation facilities and assistance to new firms in developing their business plans and strategy. AviGenics (Georgia) and HT Medical (Maryland) used such services provided through public universities. AviGenics, in particular, received funds to support its initial business planning and secured office facilities in a business incubator located on the campus of the Georgia Institute of Technology. HT Medical received assistance from the University of Maryland's business school faculty and students in revising its business plan.

According to Combes and Todd (1996), the Advanced Technology Development Center (ATDC) in Georgia was originally conceived to be an NSF-sponsored industry-university center; however, the center was not awarded any federal funding. In 1986, with funding from the state and additional support provided by the Georgia Tech Research Corporation, the ATDC was established as an incubator of new high-tech business ventures, providing access to facilities, personnel and students throughout the University of Georgia system. The ATDC is situated on the campus of the Georgia Institute of Technology as part of the Economic Development Institute and manages the Institute's new enterprise development activities. At this facility, early-stage companies enjoy a strong entrepreneurial working environment and have access to professional business consulting, contact with university research faculty, and modern office and laboratory facilities with central staff support. In 1992, the ATDC established the Faculty Research Commercialization Program. Professor Ivarie was one of three faculty members in the UGA system to receive a business planning and development grant in 1997 for the establishment of

AviGenics, Inc. In addition to these funds, ATDC also provided office space to the new business in its incubator facility.

In the mid-1990s, HT Medical Systems sought assistance from the Michael D. Dingman Center for Entrepreneurship at the University of Maryland to revise its business plan. Under that program, experienced businesspeople work with students to assist local companies develop business plans. One outcome from HT Medical's participation in that planning process was to re-focus the firm solely on its VR technology for medical procedures. As a result, in 1998, HT spun off a new company called Sky Fitness, Inc., which specialized in the production of a suspended recumbent bicycle with an interactive computer game on a monitor mounted on the front of the bike. The market for this product was physical rehabilitation and fitness centers.

Summary and Conclusions

The new companies we studied have all been successful in raising funding from both private and public external sources. All have succeeded in developing a technology that has proven to be of value to other organizations. Moreover, each company has received national recognition for the kinds of technical advances made. Few new companies are as successful as these companies have proven to be. For that reason, we choose to focus on identifying the resources that state governments have provided these companies. We do not wish to imply that states should focus all of the resources now devoted to technology and economic developments to the types of programs we have discussed here. Although we are hesitant to generalize from such a small number of cases, they are instructive as to how technology pioneering companies have exploited the resources and serviced provided through state governments that warrant further investigation.

Although the technologies being developed by the four companies we studied are very different, all relied on the resources of universities and received subsidies from the states to do so. While the federal government contributed the greatest share of public funds for the sponsored research activities of these companies, the states also provided support to the firms for their research activities. With respect to sponsored research, Connecticut, Georgia, New Jersey and Maryland subsidized the collaborations between university-based scientists and engineers and those employed by the company. The specific university-firm partnerships subsidized by the states include: AviGenics with the University of Georgia, CuraGen with Yale University, SAGE Electrochromics, Inc. with Rutgers University, and HT Medical Systems, Inc. with the University of Maryland. In addition to financial support for university-firm research collaborations, the states also augmented the research capabilities of technology pioneers by allowing these companies to access specialized laboratory facilities and equipment and the expertise of the technical staff employed by universities in these facilities. AviGenics had access to laboratory facilities devoted to genetic research in the Life Sciences Laboratories at the University of Georgia. SAGE drew on the instrumentation and staff expertise available through the Center for Ceramics Research at Rutgers University, and CuraGen utilized the specialized micro-fabrication laboratory at the University of California at Berkeley. In each case, the company financed the research and paid fees to the university for the use of its facilities. Since the education and training of scientists and engineers is the main purpose and justification for public investment in university laboratories and equipment, technology pioneers' use of these public resources is relatively minor and the financial contribution to the university from such partnerships is relatively small. As a consequence, state governments will continue to bear the major responsibility for sustaining this infrastructure.

Another way in which the states provided access to resources of public universities was through the licensing of university-owned inventions. Both AviGenics and CuraGen secured licenses for the use of university inventions. In the case of AviGenics, the license was for an invention developed by the company's founder, Dr. Robert Ivarie, in the research laboratory provided him in his capacity as a faculty member employed by the University of Georgia. For CuraGen, the licensed inventions came from researchers employed by the University of Florida. In each case, the licensing agreement was with a non-profit organization established by the state to manage university intellectual property. Moreover, both foundations chose to hold equity in the firm, instead of requiring the payment of licensing fees. The Plattsburgh College Foundation of the State University of New York at Plattsburgh actually invested funds in HT Medical in return for royalties on subsequent sales of the technology that was partly developed with information provided by college faculty.

States also made other equity investments directly in these firms. Maryland provided capital to HT Medical from two different public venture capital funds established by the state. Connecticut provided long-term low-interest loans to CuraGen that were subsequently converted to common stock in the company. In effect, through the use of equity, states and the foundations are depending on the subsequent commercial success of the companies and the increased value of the company stock for a return on their investments. If the company is successful, the financial return on the state's investment may be substantial.

