UNIVERSITY RESEARCH AND LOCAL ECONOMIC DEVELOPMENT

August 2006

Kent Hill, Ph.D.
Research Professor, Department of Economics; and Principal Research Economist,
L. William Seidman Research Institute

P3 PRODUCTIVITY AND PROSPERITY PROJECT

ASU W. P. CAREY SCHOOL of BUSINESS
ARIZONA STATE UNIVERSITY

UNIVERSITY RESEARCH AND LOCAL ECONOMIC DEVELOPMENT

A Report from the Productivity and Prosperity Project (P3), Supported by the Office of the University Economist

August 2006

Kent Hill, Ph.D.
Research Professor, Department of Economics;
and Principal Research Economist, L. William Seidman Research Institute

Center for Competitiveness and Prosperity Research
L. William Seidman Research Institute
W. P. Carey School of Business
Arizona State University
Box 874011
Tempe, Arizona 85287-4011

(480) 965-5362
FAX: (480) 965-5458
EMAIL: Kent.Hill@asu.edu
wpcarey.asu.edu/research/competitiveness-prosperity-research
economist.asu.edu

W. P. CAREY
SCHOOL of BUSINESS
ARIZONA STATE UNIVERSITY

TABLE OF CONTENTS

Summary	1
University Research and Local Economic Development	6
Science, University Research and Economic Progress	7
Why Would University Research Have Local Economic Development Impacts?	10
Evidence of Local Effects	14
Conditioning Factors	22
How Does the Phoenix Metropolitan Area Rate?	29
Concluding Remarks	33
References	35

LIST OF TABLES

1. Characteristics of the Electronics Industry in 2004	15
2. Patent Income in 2000: Top 15 Universities	18
3. University Research and Development in the 25 Largest Metropolitan Areas in 2003	30
4. Quality of Life Sciences and Engineering Departments in Universities in the 25 Largest Metropolitan Areas in 1993	31
5. Science and Engineering Workers in the 25 Largest Metropolitan Areas	32
6. Venture Capital Funding for Selected Regions	33

LIST OF CHARTS

1. Graduate Degree Educational Attainment and Degrees Awarded Adjusted for Weather	13
2. Patent Productivity and City Size	27

SUMMARY

This paper provides a review of studies that examine the extent to which university research promotes local economic growth and development. The primary focus of the paper is on economic impacts that derive from the innovative outputs of faculty. These impacts include the attraction of industrial laboratories to the local area, the start-up of new high-tech businesses, and any competitive advantages enjoyed by local businesses when their technology is advanced by university research. Because it is difficult to separate research from education, especially graduate education, contributions that research universities make to the local economy through their graduate programs also are considered. Students who graduate with advanced degrees may remain in the local area to work in industrial labs or they may start new science-based businesses. The paper does not specifically deal with economic impacts that derive from university spending. The focus is on the jobs and incomes created by the research findings of faculty rather than impacts generated by the research budgets themselves.

One reason why university research generates local economic impacts has to do with impediments in the transfer of tacit knowledge. Research findings that can be codified, and expressed through formulas or text, can be made available to anyone anywhere. There is no compelling reason for this kind of knowledge to be commercially developed close to the original source. But in many cases of scientific discoveries with revolutionary commercial potential, including integrated circuits, recombinant DNA, and nanotechnology, knowledge is tacit and difficult to communicate without frequent face-to-face contact. The knowledge is embodied in the intellectual capital of the discovering scientist and can only be transferred to industry through active working relationships with the scientist. If the pioneering scientist has a university appointment that he wishes to maintain, he will serve as a fixed factor determining the location of new firms entering the market to develop the technology.

Research universities also generate local economic impacts through their graduate programs. Availability of scientific labor is an important concern for managers of industrial laboratories, and they may choose to site a lab in an area if local universities can provide a steady supply of highly qualified science and engineering graduates. Because of a variety of local attachments people develop while in school, young professionals often prefer to remain in the vicinity of their graduate school, especially if that school is located in a large urban area. The likelihood of a graduate remaining in the area depends on his field of study. When skills serve primarily a local market, as in the case of medical doctors and lawyers, many graduates will end up leaving the area if the number of new graduates exceeds what the local market can absorb. Cities can absorb large numbers of graduates, however, if they are being trained to work for firms that serve an external market.

Evidence of local economic impacts from university research comes from a variety of sources: case studies of local industries born from the ideas of university scientists, university records of income earned and new businesses formed from university research findings, and econometric evidence identifying a statistical association between the level of economic activity in an area and the presence of a research university. The evidence shows conclusively that university research programs have local economic impacts. The largest impacts are found for specific industries known to depend heavily on new scientific findings and in cities that are home to universities with faculty that are leading contributors to new scientific areas. Studies that look systematically across many research universities, multiple urban areas and all industries in the

economy generally find that university research has effects that are discernable and statistically significant, but modest in size.

The most spectacular examples of local economic development stimulated by university research are the electronics clusters in Silicon Valley (with ties to Stanford University) and Route 128 near Boston (with ties to the Massachusetts Institute of Technology). In these cases, local university research has not only served to expand the employment base, but to dramatically raise average income levels. These are the success stories. But there are also examples, such as Johns Hopkins University in Baltimore, of universities with prestigious research programs that have had very little impact on high-tech industry in the local economy. What is needed is a more systematic test of local economic impacts from research universities throughout the country.

When looking for university-related impacts, the most promising place to start is with industries known to rely heavily on advances in science. Biotechnology offers an example of an important new industry built directly on basic scientific research in which commercial firms have close ties to university-based scientists. Studies have found a strong geographic correspondence between the locations of university scientists who made early contributions to gene sequencing and the locations of commercial biotech firms. Biotech firms that have had the most financial success are those that maintain close working relationships with university scientists. Many of these relationships are local, but not all of them. One study found that approximately one-half of the university scientists who have affiliations with Boston-area biotech firms have appointments with Boston-area universities. But firms in San Diego and New York draw only one-quarter of their university scientists from local universities. While geographic proximity between university scientists and biotech firms has been important, other factors, such as those related to agglomeration, have also played an important role in the siting of firms.

One measure of the economic value of university research is the income universities receive from the licensing of university-owned patents. Much of the business activity related to these patents is local. Start-ups and small firms account for two-thirds of the businesses that enter into university licensing agreements, and most of these firms are locally based. While a few university patents do generate millions of dollars each year for their universities, most patents fail to earn enough revenue to cover the costs of filing them. In the year 2000, patent income accounted for less than 3 percent of total university revenues at ten of the 15 universities with the largest patent income. In general, university records of patent income and university-related start-ups indicate that the effects of university research on the local economy are, on average, very modest. It should be noted, however, that these statistics are sure to understate the local economic impacts of research universities. Channels of technology transfer other than licensing, such as consulting and contract research, are often more important ways in which faculty transfer research findings to local firms. Research universities also make important contributions to the local economy through the entrepreneurial efforts of their graduates. A few universities have tried to document the extent of these student-related impacts. But for most universities, these records are either nonexistent or highly incomplete.

The case for linkages between university research and local economic development hinges on the argument that knowledge created at universities tends to stay in the local area. One way to trace knowledge flows is by using information from patent records on subsequent citations and the geographic location of inventors. Studies of patent citations find strong evidence of geographic localization of knowledge flows. One prominent study found that a university-owned patent is six times more likely to be cited in the same metro area than what would be expected in a random sample. Knowledge flows from universities are, nevertheless, predominantly external. Less than 10 percent of university patent citations are local.

One way in which university research is thought to affect the local economy is by stimulating corporate research and development (R&D) activity. Industry labs directly promote local economic development by providing high-paying jobs for scientists and technical workers. They may also generate competitive advantages for local producers who make use of the innovations coming out of the labs. Several econometric studies have found a positive statistical association between the level of university research expenditures in an area and both corporate innovative activity, as measured by patents and counts of product innovations, and corporate R&D expenditures. Also, university research expenditures have been found to have a statistically significant, although quantitatively small, effect on local area employment of those with a doctorate degree (Ph.D.) in corporate laboratories.

A number of econometric studies have looked at whether the presence of a research university affects the general level of economic activity in a metropolitan area. Economic activity is measured in a variety of ways including starts of new manufacturing firms, growth in total metro area employment, and average earnings across all jobs in the metro area. The results of these studies are mixed. In many cases, a positive and statistically significant relationship is found between a research university variable and a measure of local economic activity, but the strength of the relationship is usually weak.

In econometric studies of university impacts, it is difficult to separate contributions of research from graduate instruction. Universities with large and prestigious research programs tend to have both highly productive faculty researchers and highly rated graduate programs. It is not clear whether the local economy benefits more from having special access to new scientific findings or by having a supply of well-trained scientists and engineers who can work in industrial labs or start new businesses themselves.

Two universities with similar research efforts can have very different local economic impacts. Certain complementary factors may need to be present if a university is to significantly affect the local economy. These factors include the quality of faculty and graduate programs, the presence of corporate research activity and high-technology production in the local area, the general size and amenity appeal of the urban area, policies regarding permissible forms of licensing of university-owned patents, and local availability of venture capital.

Universities with the greatest local economic impacts are generally those with the highest quality research programs. The most compelling reason for technology-based firms to locate near universities is to facilitate tacit knowledge transfer from faculty who are on the leading edge of scientific breakthroughs. It is only these star researchers who have the power to determine firm location. University scientists with a national reputation are more likely to be able to attract venture capital, management, and the technical workers necessary to start new companies. In addition, while studies show that availability of science and engineering workers is an important factor in the location of industrial research laboratories, R&D managers are particular about the institutions they hire from and view only the best graduate programs as an attracting factor.

Agglomeration economies are known to be an important factor in the production of knowledge. Spatial concentration of research activity promotes the development of markets for specialized suppliers of materials, testing equipment, and legal services. Agglomeration also helps to support informal channels of knowledge transfer. University research will be more productive and more likely to influence local economic activity if it takes place in an area with an existing concentration of corporate research activity and high-tech production.

Apart from the size of particular industries, the general size of an urban area affects the scale and productivity of local research. Cities with 1 to 4 million people produce twice as many patents per capita as do cities with a population less than 250,000. New product innovations are introduced disproportionately by firms in large metro areas. Studies also show city size to be a more important siting variable for high-tech companies than low taxes or low wages. One reason for these findings may be that large urban areas better promote knowledge spillovers between different industries. Also, city size is thought to be an important locational consideration for science and engineering workers. Large urban areas offer amenities that professional workers value, and they make it easier for spouses to find employment.

University culture and policies can have important effects on the extent to which faculty engage in and develop commercially relevant research. In an attempt to raise what are generally considered to be disappointing financial returns from resources used to promote technology transfer, more universities are making use of equity arrangements when licensing university inventions. Many university-owned patents fail to generate significant income because faculty do not take the time to develop their ideas and concepts into a commercially viable product. When faculty have a financial interest in the performance of the firm that licenses their research, they are more likely to assist the firm in product development. Licensing firms believe that university equity positions confer a kind of halo effect that helps them secure venture capital funding. Data analysis indeed shows that universities that are permitted to take an equity position in companies that license their research have 70 percent more start-ups than universities who cannot.

Venture capitalists can play an important role in the start-up of science-based companies. Venture capitalists not only provide risk capital, but they help to connect company entrepreneurs with management teams, key technical employees, suppliers, and customers. Unlike other financial markets, venture capital markets tend to be local. Availability of venture capital can then be a constraint on the ability of a local area to commercialize new scientific findings. While there is much empirical support for the idea that venture capitalists impose geographic constraints on new high-tech businesses, there is also evidence that venture capitalists can be drawn to an area if it is home to a star scientist or an eminent research program.

Surveys of corporate R&D managers show that newer industries (such as pharmaceuticals, semiconductors, and medical instruments) are more likely to utilize university research findings in their own research projects than are mature industries (auto parts, motors and generators, and industrial chemicals). These surveys also show that academic research in applied fields (engineering, computer science, and materials science) is more likely to be of direct use to industry R&D than is research in the basic sciences (physics, chemistry, and mathematics). The apparent implication is that university research that occurs in applied fields and is directed at new industries offers the most potential for stimulating local economic activity. Economic historians and innovation scholars are quick to point out, however, that most inventive activity is carried out in private industry, and industry is more interested in universities as educators of students in basic theory and research methods than as sources of new industrial technology. When thinking broadly about the role of universities in the process of economic growth, it is important for universities to have high-quality programs in both basic and applied fields.

With the above literature review as a backdrop, this paper evaluates Arizona State University and the Phoenix metropolitan area in terms of factors that enhance the local economic impact of university research. The potential for local impacts from ASU's research and graduate programs is greatly aided by the fact that ASU is located in a major metropolitan area with a climate and other natural amenities that mobile professional workers find attractive. Phoenix also rates highly in many measures related to engineering, including a large local electronics industry and a number of highly rated engineering departments at ASU. Compared to other major metro areas, however, Phoenix has little life science research activity. This is partly attributable to the fact that Arizona's medical school is located in Tucson. State law currently forbids ASU from taking equity positions in firms who license university-owned patents. This is probably a barrier to university-related economic development since recent studies suggest that equity arrangements increase the likelihood of commercial success in university innovations. Also working against ASU is that there is very little venture capital financing in Arizona. This constraint on new business formation can be mitigated, however, if ASU acquires faculty and builds programs with national reputations.

UNIVERSITY RESEARCH AND LOCAL ECONOMIC DEVELOPMENT

Universities have played a key role in the process of economic growth, as both a source of new knowledge and a trainer of scientists and engineers who work in industrial laboratories. Universities are considered to be the principal strength of the U.S. national innovation system. The question reviewed in this paper is whether the economic effects of university research are disproportionately local. Are local economies more prosperous if they have a research university? How important is having a research university to economic growth and development in a city or region?

The perspective in this paper is one of economic impact analysis rather than cost-benefit analysis. The central question is whether university research programs tend to stimulate employment and raise the average level of income in the local area economy. The public policy issue of whether university research should be subsidized is not addressed directly. The public policy question hinges on whether there is market failure in the production of knowledge, e.g., whether inventors can appropriate the value of their discoveries. This is a separate issue from whether university research stimulates local business activity.

The economic impacts of primary interest here are those related to private-sector development or implementation of university research findings. This includes an attraction of industrial labs to the local area, the start-up of new high-tech businesses, and the competitive advantages enjoyed by local businesses when their technology is advanced by university research. One traditional area of university economic impact analysis that will not be considered are the jobs and incomes supported by research grants that a university may acquire from outside sources. This paper concentrates on economic impacts that arise from the innovative outputs of faculty, not the money used to pay them.

The focus is primarily on impacts from university research rather than education. But it is difficult to separate education from research, especially graduate education. Institutions with prominent research faculty also tend to have prestigious graduate programs. Students who graduate with advanced degrees in science and engineering may remain in the local area to work in industrial labs or to start new science-based businesses. Studies of the economic impacts of universities find it difficult to separate the effects of research from education. So, in reviewing how universities shape local economies, the role of universities as a trainer of new scientists and engineers also is considered.

The first section of this paper reviews the role that universities have played in the general course of economic progress. A distinction is made between university research that becomes directly incorporated into new industrial products/processes and advances in basic scientific understanding that may eventually have profound effects on technology but do so after crossing many disciplinary and industry boundaries. University research that is of a basic nature and requires long periods of time before fully contributing to technology is likely to have very diffuse economic impacts, most of which will accrue outside of the local area economy.

In the second section of the paper, two reasons are provided for why university research might have economic impacts that are local. The first has to do with the transfer of tacit knowledge. Firms that wish to commercially develop major scientific advances need to establish close working relationships between their own scientists and the inventors. If the inventors are university faculty who do not wish to leave their university positions, this may require that the firms locate near the university. The second reason for why universities with strong research programs stimulate local business activity involves graduate students. Despite the high mobility of the population, young scientists and engineers tend to remain in the vicinity of their graduate school, especially if that school is located in a large urban area.

The third section of the paper provides an extensive review of empirical evidence on the local economic impacts of university research. The evidence comes from a variety of sources, including case studies of local industries born from the ideas of university scientists, university records of patent income and start-up companies, and econometric studies of determinants of urban employment and income growth. The evidence shows conclusively that university research programs have local economic impacts. But these impacts are highly skewed across universities and, on average, are moderate in size.

Section four reviews what is known about complementary conditions that may need to be present if a university's research program is to have a significant effect on the local economy. Factors examined include the quality of university faculty and graduate programs, academic fields most directly linked to industrial innovations, an existing concentration of industrial labs and high-tech industry in the local area, the size of the city in which the university is located, university policy governing the licensing of patented research, and the availability of venture capital.

The fifth section of the paper compares the 25 most populous U.S. metropolitan areas, including Phoenix-Mesa-Scottsdale, in terms of the amount of local university R&D spending, the quality of the university science and engineering departments, and the number of non-university scientists and engineers working in the area. Phoenix rates highly among U.S. metro areas in all categories related to engineering. Phoenix has only a small amount of life science research activity, however. This is partly attributable to the fact that Arizona's medical school is located in Tucson. Further, there is relatively little venture capital funding in Arizona. This constraint on new business formation can be mitigated, however, if local area universities acquire faculty and build programs with national reputations.

The final section of the paper warns policymakers not to have unrealistic expectations about the potential local economic impacts from university research and not to lose sight of the value of general education and basic scientific research.

Science, University Research, and Economic Progress

Science as a Basis for Industrial Innovation

The most important source of technological progress over the past 150 years has been the advance of scientific knowledge. A dependence of industrial innovation on science first became evident in the last few decades of the 19th century. Application of principles of chemistry and physics became central to the commercial success of manufacturers of steel, rubber, chemicals, drugs, and electricity. Industries came to rely on universities to train the scientists and engineers they would employ in their research laboratories. From 1900 to 1940, the number of chemists employed in the economy increased six-fold and the number of engineers employed increased seven-fold [Goldin and Katz (1999, p.39)].

University research itself also made direct contributions to technical advance in industry. From the late 19th century up until World War II (WWII), research at American public universities was funded by state governments and, as a result, was oriented to solving practical problems in local industry. Joint university-industry research programs were especially important to technological progress in agriculture, mining, and oil exploration [see Rosenberg and Nelson (1994) and Goldin and Katz (1999)].

A major change in the scale and direction of American university research took place following WWII when the federal government initiated a massive campaign to fund research at universities. Between 1940 and 1950, the contribution of the federal government to university incomes increased from $39 million to $524 million. The nature of university research was transformed by this new source of funding. The direction of university research shifted away from research intended for local industry application to more basic scientific research, with applications to national goals in defense and health care. The old service role of universities diminished in importance, especially for agriculture and forestry products. Today approximately two-thirds of the research done at universities is classified as "basic," which the National Science Foundation defines as research aimed at gaining a fundamental understanding of a subject, without specific applications in mind.

Long-term Effects of University Research on Industrial Innovation

In a view repeatedly expressed by Richard Nelson and others [see Nelson (1986), Rosenberg and Nelson (1994), and Klevorick et al. (1995)], university research does not directly generate new commercial products or technology as much as it raises the productivity of industrial R&D. The primary share of inventive activity is carried out in industry. But industrial scientists rely on basic science as a stock of knowledge and a set of tools useful for solving specific commercial problems. In carrying out their research, industrial scientists are as likely to use old science as they are new scientific discoveries. From this perspective, the most important contribution universities make to technical advance in industry is in the training of industrial scientists and engineers.

There have been cases where advances in basic science have led quickly and directly to important industrial applications. Perhaps most famous is the development of the atomic bomb in the early 1940s following discoveries in basic physics made during the 1930s. More recently, the biotechnology industry grew quickly once principles of recombinant DNA were discovered, with the pioneering firms working closely with university scientists involved in the frontiers of gene sequencing. Direct links from university research to industry are also common in some applied sciences such as metallurgy, materials science, computer science, and electrical engineering. Nevertheless, the mainstream view among economic historians is that while most technological breakthroughs ultimately can be traced to advances in science, many of which are made in universities, the benefits of scientific advance on industry innovation take a long time to be realized and the links are difficult to trace as they cross a variety of disciplinary and industry boundaries.

Evidence from the 1983 Yale Survey

An important source of information on the role of science and university research in industrial innovation is the 1983 Yale Survey on Industrial Research and Development, analyzed and reported on by Nelson (1986), Rosenberg and Nelson (1994), and Klevorick et al. (1995). In the survey, 650 high-level R&D managers representing 130 industries were asked to rate (1) the general relevance of fields of science and (2) the specific relevance of university research in these fields to recent technical advances in their industries. A high score on the first question is interpreted as indicating that university *training* in that field is important for carrying out industrial R&D, while a high score on the second question signals that new findings from university *research* are in themselves important inputs into industrial innovations.

For all fields of science, a much larger number of industries found the field itself to be relevant to industrial innovation than found university research in that field to be relevant. For example, 43 industries gave a rating of 6 or higher (on a Likert scale of 1 to 7) when assessing the general relevance of chemistry as a field of science to invention in their industry; but only 3 industries gave university research in chemistry a rating of 6 or higher. These findings do not imply that technical advance in these industries is not science-based. It may simply mean that the science used is not new. Science is important to industrial R&D in that it provides a pool of knowledge and research techniques which industrial researchers use to solve particular research problems.

Another noteworthy finding from the survey was that the difference in ratings between the general field and university research were greater for basic sciences than for applied sciences. The authors interpret these findings to mean that advances in fundamental knowledge in basic fields of science contribute to technical advance in industry after working their way into the applied fields. The survey respondents understood that while academic research findings in applied fields like electrical engineering and medical science were more likely to be of direct relevance to their own research, those disciplines, in turn, were strengthened by new findings in more basic sciences such as physics and molecular biology.

Short-term Effects of University Research on Industrial Innovation

While cases of direct incorporation of university research findings into commercial innovation are relatively uncommon, they are apparently important enough in size to yield a high overall rate of return on university research. Mansfield (1991) analyzed data from a survey of R&D executives of 76 major American firms who were asked about the proportion of new products and processes introduced from 1975 to 1985 that could not have been developed (without substantial delay) in the absence of academic research that had been conducted during the previous 15 years. The responses indicated that 11 percent of new products and 9 percent of new processes could not have been developed without the aid of recent academic research. By supplementing these figures with information on the value of sales of new products and cost savings from new processes, Mansfield estimated that the social return to investment in academic research during the period from 1975 through 1978 was 28 percent.

There is also evidence that short-term linkages between academic research and industrial innovation have increased in importance over the past few decades. From a 1994 Carnegie Mellon survey of 1,478 industrial R&D lab managers (administered eleven years after the Yale survey), Cohen et al. (1998) found more widespread acknowledgement of utilization of recent academic research in industry R&D. Two-thirds of the industries surveyed said that academic research was at least “moderately important” to their R&D activities. Patents issued to universities and counts of start-ups by university Offices of Technology Transfer also have risen dramatically. University patents have increased tenfold since the mid-1970s. University patents now account for 4 percent of all U.S. corporate patents, up from only 1 percent in the mid 1970s [U.S. Patent and Trademark Office (2004)]. The annual number of start-up companies based on university inventions was four times as great in the late 1990s as it was during the 1980s [Graff et al. (2002, p.101)].