Most state governments evaluate the outcomes of their science and technology programs in terms of the gains in employment from the growth of companies within its jurisdiction (Cozzens and Melkers 1997). While understandable, the emphasis on local employment growth may be shortsighted. The financial return from equity investments in these firms is a potentially important benefit to the state. Moreover, the exchanges of knowledge between industry and university research partners also benefit the region, whether or not the partnering firm expands within the state.

As the following examples indicate, state support of technology-pioneering companies is not always local. In the case of HT Medical Systems, early state support came from New York to this Maryland-based company. CuraGen, a Connecticut-based company drew on the resources of two other states: California and Florida. While California provided access to laboratory facilities, Florida allowed CuraGen the use of university-owned patented inventions. Moreover, the state that initially supports a company's early R&D activities may not derive any long term economic benefit in the form of employment increases related to the commercialization and production of a company's innovation. The case of SAGE illustrates this situation.

New Jersey proved to be fertile ground for SAGE in the early stages of its R&D activities. The state has a unique concentration of public and private research laboratories engaged in research on new materials and chemicals. SAGE's founders were drawn from other companies in the state, and the company conducted all of its early research at Rutgers University's Center of Ceramics Research. However, having developed a prototype of its technology, SAGE began a search for a partner with both the manufacturing and marketing capability needed to commercialize SAGEGLASS®. SAGE found such a partner in Minnesota. Subsequently, SAGE re-located its New Jersey operation to Minnesota in order to exploit the synergy of co-location with its partner during the crucial scale-up phase of production. Minnesota and other locales with manufacturing facilities of Apogee Enterprises are the likely beneficiaries of any subsequent growth in employment that derives from the commercial success of products using SAGEGLASS®.

University faculty and students learn from these partnerships. The knowledge gained is subsequently incorporated in both the research and educational activities of the university. The reputation of the university is enhanced when companies like SAGE employ their graduates. That enhanced reputation attracts new and better students. Since university-industry collaborations are also important in making scientific advances in certain fields (Kogut and Gittelman, 2001), the scientific reputation of the faculty is also enhanced and is a valuable asset of the university in its efforts to recruit new faculty.

Eventually, through an evolutionary process of research and invention, university-industry collaborations may yield additional advances in knowledge that have important applications in industry. The reputation of the university as a source of knowledge is a strong incentive for new spin-off firms to form (and to attract private investors) and for existing firms to locate near the university (Zucker and Darby, 1998). Over time, a cluster of innovating firms may congregate in the region to exploit the synergy achieved by university-industry collaborations. As long as the community of institutions in the region continues to be creative, it is likely to be fertile ground for new enterprises wanting to leverage these resources in developing new products and services.

State should not rely exclusively on the generation of new firms as a policy for sustaining economic growth. Too few new firms succeed, and even when they do, the state that spawns the new enterprise and contributes to its R&D capabilities may not benefit from the downstream employment generated by the production and application of the innovation. In this paper, we have shown that universities are an important source of knowledge that, in turn, provides the basis for innovation, in emerging industries. Other research has shown that universities are an important to the implementation of new technologies in more mature sectors (Kelley and Arora 1996; McEvilay and Zaheer 1999). These findings suggest that perhaps the most important technology policy of state governments is their investments in the scientific and technical infrastructure of the universities within their jurisdictions.

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Endnotes:

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[1] Established in 1990, the ATP holds annual competitions, judged by external peer review, on industry proposed research topics that have the potential for broad-based economic benefit. This encourages projects that address problems that firms have identified but do not have the resources to address. The ATP supports high risk, high impact, pre-competitive research and development carried out by industry. Hill (1998) describes the background of the program.

[2] The term serial entrepreneur is used to refer to an individual who has been involved in a number of start-ups companies. Typically the pattern is sequential as entrepreneurs cash out of one venture and use their funds and expertise to start another venture.

[3] The following six patent numbers refer to patents assigned to CuraGen by the U.S. Patent Office in 1999: 5,871,697; 5,938,904; 5,972,693; 5,977,311; 5,986,055; 5,993,634. As of April 1, 2000, three additional patents were assigned to CuraGen: numbers 6,013,630; 6,017,434 and 6,027,941.

[4] As the world's leading certification laboratory for energy-saving technology, the NREL's assessment of SAGE's technology was influential. Compared to other technologies tested at the same time, the NREL concluded that SAGE's windows demonstrated the best overall performance. This assessment proved to be a critical factor to the company

[5] www.ssti.org provides a comprehensive guide to state science and technology programs and links to relevant state web sites.

[6] AviGenics is a university-formed start-up, as defined by the Association of University Technology Transfer Managers (AUTM 1999).

[7] Debt convertible to equity or debt with warrants.

[8] We do not know if CII has retained its CuraGen stock, or sold it. If CII had held these shares until March 2000 and then sold them, the stock from the initial $600,000 investment would have been valued in excess of $30 million. However, since that high, CuraGen's stock price has declined.