Cohen et al. (1998) conjecture that the deepening of ties between universities and industry stems both from (1) changes in policy that provide stronger incentives for universities to engage in applied research (i.e., passage of the Bayh-Dole Act of 1980) and (2) industry trends toward downsizing central and upstream R&D activities. Mowery et al. (2001) also note that much of the recent increase in university patenting activity has been in biomedical patents whose growth, along with that of the entire biotechnology industry, can be traced simply to a burst of scientific innovation following the discovery in 1973 by Cohen and Boyer of the basic technique for recombinant DNA.

Why Would University Research Have Local Economic Impacts?

Prior to WWII much university research, especially that in public universities, was funded by state governments. In return, universities were expected to train students for employment in local industry and to help local firms solve industrial research problems. The local economic impacts of university research and graduate training were highly visible. After WWII, however, the federal government became the dominant source of university research funding, with goals that were national in scope and unrelated to the needs of local industry. Academic research also became less proprietary and conducted more in an open science format. Research findings were published in journals, presented at seminars, and available to anyone. Without formal ties between a university and local industry, it was not clear that any of the competitive advantages that derive from commercial application of university research would accrue locally.

There are two reasons why university research programs are likely to generate local economic benefits, even without an administrative mandate to do so. First, some research findings, especially those that are revolutionary and have the potential to create new industries, are difficult to transfer to industry without frequent face-to-face contact between university and industrial scientists. This aspect of knowledge transfer encourages commercial start-ups to locate near university scientists. Secondly, even though U.S. residents are highly mobile, there is still a tendency for graduates with advanced degrees to remain and work in the local area, especially when the degree-granting institution is located in a major metropolitan area. Young scientists and engineers who stay in the area help to transfer university research findings to local firms or they may work in industrial labs that create knowledge that is valuable to local businesses.

Tacit Component of Scientific Breakthroughs

Information theorists distinguish between two types of knowledge: *codified* and *tacit*. Codified knowledge is information that can be written down and easily transferred through formulas or text. With recent advances in telecommunications, the cost of transmitting codified knowledge across space has become negligible. Proximity to an original source of codified knowledge is unimportant. Tacit knowledge, on the other hand, is highly complex and difficult to write down. The transfer of tacit knowledge requires frequent face-to-face interaction with the knowledge source. Geographic proximity is critical for transferring tacit knowledge.

Darby and Zucker (2003) have argued that “metamorphic” innovations — those associated with the creation of new industries or the radical technological transformation of an existing industry — typically are driven by breakthrough discoveries in science and engineering. Examples include integrated circuits, recombinant DNA, and nanotechnology. These kinds of discoveries are not well understood initially and cannot be codified. In the beginning, the new knowledge is largely tacit, and it is difficult for anyone other than the discoverer to see commercial value in the findings. Transfer and application to industry require bench-level relationships between industry scientists and the pioneering scientists.

One implication of this scenario of technological progress is that the discovering scientists, with whom close contact is required for knowledge transfer, have control over who learns the new technology and are in a position to appropriate much of its economic value. There need be no leakages or unintended spillovers of knowledge that lead to incentive failures in innovative effort.

More importantly for the subject of this paper, if the scientist making the metamorphic discovery has a university appointment that he wishes to maintain and does not want to commute long distances, he will serve as a fixed factor that determines the location of firms entering the market to develop the new technology. Audretsch and Stephan (1996), Zucker, Darby, and Brewer (1998), and Zucker, Darby, and Armstrong (1998, 2002) have documented the role of pioneering university scientists in the growth and geographic distribution of the American biotech industry. These studies will be reviewed in greater detail below.

The period during which discovering scientists play a major role in transferring new knowledge to industry may only last 10-to-15 years. Eventually, scientific findings become codified and can be learned by graduate students at any major research university. But once an industry has been established in a given location, agglomeration economies associated with the rise of specialized suppliers or markets for specialized labor may serve to lock in an industry's location. In this way, the initial geographic residences of path-breaking researchers have a long-term effect on industry location.

Locational Persistence of Graduate Students

One of the most salient features of the U.S. university system is its coupling of research and graduate education [Hill (2006)]. Compared to other countries, a relatively large percentage of U.S. basic research is performed at universities by faculty who are also actively involved in education, especially graduate education. To this feature of the system many observers attribute the continued leadership and success of the United States in world science and innovation. It is difficult then to separate research from graduate education when evaluating the contribution of university research to local economic development. University research and graduate programs go hand in hand. The research process itself is aided by the participation of graduate students; and graduate instruction is more effective, especially the training of industrial scientists, when the teachers themselves are involved in research.

As noted earlier, one of the most important contributions universities make to the national innovation system is through their training of industrial scientists and engineers. The bulk of inventive activity takes place in industrial labs that are staffed by researchers who learned both old science and new research methods at universities. Where these new industrial scientists end up living greatly affects the geographic pattern of the economic benefits of innovation. Industrial labs are considered prized economic development targets. The labs themselves are clean and high paying, and they can generate spin-offs and other new high-tech businesses.

Where young scientists and engineers choose to locate depends on both demand and supply factors. On the demand side, some states have a comparative advantage in the use of highly trained workers with graduate degrees. States bordering the nation's political and financial capitals (Washington, D.C. and New York City), for example, long have been important importers of highly educated workers. Strong demand in these areas derives, in large part, from an arbitrary historical concentration of firms and institutions that make intensive use of highly educated labor.

As argued by Malecki (1987) and Malecki and Bradbury (1992), supply factors and the locational preferences of R&D workers also play an important role in the location of industrial labs. R&D operations are seriously constrained by the labor market for scientists and engineers. Given that availability of scientific labor is a critical locational consideration for R&D facilities, is there any advantage to siting in an area with a research university that trains a large number of scientists and engineers? Do cities or states with important university graduate programs end up employing a relatively large number of highly educated workers? The U.S. population is highly mobile, especially educated workers. Even so, there is a high degree of locational persistence in people's decisions. People build relationships in school, relationships that have value in the workplace after graduation. Those attending graduate school also may have spouses and/or children that tie them to an area.

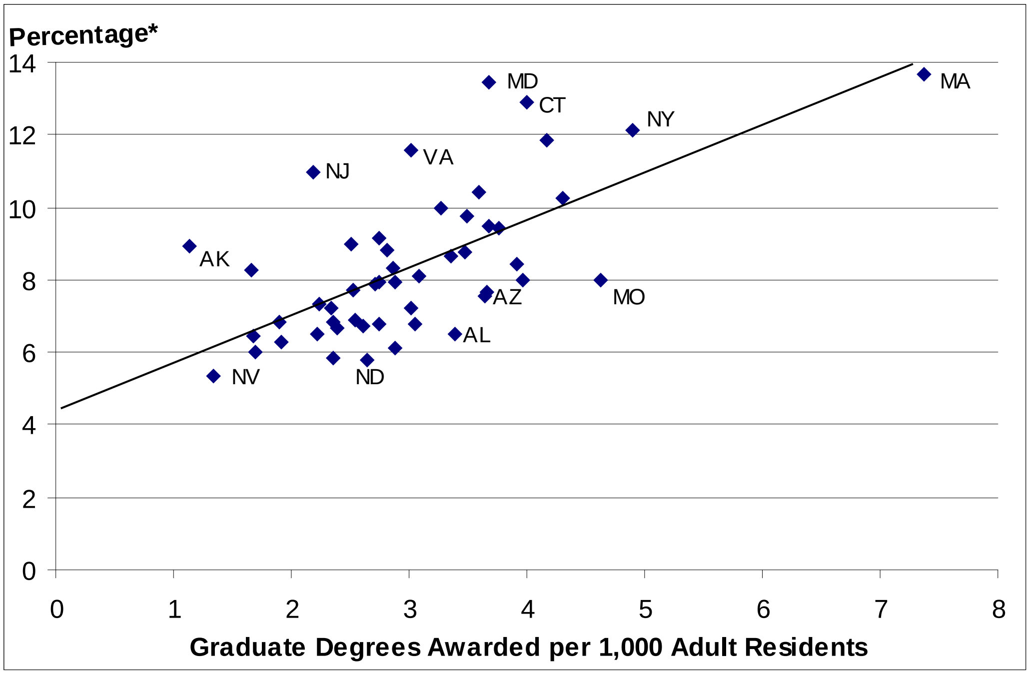
Data correlations suggest that university graduate programs positively affect the number of highly educated workers in the adult resident population. Chart 1 shows a scatter plot of states with the percent of the adult population with a graduate degree plotted against the annual number of graduate degrees awarded per thousand adult residents. Data are circa 2000. Graduate degrees include master's, doctorate, and professional. The percent of the population with a graduate degree was adjusted for weather, as explained in Hill et al. (2005). Weather is known to be an important amenity that affects migration decisions. States with relatively high production of degrees are disproportionately represented in the East and upper Midwest, parts of the country with a climate generally perceived to be undesirable. Because of this relationship between weather and degrees awarded, a simple correlation between degrees awarded and share of the population with a graduate degree will understate the causal role played by local production of degrees.

There is a statistically significant and surprisingly strong relationship between graduate degrees awarded in a state and the share of the state's population with a graduate degree. Based on the measured relationship, if the state of Arizona, for example, were to permanently raise the number of graduate degrees awarded from its present rate of 3.7 degrees per thousand to 4.7 degrees per thousand, the long-term effect would be to increase the share of the population with a graduate degree from its current level of 8.4 percent to 9.6 percent.

These are correlations, of course; causality does not necessarily run entirely from annual production of degrees to share of the population with a graduate degree, rather than vice versa. If a local area already has an industry that employs large numbers of professional workers, firms in that industry may provide funds to the local university to help attract talented faculty and build a graduate program to feed workers to the industry. Electronics firms are known to contribute to local university engineering departments to help build quality graduate programs.

The scatter of points around the regression line in Chart 1 indicates the presence of other factors that influence the size of the local educated population. Most importantly, the analysis has not accounted for factors that influence the demand for highly educated labor in a state. Maryland and Virginia benefit from the large number of government jobs that require an advanced degree.

CHART 1
GRADUATE DEGREE EDUCATIONAL ATTAINMENT AND DEGREES AWARDED ADJUSTED FOR WEATHER



* Percentage of Adult Population with a Graduate Degree

Source: Source: Groen (2004), Table 4, p. 135. Based on a national sample of 12,781 students from 30 selected colleges and universities. Students entered college in 1976 and were surveyed for current state of residence in 1996 (when they were 38 years old on average).

A strong financial services industry helps attract professional workers to New Jersey and Connecticut. Alaska is a destination state for highly trained workers in the oil industry. In contrast, some states have a relatively weak demand for highly educated labor that makes it difficult to retain graduates. Notable among these outliers are Alabama, Missouri, Nebraska, and North Dakota.

The relationship described in Chart 1 is for all graduate degrees. But the extent to which local production of degrees results in local employment of degree holders depends greatly on the specific field. Local markets for medical doctors, for example, have little potential to absorb new graduates. Almost no relationship exists between the number of M.D.s trained in an area and the number of doctors living there. Students pursuing a Ph.D. with an interest in a university faculty position are almost certain to leave the area following graduation. Producers of goods and services that can be exported out of state, on the hand, have the potential to absorb large numbers of local graduates. A positive relationship has been found between the number of graduates from local institutions and use of college-educated labor in that area for sectors producing goods and services traded across states [Bound et al. (2004)]. Students receiving graduate training in science and engineering, with an interest in working in industrial labs or other private-sector employment, have high retention potential.

Evidence of Local Effects

Evidence of local economic impacts from university research comes from a variety of sources: case studies of local industries born from the ideas of university scientists, university records of income earned and new businesses formed from university research findings, and econometric evidence identifying a statistical association between the level of economic activity in an area and the presence of a research university. The evidence shows conclusively that university research programs have local economic impacts. But these impacts are highly skewed across universities and, on average, are modest in size.

Silicon Valley and Route 128

The most highly celebrated cases of local economic development stimulated by university research are the electronics clusters in Silicon Valley, California, and the Route 128 beltway around Boston, Massachusetts. Agglomeration economies associated with knowledge spillovers and thick markets for specialized suppliers have played an important role in reinforcing industry growth in these areas. But the conventional wisdom is that the initial reason the industry took root in these particular locations is to be close to researchers and research facilities at Stanford University and the Massachusetts Institute of Technology (MIT). Local firms also were aided by a readily available supply of electrical and computer engineers graduating from nearby schools. See Dorfman (1983), Rogers and Larsen (1984), and Saxenian (1996) for a review of the origins of the electronics industry in Silicon Valley and Route 128.

Table 1 shows how dramatic an effect new industries spawned from university research can have on a local economy. To tie in with government statistics available by county, Silicon Valley is represented by Santa Clara County and the electronics cluster in Massachusetts is represented by Middlesex County, which contains by far the highest percentage of electronics employment of any county in the state. The data in the table show how this one industry has profoundly shaped the economic structure of the two counties. In Santa Clara County, even a narrow definition of the industry which includes only electronic and computer manufacturing, computer services, and research and development services shows that computers and electronics accounted for more than 15 percent of county employment in 2004 — more than six times the share of the industry in national employment. Similarly, the industry in Middlesex County accounted for 10 percent of county employment, more than four times the national share.

Industries built on scientific advance not only provide growth in the local employment base but, since they employ a large number of highly skilled and educated workers, also serve to raise average earnings in the area. The electronics industry in Santa Clara County paid its employees nearly $100,000 per worker — helping the countywide average in earnings per worker 65 percent higher than the state average and 87 percent higher than the national average. Average earnings per worker in the Middlesex County electronics industry was nearly $93,000, helping to raise average earnings in the county 13 percent above the state average and 39 percent above the U.S. average.

Silicon Valley and Route 128 represent best-case scenarios of university research promoting local economic development. There are many examples of highly prestigious research universities that have had very little impact on the local economy. Feldman and Desrochers

TABLE 1
CHARACTERISTICS OF THE ELECTRONICS INDUSTRY IN 2004

	Silicon Valley (Santa Clara County, CA)	Route 128 (Middlesex County, MA)	United States
Electronics Employment	131,077	80,527	2,854,373
Electronics Employment as a Percentage of Total Private-Sector Employment	15.4%	10.2%	2.5%
Electronics Earnings per Worker	$99,879	$92,920	$68,434
Private-Sector Earnings per Worker	$69,107	$51,274	$36,967
Private-Sector Earnings per Worker in the State	$41,820	$45,389	-

Note: The electronics industry is defined as the sum of NAICS 334: Computer and Electronic Product Manufacturing (including semiconductors), NAICS 5415: Computer Systems Design and Related Services, and NAICS 5417: Scientific Research and Development Services.

Source: U.S. Census Bureau, County Business Patterns.

(2003), for example, document how and offer reasons for why Johns Hopkins University in Baltimore, Maryland, has had little impact on the regional economy despite a long history of substantial academic achievement. In a later section of the report, some of the complementary factors that may be necessary for university research to yield significant local economic development benefits are reviewed.

The Biotech Industry

Biotechnology offers the most recent example of an important new industry built directly on basic scientific research in which commercial firms are known to have close ties to university-based scientists. A single scientific moment defines the beginning of the industry—the 1973 discovery by Stanford professor Stanley Cohen and University of California-San Francisco professor Herbert Boyer of the basic technique for recombinant DNA. Techniques for genetic engineering would eventually become standardized, mechanized, and widely known. But for 15 years following the discovery, knowledge of

how to identify promising gene sequences and even the skills of gene transfer were held by a small group of discovering scientists and their co-workers. Knowledge of the techniques was difficult to transfer because of its complexity and tacitness. Commercial development required frequent face-to-face contact with discovering scientists. Since many of these scientists were academics who were unwilling to leave university appointments, their location often served to determine the location of commercial firms. The most successful biotech firms were those in which discovering scientists had a financial interest and were actively involved in bench-level scientific collaboration with industry scientists.

Zucker, Darby, and Brewer (1998) were among the first to systematically test for a geographic coincidence between new biotechnology firms and university scientists who made early contributions to gene sequencing. The geographic units in their study were the 183 functional economic areas defined by the U.S. Bureau of Economic Analysis. The authors first identified a set of 327 “star” scientists who were highly productive in discovering gene sequences, — each had discovered more than 40 gene sequences by 1990, as reported in *Genbank*. These star scientists represented only 0.75 percent of the authors in *GenBank*, but accounted for 17 percent of the published articles — 22 times the number of the average author. Zucker et al. found the location of star scientists who were active in gene sequencing research between 1976 and 1980 to be a powerful predictor of the geographic distribution of biotech firms in 1990.

Zucker et al. also checked to see whether the quality of local universities had a separate effect on the location of biotech firms. A university was considered to be of "top" quality if one or more of its departments of biochemistry, molecular biology, or microbiology received a reputational rating of 4.0 or higher in a 1982 National Research Council survey. There were 20 such universities in the United States. Local university quality proved to have a positive and significant effect on the location of biotech firms. Its inclusion only moderately diminished (by 20 percent) the numerical size of the coefficient for star scientists. As expected from the hypothesized scenario of how tacit knowledge transfer affected the evolution of the biotech industry, the location of individual star scientists was found to play an important role apart from the general quality of the university departments to which they belonged.

Audretsch and Stephan (1996) authored another early paper on links between biotech companies and pioneering scientists. Their analysis differs from that of Zucker et al. in that by examining the prospectuses of biotech companies that made an initial public offering (IPO) in the early 1990s, they were able to identify and determine the nature of specific affiliations between university-based scientists and biotech firms. Audretsch and Feldman found that relationships between scientists and firms are not always local, and the degree to which firms rely on local scientific talent varies. Approximately one-half of the university scientists who have affiliations with Boston-area biotech firms have appointments with Boston-area universities. Firms in San Diego and New York, on the other hand, draw only one-quarter of their university scientists from local universities. Audretsch and Feldman concluded that while geographic proximity between university scientists and biotech firms has been important, other factors, such as those related to agglomeration, have also played an important role in the siting of firms.

Audretsch and Stephan hypothesize and find support for the idea that whether a university-based scientist works locally or has a long-distance affiliation with a biotech firm depends on personal characteristics of the scientist and the nature of the services he provides to the firm. If the scientist is a star, in the sense that he has received a Nobel Prize, he is more likely to work with a local firm. Star scientists have more 'drawing power' which allows them to attract venture capitalists and other key members of high-tech, start-up companies. Audretsch and Feldman also found that local affiliations are most common when the service provided by the scientist is one of knowledge transfer. It is less important for a university scientist to live in the same area as the firm if his primary function is to signal the quality of the firm to the scientific and financial communities.

Zucker, Darby, and Armstrong (1998, 2002) argue that firm performance in new knowledge-based industries such as biotechnology depends on the extent to which discovering scientists are actively involved with the firm. They sharpen their review of gene-sequencing articles to focus on research articles co-authored by star scientists and firm scientists. The authors find that the presence of collaboration between star and firm scientists has a strong positive effect on firm performance, as measured either by employment growth or the number of products in development or on the market. Co-authorship, they argue, is a good indicator of tacit knowledge capture by the firm since collaboration will generally require a close bench-level working relationship between the scientists. Zucker et al. also found through telephone interviews that discovering scientists who collaborate with firm scientists are likely to be linked to the firm by contract or ownership.

University Licensing Income, Counts of Start-ups

One measure of the commercial value of academic research is income earned from the licensing of university-owned patents. Patent income at U.S. universities grew rapidly from around $200 million in 1991 to over $1.2 billion in 2000. Technologies most commonly represented in university patents are biotechnology, pharmaceuticals, and superconductors. Patent income is concentrated in a few academic fields. Medicine accounts for 55 percent of university licensing income. Engineering and physics together account for 24 percent of licensing income. [Graff et al. (2002)]

Authors of papers analyzing the commercial value of university patents liken the odds of success to that of winning a lottery. In the words of Graff et al. (p.111), “it is rare to make a commercial hit, but when it happens, it can often be a home run.” Examples of patents that have generated millions of dollars for their universities include the Cohen-Boyer technique for gene splicing (University of California and Stanford), Gatorade (University of Florida), Cisplatin (Michigan State), Fax technology (Iowa State), and Taxol (Florida State University). Most university patents, however, fail to earn enough revenue to cover the costs of filing them. Feldman et al. (2002, p.108) cite a rule of thumb among university technology transfer officials that the average yield for every 100 inventions disclosed by faculty is 10 patents and 1 commercially successful product.

The distribution of patent income across universities is highly skewed. The top 15 universities accounted for 65 percent of total university licensing income in 2000 (see Table 2). While there have been some spectacular successes, most universities do not earn significant income from their patent portfolios. Patent income represents less than 3 percent of total university revenues for 10 of the top 15 universities in Table 2 and less than 2 percent of revenues for six of the top universities.

Established companies that license a university’s technology may be located anywhere, even in other countries. Apart from the income that accrues to the university and its faculty, these licensing agreements may do little to support regional earnings and employment. Licensing agreements that result in new business formation, on the other hand, tend to be a local affair. Survey data for 1999 from the Association of University Technology Managers indicate that four-fifths of university-licensed technology start-ups are founded in the same state as the licensing institution [Di Gregorio and Shane (2002, p.210)]. Start-ups and small firms account for two-thirds of the businesses that enter into university licensing agreements [Graff et al. (2002, p.101)].

University patenting and licensing represents, of course, only one channel, and perhaps one of the least important channels, by which faculty research findings are transferred to industry. In summarizing results from the 1994 Carnegie Mellon survey, Cohen et al. (1998, p.180) report that only 10 percent of industrial R&D lab managers said that licensing agreements with universities were “moderately” or “very” important to their R&D activities. The most important channels of information transfer were publications (with 41 percent of respondents indicating

TABLE 2
PATENT INCOME IN 2000: TOP 15 UNIVERSITIES

	Patent Income (Millions of $)	Percentage of Total Revenues
University of California	$261.5	3.2%
Columbia University	138.6	7.2
Dartmouth College	68.4	17.2
Florida State University	67.5	11.3
Stanford University	34.6	2.5
University of Washington	30.2	1.4
Massachusetts Institute of Technology	30.2	2.8
University of Pennsylvania	26.5	0.8
University of Florida	26.3	2.0
Georgetown University	26.0	5.3
Michigan State University	25.7	2.0
California Institute of Technology	23.7	1.6
University of Wisconsin	22.8	1.2
University of Minnesota	22.7	1.3
State University of New York	16.5	0.8
Total of All Universities	1,263.0	
Average per University	6.7	

Source: Association of University Technology Managers Licensing Survey, Fiscal Year 2000, as reported by Graff et. al. (2002, p.110) and National Center for Education Statistics, IPEDS.

that publications were at least "moderately" important), informal channels (35 percent), public meetings and conferences (34 percent), consulting (32 percent), and contract research (21 percent). An important exception to these general findings, however, was the pharmaceutical industry where 35 percent of respondents considered licensing to be an important means of acquiring technology from universities.

In a paper that similarly concludes that university licensing is a relatively unimportant means of technology transfer, Agrawal and Henderson (2002) look at data from faculty interviews and research records from the Departments of Mechanical and Electrical Engineering at MIT. They find patenting to be a minor activity among faculty, accounting for less than 10 percent of the knowledge transferred from MIT labs. Far more important is the publishing of academic papers.

Technology that is transferred from universities through "open" sources such as publications and public conferences may not have strong local economic development effects, but instead may be used by firms operating anywhere in the world. However, other non-licensing channels such as consulting and contract research often do involve close working relationships between faculty and local firms. The prevalence of these forms of technology transfer is a reminder that statistics from university technology transfer offices are certain to underestimate the effects of university research on local entrepreneurship and job formation.

One report that provides a useful perspective on the variety of ways universities affect local business formation is an economic impact report prepared for Harvard University by Appleseed, Inc. (2004). The report notes that as of 2003, there were 14 companies in the Boston area, employing almost 1,000 people, that were built on technology licensed from Harvard. More significant, however, were companies created by faculty that do not involve university-licensed technology. The Harvard report gives an example of four such firms that together employ 4,500 people in the Boston area.

The greatest contribution a university makes to local entrepreneurship is its graduates. Appleseed, Inc. cites a sample of only 10 companies founded by Harvard graduates that employ approximately 7,000 people in the Boston area. In an earlier report for MIT, the Bank of Boston (1989) confirmed the existence of 198 companies, two-thirds of which were in the Boston area, that were started by MIT alumni between 1980 and 1988.

Analysis of Patent Citations

The case for linkages between university research and local economic development ultimately hinges on the argument that knowledge created at universities tends to stay in the local area. Adam Jaffee, Manuel Trajtenberg and their co-authors have a clever way of finding a "paper trail" with which to track invisible knowledge flows. Patent records contain highly detailed information on the identity and location of the inventor and references or citations to previous patents. The citations make it possible to study knowledge spillovers by tracing the links between inventors. The authors have assembled a massive database of more than 16 million citations made by patents granted between 1975 and 1999. A collection of papers using this database to analyze patent citations is available in Jaffee and Trajtenberg (2002).

Tests for local connections between patents must control for correlations that may be due simply to an existing concentration of economic activity in the same technological area as the patent. But after controlling for this effect, there is conclusive evidence of geographic localization of knowledge flows. In one particular analysis of patents originating in 1980 and their citations through 1989, Jaffee, Trajtenberg, and Henderson (1993) find that after excluding self-citations, the frequency that a university-owned patent is cited in the same metropolitan area as the university is 6 times higher than what would be expected given the existing distribution of technical activity. Overall, only 7 percent of university patent citations are local, but this number is highly significant on a statistical basis.

The existence of a local component to knowledge flows says nothing, however, about the channels for these flows. Does knowledge flow through informal and fluid networks, as in the well-known case of semiconductor workers in Silicon Valley. Or is it through formal market contracts? In the case of universities, for example, does knowledge flow through uncompensated channels such as seminars or the hiring of students, or is it through faculty start-ups or other contractual arrangements with faculty? Zucker, Darby, and Armstrong (1998, 2002) have found in their research on the biotech industry that most faculty connections to industry R&D are formal and market-driven. So there is no externality or uncompensated knowledge flow.

The work on patent citations constitutes a major strain in the empirical literature on knowledge spillovers. These papers provide empirical support not only for the contribution of university research to local economic development, but also for theories of agglomeration in economic geography and for theories of economic growth based on increasing returns.

Location of Corporate Innovation and R&D Labs

A number of authors have used econometric techniques to empirically test for a geographic coincidence between university research and corporate R&D activity. Industry labs directly promote local economic development by providing high-paying jobs for scientists and technical workers. They may also generate competitive advantages for local producers who make use of the innovations coming out of these labs.

Jaffe (1989) used state-level data covering 29 states and eight years from 1972-to-1981 to relate the number of patents assigned to corporations in a state to the quantity of industry R&D and university research in the state. Jaffee found a large and statistically significant effect of university research on corporate patent activity. His results indicate that the direct impact on corporate patenting per dollar of research expenditure is two-thirds as large for university research as it is for industry R&D. Jaffee found university research to have an even larger indirect effect on corporate patenting in that university research expenditures induce corporate R&D expenditures. His estimates suggest that the indirect effect of university research on corporate patents is six times as large as the direct effect.

Jaffee also analyzed data by technical area using the classifications available in U.S. patent data. The strongest links between university research and corporate patenting were found for drugs and medical technology. Jaffee found smaller but still significant effects in electronics, optics, and nuclear technology. The effects of university research on patents were statistically insignificant in the mechanical arts.

Anselin, Varga, and Acs (1997) use the same model as Jaffee to represent the relationships between corporate innovation, corporate R&D, and university research. Counts of innovation are measured, however, using data from the Small Business Administration (SBA) on the number of new high-technology products introduced into the U.S. market in 1982. The SBA data were compiled from an extensive review of new product announcements in trade and technical publications. Anselin et al. were able to sharpen the geographic focus of Jaffee's analysis by using professional employment in private high-tech research laboratories as a proxy for corporate R&D activity. The employment data were aggregated to the MSA level. Anselin et al. also were able to control for agglomeration economies by including in their regressions local high technology employment, a location quotient for high-tech employment, and local employment in business services. The final data set consisted of a cross section of 125 MSAs for which there were positive values for innovations, corporate R&D activity, and university research expenditures.

The findings of Anselin et al. generally confirm the earlier results of Jaffee, but for a finer level of geography. University research has a positive and significant effect on local corporate innovation, both directly and through its effect on private R&D activity. The inclusion of agglomeration variables significantly reduces the estimated coefficient for private R&D effort but has only a small effect on the coefficient for university research. Anselin et al. also tested to see whether the effects of corporate R&D and university research on corporate innovation extend beyond the metropolitan area. Spillovers from university research to corporate innovation were found for counties within 50 miles of the center of the innovating metro area. No such spillovers were found for private R&D. The effects of private R&D were confined to the metro area itself.

Bania, Calkins, and Dalenberg (1992) examine the role of university research and other factors in determining the geographic distribution of industry R&D activity. R&D activity is measured by the number of Ph.D.s working in industry labs. The geographic unit of analysis is the metropolitan area and the data are for 1986. Bania et al. find that university research expenditures have a statistically significant effect on R&D doctorate employment. The estimated effects are fairly small, however. A 10 percent increase in university research spending generates only a 0.4 percent increase in doctoral employment. One of the other variables included in the regression is the percentage of the population with four or more years of college. Thus, the measured contribution of university research to industry R&D activity may not include the potentially significant effect that research universities have on the education level of the local workforce. University research is only one of several variables identified as being important to the size of local industry R&D activity. Other significant variables include the share of the population that is college educated and the size and density of the metro area population.

Firm Start-ups

In a broad test of the effect of university research on local economic growth, Bania, Eberts, and Fogarty (1993) examined the number of start-ups of new manufacturing firms in 25 large metropolitan areas over the period from 1976 through 1978. Bania et al. try to explain firm births using an econometric model with both traditional business climate variables, such as labor costs and taxes, and variables relating to knowledge infrastructure, including university research expenditures and the percent of employed workers who are scientists or engineers. The authors found mixed evidence for the effect of university research on new company start-ups. University research had a positive and significant effect on new business formation in the electronics industry. But university research was statistically insignificant for instrument manufacturing and for four other manufacturing industries.

The authors conjectured that the reason their strongest findings were for electronics was because their period of study coincided with the emergence of the electronics industry. They offered these results as evidence supporting the theory that the local impacts of university research are greatest in newly emerging industries.

As in other econometric studies, Bania et al. were unable to identify the specific mechanisms through which universities influence local economic growth. Local firms may benefit from having research universities nearby by being able to hire graduates with human capital that embodies new research findings. Or perhaps local firms are able to tap into university research by hiring faculty as consultants, attending seminars, or utilizing university laboratories and research facilities.

Income and Employment Growth

In another high-level attempt to discern local economic impacts from universities, Beeson and Montgomery (1993) used Census Bureau data for 218 metropolitan areas to econometrically measure the contribution of university variables to a variety of measures of labor market activity, including average individual income in 1980 and employment growth over the periods from 1975 to 1980 and 1980 to 1989. University characteristics included in the regressions were university R&D funding, university quality (as measured by the number of highly rated science and engineering programs), the total number of bachelor's degrees awarded, and the percent of degrees awarded in science and engineering. The authors also included other variables that might affect the local labor markets such as weather, crime rates, taxes, and the size of the metro area population.

Beeson and Montgomery found that none of the university variables were statistically significant in explaining average income, at least in random effects models that allow for metro area-specific error components. The estimated coefficients also were small in value. The authors reported, for example, that university R&D spending that is one standard deviation above its mean value has the effect in their model of raising the average level of individual income by only 2 percent.

More significant relationships were found between university characteristics and metro area employment growth. For both time periods considered, the authors were able to reject the hypothesis of no relationship between university variables and the rate of employment growth. The estimated coefficients also were significant in size. Based on results for the 1975-80 period, a one standard deviation increase in university R&D funding is estimated to increase the average annual rate of employment growth from 3.15 to 3.51 percent. For the 1980-89 period, a doubling of the number of bachelor's degrees awarded (which is less than one standard deviation from the mean) has the effect of increasing average annual employment growth from 2.2 to 2.5 percent.

Goldstein and Renault (2004) use annual data on 312 metropolitan areas from 1968 through 1998 to test for the effect of universities on local economic development. Economic development is measured by an index that indicates whether and in what direction relative earnings in an area changed over time. The presence of a university was measured by whether there is a top-50 research university, the size of university R&D, the number of degrees awarded, and the number of patents assigned to universities within the MSA. Goldstein and Renault find that over the period from 1969 through 1986, universities had no effect on an area's relative earnings. However, the presence of universities did become significant in the 1986-98 period. The authors attributed this result to the often-cited claim that economic activity in the U.S. has become more knowledge-based over the past two decades.

Although university variables are statistically significant in the 1986-98 period, the strength of their effect on relative earnings is modest. Based on their estimated findings, the authors report that if universities in an average metro area increased their R&D spending by $10 million (about a 33 percent increase), this would only serve to raise the relative earnings index from 100.00 to 100.36.

Goldstein and Renault also find that university patenting plays no role in explaining local economic development once total university R&D activity is taken into account. The authors conclude that the channels through which university research affects local economic activity must be broader than patenting and licensing.

Conditioning Factors

Two universities with research programs that are similar in scale and quality may have very different local economic impacts. MIT and Harvard University have had huge documented effects on the Boston area economy. However, Johns Hopkins University, which is routinely among the largest recipients of federal government research funds, has failed to stimulate significant high-tech production in the Baltimore area. Stanford University and Duke University each had sponsored research expenditures of over $350 million in 1997. But Stanford generated 25 start-up businesses from university-licensed technology while Duke generated no start-ups [Di Gregorio and Shane (2003, p.209)]. Clearly, high research activity is not a sufficient condition for a university to have large impacts on jobs and incomes in the local economy. This section reviews what is known about other complementary factors that may need to be present if a university's research and its graduate programs are to generate significant local economic impacts.

Quality of University Research and Graduate Programs

There are several reasons to think that universities with the greatest local economic impacts are those with the highest quality research and graduate programs. First, as argued by Zucker, Darby, and Brewer (1998) and Darby and Zucker (2003), the most compelling reason for new firms to locate near universities is to facilitate tacit knowledge transfer from faculty who are on the cutting edge of scientific breakthroughs. In metamorphic scientific discoveries, knowledge is embodied in the intellectual capital of the discovering scientists and only can be transferred to industry through active working relationships with these scientists. It is only the leading-edge researchers in these metamorphic discoveries that have the power to determine firm location.

A second reason for why star academic researchers are the ones most likely to be successful in attracting new industry to an area is what Audretsch and Stephan (1996) refer to as "drawing power." University researchers with a national reputation or researchers from an eminent university serve as a signal of quality which helps to attract resources such as venture capital, management, and technical workers that are necessary to start up new companies.

Finally, Malecki (1987) argues that availability of science and engineering workers is an important determinant of the location of industrial R&D facilities. But he notes that firms are particular about the institutions they rely on for new researchers and that, especially among large firms, only the best graduate programs are an attracting factor. While top university researchers generally go hand in hand with top graduate programs, the locational attractiveness of universities as stressed by Malecki has more to do with graduate programs than with faculty research per se.

There is empirical support for the idea that the size of the impact of university research on the local economy depends on the quality of the university's faculty and graduate programs. The strongest evidence comes from the study of specific industries known to rely on university research for technical advance. In their study of the biotech industry, Zucker, Darby, and Brewer (1998) focused on academic "stars" who were highly productive in gene sequencing research. It was this small group of star performers who best predicted the geographic distribution of commercial biotech firms. Zucker et al. also found that the quality of academic departments especially relevant to the biotech industry (e.g., biochemistry, cellular biology, and microbiology) had a positive effect on the birth of commercial firms in an area, apart from the number of star researchers in those departments. In their own study of the biotech industry, Audretsch and Stephan (1996) found that university faculty who were involved with commercial biotech firms were more likely to be involved with local firms if they had won a Nobel Prize.

In an alternative test of the importance of university quality, Di Gregorio and Shane (2003) analyzed the number of new firms founded from university-assigned patents at 116 universities over the 1994-98 period. The dependent variable in their study relates to local economic activity since start-up firms who license university technology tend to locate in the same area as the licensing institution. Included among the explanatory variables was the intellectual eminence of the university, as measured by ratings of graduate schools as published in Gourman Reports. The intellectual eminence of a university was found to have a statistically and numerically significant effect on start-up activity. An increase in intellectual eminence of one standard deviation was associated with one additional start-up firm per year.

Authors have been less successful in finding local impacts from universities when analyzing data on overall income and employment in an area. For example, Beeson and Montgomery (1993) in their study of economic activity in metropolitan areas found that the quality of university science and engineering departments in an area had no effect on mean individual income in 1980. Program ratings did have a statistically significant effect on employment growth, but the estimated effects were small. Based on results for the 1975-80 period, the predicted effect of an SMSA having one additional science or engineering program rated in the top 20 nationwide was to increase average annual employment growth by less than 0.04 percentage points.

Areas of Research

Academic research that is most likely to have an impact on the local economy is research that directly influences industrial innovation. The Yale and Carnegie Mellon surveys reviewed earlier provide information useful in determining which industries are closest to university science and which academic fields are most important to industrial research. Two general conclusions emerge: (1) new industries are more reliant on university research than are mature industries, and (2) research in applied academic fields is more directly relevant to industrial innovation than is research in basic fields.

Which industries rely most heavily on science and university research for their technological advance? In the 1983 Yale survey, managers of industrial R&D departments were asked to rate the relevance of various fields of basic and applied science to technical advance in their line of business. Industries awarding the highest scores were pharmaceuticals, semiconductors, medical instruments, and petroleum refining. Industries for whom science was least relevant were motor vehicle parts, motors and generators, and industrial chemicals [Klevorick et al. (1995, p.195)]. The 1994 Carnegie Mellon survey asked industrial R&D managers about the percentage of their projects that over the previous three years had made use of university research findings. Industries identified in the survey as making the greatest use of university research were TV/radio, communication equipment, pharmaceuticals, semiconductors, and petroleum refining. Industries reporting relatively little use of university research findings included steel, textiles, motors and generators, car parts, and plastics [Cohen et al. (2002, p.9)]. Both surveys found that new, high-tech industries were more influenced by science and university research than were more mature industries.

An alternative way of arranging the survey findings is by academic field. In the Yale survey, R&D managers were asked to rate the relevance of university research in various fields (as opposed to science in general) to technical innovation in their industry. Areas receiving the highest ratings were applied fields such as computer science, materials science, and mechanical, electrical and chemical engineering. The two basic fields that received high ratings were biology and chemistry. This reflects the fact that much of the nation's agricultural and medical research is carried out in universities, and industries with technologies rooted in the biological sciences rely heavily on new scientific developments [Klevorick et al. (p.197)]. In the Carnegie Mellon survey, firms were asked to rate the importance to their own R&D of public research in various academic disciplines. Of the basic sciences, only chemistry was found to be broadly relevant to industrial R&D. Biology was highly important to the pharmaceutical industry, and physics was very important to semiconductors. But neither of these basic fields had a high overall rating. The fields with the most pervasive impact on industrial R&D were, as in the Yale survey, the applied fields, especially materials science and computer science.

Another source of information on the direct relevance of academic disciplines to industrial progress is university offices of technology transfer. In a recent survey of information from these offices, Graff et al. (2002, p.109) note that patenting and income from the licensing of university research are concentrated in just a few academic fields, namely biomedical, engineering, and software.

The academic fields noted above as being important to industrial progress were identified on the basis of the commercial relevance of university research. As mentioned previously, however, universities serve an equally important role in the process of technological change as trainers of young scientists and engineers for employment in industrial labs. The value and productivity of these workers is directly related to their knowledge of basic scientific principles and research methods—knowledge that is learned in both basic and applied fields of science. In the Yale survey, R&D managers gave significantly higher ratings to basic fields of science such as chemistry, physics, and mathematics when asked about the relevance of generic science to their operations, as opposed to current university research. Klevorick et al. (p.197) interpret these results to mean that the basic sciences are recognized as being important in influencing the general knowledge and techniques that industrial scientists and engineers bring to their jobs. When looking at universities as suppliers of skilled labor, it is important for universities to have high quality programs in both basic and applied sciences.

Agglomeration and Research Networks

Agglomeration economies are known to be an important factor in the production of knowledge. First, spatial concentration of research activity promotes the development of markets for specialized suppliers. A notable strength of the research complex in Silicon Valley, for example, is the availability of specialized firms that manufacture capital equipment, specialty chemicals, and other items necessary for the testing and development of semiconductors [Saxenian (1996)]. As another example, a concentration of biomedical research activity in an area helps to support a local market for law firms that specialize in intellectual property protection for biomedical technologies [Bania et al. (1992)]. Secondly, agglomeration in research activity facilitates the matching of jobs and workers in specialized labor markets for scientists and engineers. Finally, a spatial concentration of research workers promotes informal channels of knowledge transfer. Knowledge spillovers are considered to be another strength of the decentralized network of firms doing semiconductor research in Silicon Valley [Saxenian (1996)].

It stands to reason that university research will be more productive and more likely to influence local economic activity if it takes place in an area with a large existing concentration of research activity or high-tech production. Audretsch and Stephan (1996, p.645) provide evidence of this effect in their study of university-firm associations in the biotech industry. They find that for faculty located in the three regions with the highest number of university-firm relationships (San Francisco, Boston, and San Diego), 65 percent of their associations are with biotech firms in the same area. On the other hand, for faculty who reside in the next five largest regions (New York, Philadelphia, Maryland, Houston, and Dallas), only 28 percent of their associations are with local area firms. These data suggest that university faculty who collaborate with industry in commercial ventures are more likely to do so with local area firms if the industry has a significant local presence. Otherwise, faculty involvement will be long-distance. As noted by

Audretsch and Stephan (p.644), in firm location decisions, the benefits of proximity to university researchers to promote knowledge transfer always are being weighed against the advantages of agglomeration and being close to other firms and inputs.

In a case study of the Cleveland area, Fogarty and Sinha (1999) find that technology developed in local universities does not generate local jobs and incomes but instead is quickly diffused to Japan, California, and Texas. The authors attribute this to the fact that the Cleveland economy is heavily oriented toward mature industries and lacks the local research networks necessary to develop university technologies. Fogarty and Sinha measure the extent of local research networks by tracing the direct and indirect citations of university patents and calculating the tendency for subsequent innovations to be localized. Metropolitan areas with the strongest local R&D networks are San Francisco, New York, Boston, and Los Angeles. Areas with much weaker networks are Washington-Baltimore, Philadelphia, Chicago, Detroit, and Cleveland.

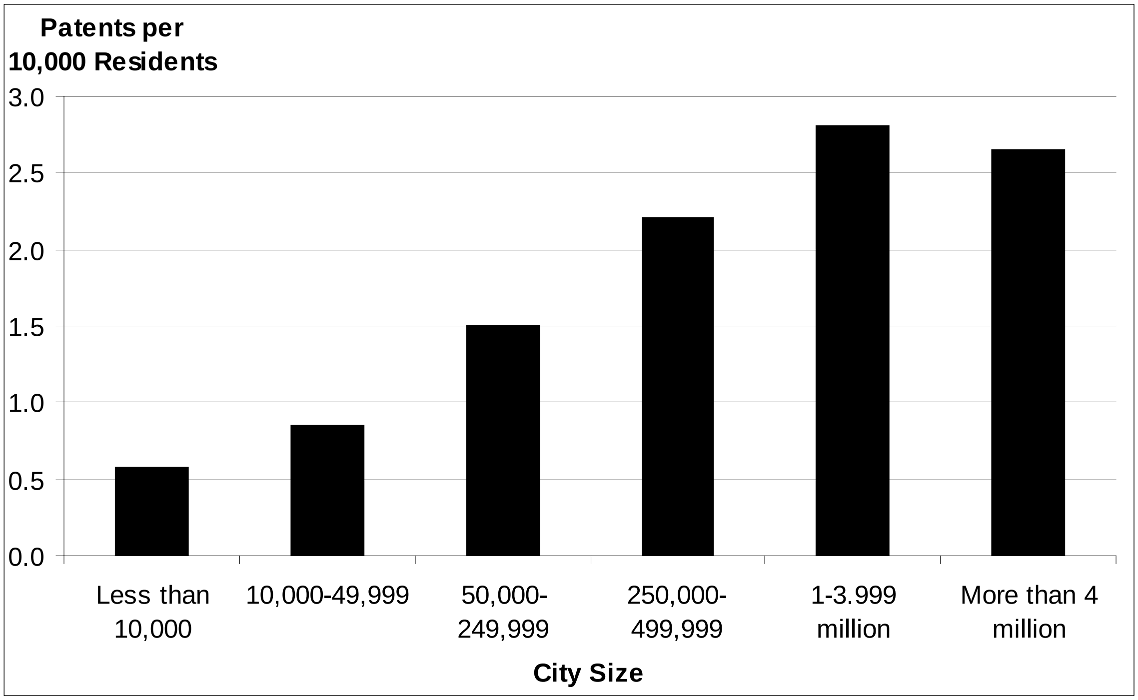
Varga (2000) provides an exacting test of the importance of agglomeration as a factor conditioning the size of the effect of university research on local innovative activity. He uses an econometric model to explain variations across metropolitan areas in counts of new product innovations made by the Small Business Administration for 1982. Agglomeration effects are identified using the amount of high-tech employment in a metro area. Using interactive variables, Varga finds that university research leads to a significant number of local area innovations only when high-tech employment is at least 160,000 workers.

Large Metropolitan Areas

Economic geographers have long recognized that innovative activity tends to concentrate in large cities. One of the reasons for this may be the agglomeration effects described above. Geographic concentration of an industry serves to reduce industry costs by allowing for the existence of specialized suppliers and by promoting knowledge spillovers between workers and firms in the same industry. In an alternative view, Jacobs (1969) argues that the most important knowledge spillovers are those that occur between different industries and that large urban areas are effective in promoting these kinds of spillovers because of the diversity of economic activity made possible in large cities. Finally, Malecki (1987) and Malecki and Bradbury (1992) argue that the siting of corporate R&D laboratories is increasingly guided by the locational preferences of the science and engineering workers who staff them and that city size is an important locational consideration for these workers. Large urban areas offer amenities that professional workers value, and they make it easier for spouses to find suitable employment. Malecki (1987, p.216) notes that city size has been found to be more important as a siting variable in high-tech studies than low taxes or low wages and argues that much of this has to do with the appeal that large cities have for professional and technical workers.

A positive relationship between innovation and city size is apparent in patent data. Chart 2 plots the average annual number of patents per 10,000 people during the 1990s against the size class of the city of residence of the inventor. Cities with 1 to 4 million people produced twice as many patents per person as did cities with a population between 50,000 and 250,000. New product innovations also are introduced disproportionately by firms in large metro areas. In the 1982 SBA data, for example, metro areas accounted for 96 percent of product innovations but only 30 percent of the population [Feldman and Audretsch (1999, p.415)].

CHART 2
PATENT PRODUCTIVITY AND CITY SIZE
Average Annual Patent Rate During 1990s



Source: Orlando and Verba (2005, p.34).

Whatever the forces at work, it may be difficult for university research to stimulate additional local innovative activity if the university is not located in a large urban area.

University Policy

Patenting and licensing of university research began to increase noticeably during the 1970s, buoyed by federal funding of biomedical research, the emergence of the biotechnology industry, and federal court rulings making it easier to secure biomedical patents [Mowery et al. (2001)]. This trend was further strengthened by the Bayh-Dole Act of 1980, which allowed universities to patent and license the results of federally funded research. Technology transfer offices (TTOs), whose mission is to facilitate the disclosure and licensing of university inventions, increased in number from 25 in 1980 to over 200 by the year 2000.

Over the past two decades, universities have devoted substantial resources to technology transfer—helping faculty to obtain patents on their research, negotiating licensing agreements, and providing assistance to new firms licensing the technology in the form of incubators, research parks, and in some cases seed capital. While the number of university patents has increased sharply, the financial returns from the licensing of these patents have been modest for most universities. A few faculty have enjoyed large royalty windfalls, but most faculty consider the financial rewards to be disappointing and less than what they could earn from consulting [Feldman et al. (2002, p.108)].

When Technology Transfer Office (TTO) directors are asked why the returns from university patenting and licensing have been disappointing, a common response is that faculty are generally disinterested in disclosing their inventions and they are not willing to take time away from research to develop their ideas into a commercially viable product. A survey conducted by Jensen and Thursby (2001), covering university licensing activities during the early-to-mid-1990s, found that only 12 percent of licensed university inventions were ready for commercial use at the time of the agreement. Over 75 percent of the inventions were no more than a "proof of concept." The authors argue that the commercial success of university inventions requires an ongoing involvement of faculty. Zucker, Darby, and Armstrong (1998, 2002) arrive at a similar conclusion in their study of the biotechnology industry. They find that new biotech firms were much more likely to be financially successful if university star scientists were directly involved through bench-level collaboration with industrial scientists.

Jensen and Thursby (2001) use the economic theory of incentives and contracts to prove that fixed-fee licensing agreements provide insufficient incentives for faculty to see an invention through to its commercial fruition. They show that an optimal licensing contract requires the use of equity agreements to tie the inventor's income to the performance of the licensing firm.

In fact, there has been a recent trend toward greater use of equity arrangements in the licensing of university inventions. In their survey of TTOs, Feldman et al. (2002, p.106) found that 70 percent of their respondents had entered into at least one equity agreement by 2000. Equity was originally thought of as a last resort means of encouraging cash-poor start-up firms to license university technology. Interviews with TTO officers suggest that university officials now have a broader view of the advantages of equity arrangements. First, equity is seen to allow the university to share in the fortunes of the firm rather than just the licensed technology. The licensed invention itself may never develop into a commercially successful product. But the technology may, nonetheless, provide knowledge that enables the firm to develop other useful products. Second, equity arrangements are seen to better align the interests of the firm with those of the university. Both interests are served by a successful development of the licensed technology and by the overall profitability of the firm. Finally, licensing firms believe that university equity positions enhance their own credibility, conferring a kind of halo effect that may enable them to more easily secure venture capital financing. [Feldman et al. (2002)]

One particularly useful empirical study of the relative strengths of various university licensing policies is by Di Gregorio and Shane (2003). They use an econometric model to explain differences across institutions in the number of Technology Licensing Office (TLO) start-ups. After controlling for the number of university patents and other variables, including the intellectual eminence of the university, Di Gregorio and Shane find that two sets of licensing policies appear to influence start-up activity: whether or not the university is permitted to take an equity position in the company and the share of licensing royalties distributed to inventors. Universities that can take an equity stake exhibit a start-up rate that is 1.7 times that of universities that cannot. The percentage of royalties distributed to inventors was found to be inversely related to start-up activity. This presumably reflects the fact that inventors who receive a large royalty share if the invention is licensed to an existing firm have little reason to start a new venture. The empirical findings suggest that an increase of 10 percentage points in the inventor's share of royalties reduces the number of start-up firms by 20 percent. Two other university policy variables considered by Di Gregorio and Shane did not have statistically significant effects on start-up activity: the presence of university incubators and whether the university is allowed to make venture capital investments.

Venture Capital

Venture capitalists often play an important role in the start-up of science-based companies. Venture capitalists not only provide risk capital, but they also help to connect company entrepreneurs with management teams, key technical employees, suppliers, and customers. Unlike other financial markets, venture capital markets tend to be local. Because of the uncertainty associated with new inventions and information asymmetries between entrepreneurs and venture capitalists, it is important for venture capitalists to closely monitor their investments. Geographical proximity helps to reduce the costs of monitoring. Also, the network of contacts that venture capitalists provide to firms is more easily maintained in a local geographic area. [Di Gregorio and Shane (2003)]

Availability of venture capital then would seem to be an important conditioning factor when assessing the potential impact of university research on local business activity. While there is much empirical support for the idea that venture capitalists impose geographical constraints on new high-tech businesses, there is also evidence that venture capitalists can be drawn to a new area if that area is home to a star scientist or an eminent research program. Zucker, Darby, and Brewer (1998) found that availability of venture capital had no significant effect on the location of new biotech firms once they had accounted for the geographic distribution of star scientists and highly rated science departments. They argue that since venture capital firms have located around great universities, a failure to account for the drawing power of the university, its faculty and students has led to an overestimation of the importance of venture capitalists. Di Gregorio and Shane (2003) also found that availability of venture capital had no effect on TLO start-ups. Among the control variables in their study was the intellectual eminence of the university.

How Does the Phoenix Metropolitan Area Rate?

The evidence presented in the previous section suggests that university research is most likely to have significant local economic development impacts when several conditions are present simultaneously — e.g., the university has highly rated faculty and graduate programs in fields most directly related to high-tech industry, and it is located in a large metropolitan area with an existing concentration of industrial labs and high-tech manufacturers. This section compares the top 25 U.S. metropolitan statistical areas, including Phoenix-Mesa-Scottsdale, in terms of the amount of local university R&D spending, the quality of local university science and engineering departments and, as a measure of agglomeration, the number of non-university scientists and engineers working in the local area. In general, the data show that Phoenix rates highly among U.S. metro areas in all categories related to engineering—university R&D spending in engineering fields, the quality of local area engineering departments, and the number of non-university engineers who work in the area. However, Phoenix has only a small amount of life science research activity at the present time. Working against the city in this regard is the fact that the state's medical school is located in Tucson.

University research is more likely to have local economic impacts if the university is situated in a large urban area. Large cities help to promote knowledge spillovers and the development of markets for specialized workers and suppliers. Also, science and engineering workers are thought to place a high value on the amenities of big cities. Table 3 identifies the U.S. metro areas with the greatest university research effort. University R&D is calculated for each of the 25

TABLE 3
UNIVERSITY RESEARCH AND DEVELOPMENT
IN THE 25 LARGEST METROPOLITAN AREAS IN 2003
Per Capita R&D and Rank

	Total		Life Sciences		Engineering	
Baltimore MD	$470	1	$324	1	$148	1
San Francisco CA	236	2	197	2	37	4
Pittsburgh PA	169	3	147	5	22	6
Seattle WA	169	3	151	4	18	7
St. Louis MO	156	5	156	3	0	17
Boston MA	149	6	105	9	44	3
Houston TX	147	7	147	5	0	17
Minneapolis MN	137	8	121	7	16	8
San Diego CA	135	9	112	8	23	5
Atlanta GA	117	10	66	15	51	2
Cincinnati OH	117	10	103	10	16	8
Cleveland OH	101	12	87	11	14	11
Philadelphia PA	84	13	78	13	6	14
Portland OR	82	14	82	12	0	17
Los Angeles CA	77	15	65	17	12	13
Chicago IL	72	16	66	15	6	14
New York NY	71	17	67	14	4	16
Dallas TX	49	18	49	18	0	17
Detroit MI	38	19	38	19	0	17
Washington DC	16	20	0	20	16	8
Phoenix AZ	14	21	0	20	14	11
Denver CO	0	22	0	20	0	17
Miami FL	0	22	0	20	0	17
Riverside CA	0	22	0	20	0	17
Tampa FL	0	22	0	20	0	17

Note: The expenditures reported are based on each category's top 60 universities and colleges, as ranked by 2003 R&D spending.

Source: National Science Foundation.

largest metropolitan statistical areas using 2003 data from the National Science Foundation on R&D spending in the life sciences and engineering by the top 60 universities and colleges. Life sciences include biology, medical science, and agricultural science. The metro areas are rank ordered in the table by total science and engineering R&D per capita.

The Phoenix metro area shows no university research spending in the life sciences. This is because Arizona State University — the metro area's only major research university — does not place among the nation's top 60 institutions in life science research spending. The Phoenix area does rank tied for 11th, however, in R&D spending in engineering. In 2003, a total of $52 million was spent on engineering R&D by ASU Main. When compared against national totals, ASU's R&D spending is especially strong in biomedical engineering and civil engineering.

Industrial labs and high-tech start-ups are more likely to locate near a university if faculty are leading contributors to new research areas with great commercial potential and/or if the university has a top-notch graduate program. Table 4 ranks the largest U.S. metro areas by the quality of their university life science and engineering departments. Quality is measured using ratings from the highly regarded 1995 National Research Council study of research-doctorate programs in the United States. A new survey will be administered in 2006 with findings scheduled to be available beginning late in 2007. Arizona State University does not have any life science departments that are rated among the country's top 40. However, ASU does have three engineering programs that are rated in the top 40. These are materials science (rated 27th), electrical engineering (tied for 36th), and mechanical engineering (tied for 36th).

Agglomeration economies are important in the production of knowledge and can be a critical factor in the location decisions of high-tech firms. One way to measure the scale of existing innovative activity in a metro area is by the number of science and engineering workers employed outside of colleges and universities. These figures are shown in Table 5. Phoenix ranks

TABLE 4
QUALITY OF LIFE SCIENCES AND ENGINEERING DEPARTMENTS IN UNIVERSITIES IN THE 25 LARGEST METROPOLITAN AREAS IN 1993
Number of Departments

	Total		**Life Sciences**		**Engineering**	
	Top 20	Top 40	Top 20	Top 40	Top 20	Top 40
Los Angeles CA	15	19	8	10	7	9
Boston MA	14	17	10	13	4	4
New York NY	11	22	9	17	2	5
San Francisco CA	11	11	7	7	4	4
San Diego CA	7	7	5	5	2	2
Philadelphia PA	6	9	4	5	2	4
Seattle WA	6	8	5	5	1	3
Houston TX	5	14	4	7	1	7
Chicago IL	5	13	2	9	3	4
Baltimore MD	5	8	5	5	0	3
Minneapolis MN	4	8	0	4	4	4
Pittsburgh PA	4	5	0	1	4	4
Atlanta GA	3	6	1	3	2	3
St. Louis MO	3	5	3	3	0	2
Cleveland OH	3	4	1	2	2	2
Dallas TX	3	3	3	3	0	0
Washington DC	1	3	0	1	1	2
Phoenix AZ	0	3	0	3	0	3
Miami FL	0	1	0	1	0	0
Cincinnati OH	0	0	0	0	0	0
Denver CO	0	0	0	0	0	0
Detroit MI	0	0	0	0	0	0
Portland OR	0	0	0	0	0	0
Riverside CA	0	0	0	0	0	0
Tampa FL	0	0	0	0	0	0

Note: Life sciences departments are biochemistry, cellular biology, neuroscience, pharmacology and physiology; engineering departments are chemical, electrical, mechanical and materials science.

Source: National Academy of Sciences, *Research-Doctorate Programs in the United States: Continuity and Change*, Appendices K and N.

TABLE 5
SCIENCE AND ENGINEERING WORKERS IN THE 25 LARGEST METROPOLITAN AREAS
Number of Workers in 2005 per 1,000 Residents and Rank

	Total		Scientists		Engineers	
Washington DC	12.96	1	4.53	1	8.43	2
Boston MA	12.80	2	3.03	4	9.76	1
San Diego CA	9.78	3	3.15	3	6.63	6
San Francisco CA	9.07	4	3.24	2	5.83	9
Denver CO	9.03	5	2.00	7	7.03	5
Houston TX	8.88	6	1.67	10	7.21	4
Detroit MI	8.19	7	0.47	25	7.72	3
Minneapolis MN	8.11	8	2.21	5	5.89	8
Pittsburgh PA	7.48	9	2.08	6	5.40	11
Seattle WA	7.02	10	1.80	9	5.22	13
Dallas TX	6.65	11	0.75	21	5.90	7
Baltimore MD	6.57	12	1.87	8	4.69	15
Portland OR	6.51	13	1.18	15	5.32	12
Phoenix AZ	6.24	14	0.57	24	5.67	10
Cleveland OH	5.77	15	0.76	20	5.01	14
Cincinnati OH	5.73	16	1.29	12	4.44	16
Philadelphia PA	5.56	17	1.22	14	4.34	18
Los Angeles CA	5.35	18	0.96	18	4.39	17
Chicago IL	5.21	19	0.98	17	4.23	19
Atlanta GA	4.68	20	0.99	16	3.70	20
St. Louis MO	4.47	21	1.26	13	3.21	21
New York NY	3.73	22	1.31	11	2.42	23
Tampa FL	3.45	23	0.83	19	2.62	22
Miami FL	3.10	24	0.68	23	2.41	24
Riverside CA	2.44	25	0.73	22	1.71	25

Note: Workers classified as scientists are those in BLS occupational codes 191 and 192; engineers are code 172.

Source: U.S. Bureau of Labor Statistics (2005 employment) and U.S. Census Bureau (2004 population).

10th in terms of number of engineers employed per capita. This is not surprising given the well-known importance of electronics firms in the area. Phoenix has very little science-based research activity, however, ranking 24th per capita. Phoenix employs only 2,100 life and physical science workers.

Although the evidence is mixed, availability of venture capital is widely considered to be a potential constraint on innovation-based business in a local economy. Universities located in cities without a significant number of venture capital firms may find it more difficult than otherwise to generate local economic activity from their research. Table 6 shows recent information on venture capital funding in several regions of the U.S., including the state of Arizona. Silicon Valley absorbs a staggering one-third of U.S. venture capital. Another region that stands out is the Boston area, accounting for 13 percent of U.S. venture capital. Other regions accounting for more than 5 percent of the national total are the New York metro area, the state of Texas, and the Los Angeles-Orange County area.

TABLE 6
VENTURE CAPITAL FUNDING FOR SELECTED REGIONS
Average Annual Data for 2001 through 2005

	Total (millions of $)	Share of U.S. Total	Number of Deals
Silicon Valley	$2,130	33.6%	231
New England	845	13.3	113
NY Metro	502	7.9	61
Texas	374	5.9	49
LA/Orange County	347	5.5	43
DE/Metroplex	298	4.7	49
San Diego	276	4.4	32
Philadelphia Metro	179	2.8	24
Colorado	175	2.8	21
Arizona	35	0.6	6
All Other Regions	1,169	18.5	196
United States	6,330	100.0	825

Source: PricewaterhouseCooper and National Venture Capital Association, Money Tree Report.

The state of Arizona absorbs only 0.6 percent of U.S. venture capital funds. Colorado, a state that is comparable in size to Arizona, receives five times the amount of venture capital that Arizona does. Scarcity of venture capital may be an impediment to university-driven economic development in Arizona. But evidence from other regions suggests that this bottleneck can be overcome if universities and their faculty have enough of a national reputation to attract venture capital from outside the local area.

Concluding Remarks

Several warnings have been issued by Irwin Feller (1990, 2004), Richard Florida (1999) and others that are pertinent and well supported by the arguments and studies reviewed in this paper. First, while there is abundant evidence that university research can have important effects on jobs and incomes in the local economy, the size of these local impacts is likely to be modest for most universities. For university research to significantly affect the local economy requires a coincidence of special conditions that is difficult to create. Second, because of the long reach of science, most of the economic benefits of academic research, certainly the long-term benefits, accrue to individuals who live outside of the local community. Effective support of university research requires a heavy dose of federal funding, not just state funding. Finally, while research is an integral part of what goes on at American universities, and a necessary complement to graduate instruction, it is wise not to lose sight of the role universities play as educators of industrial scientists, engineers, and entrepreneurs. Private-sector firms, who carry out most of the innovative effort in the country, rely on universities more as a source of professional workers than a source of new industrial technology.

Silicon Valley and Route 128 are spectacular success stories of how university research findings can create new industries and raise average incomes in the local economy. But large windfalls from research that accrue either to the university, its faculty, or local businesses are rare events. Studies that have tried to find a systematic effect of university research on local economic activity have found results that meet the standards of statistical significance but that are modest in size. University research is most likely to generate large local economic impacts when faculty are on the cutting-edge of revolutionary commercial technologies, when graduate programs in science and engineering are top notch, and when the university is located in a large urban area with an existing concentration of industrial R&D and high-tech production. These conditions are difficult to replicate.

This paper has focused on economic impacts from university research that are realized in the local economy. But many of the benefits from university research accrue to individuals who live well beyond the city in which the university is located. In cases where firms can directly incorporate university research findings into new products, agglomeration economies may make it more economical to implement these ideas away from the university, even though this makes the process of knowledge transfer more cumbersome. Scholars also argue that some of the greatest benefits of university research, especially basic research, are long term in nature. The paths from original scientific discovery to industrial innovation are complex. New knowledge crosses disciplinary boundaries, industry boundaries, and most certainly geographic boundaries. With such a large share of the benefits of university research accruing to producers and consumers located outside of the local economy, research will be grossly underfunded if it is done so simply on the basis of benefits that local residents will receive.

Finally, it should be recalled that most inventive activity is carried out in industry. In doing their research, industrial scientists use old science as much as they use recent scientific discoveries. They rely on basic science as a stock of knowledge and a set of tools useful for solving specific commercial problems. From this perspective, the most important contribution universities make to technical advance in industry is in the training of industrial scientists and engineers. Surveys of industrial R&D managers indicate that industry interest in most academic departments is focused primarily on the ability of professors to train students in basic theory and research methods [Nelson (1986)]. As noted by Feller (2004), one of the policy risks in today's environment is that state appropriations targeted to niche technology areas for purposes of local economic development will substitute for and contribute to a general erosion of education and basic research.

REFERENCES

A. Agrawal and R. Henderson, “Putting Patents in Context: Exploring Knowledge Transfer from MIT,” *Management Science* 48 (2002), pp.44-60.

L. Anselin, A. Varga, and Z. Acs, “Local Geographic Spillovers between University Research and High Technology Innovations,” *Journal of Urban Economics* 42 (1997), pp.422-48.

Appleseed, Inc., “Innovation and Opportunity: Harvard University’s Impact on the Boston Area Economy,” Nov. 2004.

D. Audretsch and P. Stephan, “Company-Scientist Locational Links: The Case of Biotechnology,” *American Economic Review* 86 (1996), pp.641-52.

N. Bania, L. Calkins, and D. Dalenberg, “The Effects of Regional Science and Technology Policy on the Geographic Distribution of Industrial R&D Laboratories,” *Journal of Regional Science* 32 (1992), pp.209-28.

N. Bania, R. Eberts, and M. Fogarty, “Universities and the Startup of New Companies: Can We Generalize from Route 128 and Silicon Valley?” *Review of Economics and Statistics* 75 (1993), pp.761-6.

Bank of Boston. *MIT: Growing Business for the Future* (Economics Department, Bank of Boston, 1989).

P. Beeson and E. Montgomery, “The Effects of Colleges and Universities on Local Labor Markets,” *Review of Economics and Statistics* 75 (1993), pp.753-61.

J. Bound et al., “Trade in University Training: Cross-State Variation in the Production and Stock of College-Educated Labor,” *Journal of Econometrics* 121 (2004), pp.143-73.

W. Cohen, R. Florida, L. Randazzese, and J. Walsh, “Industry and the Academy: Uneasy Partners in the Cause of Technological Advance,” in R. Noll (ed.) *Challenges to Research Universities* (Brookings Institution, 1998).

W. Cohen, R. Nelson, and J. Walsh, “Links and Impacts: The Influence of Public Research on Industrial R&D,” *Management Science* 48 (2002), pp.1-23.

M. Darby and L. Zucker, “Growing by Leaps and Inches: Creative Destruction, Real Cost Reduction, and Inching Up,” *Economic Inquiry* 41 (2003), pp.1-19.

D. Di Gregorio and S. Shane, “Why Do Some Unversities Generate More Start-Ups than Others?” *Research Policy* 32 (2003), pp.209-27.

N. Dorfman, “Route 128: The Development of a Regional High Technology Economy,” *Research Policy* 12 (1983), pp.299-316.

M. Feldman and D. Audretsch, “Innovation in Cities: Science-Based Diversity, Specialization, and Localized Competition,” *Europena Economic Review* 43 (1999), pp.409-29.

M. Feldman and P. Desrochers, “Research Universities and Local Economic Development: Lessons from the History of the Johns Hopkins University,” *Industry and Innovation* 10 (2003), pp.5-24.

M. Feldman, I. Feller, J. Bercovitz, and R. Burton, “Equity and the Technology Transfer Stategies of American Research Universities,” *Management Science* 48 (2002), pp.105-21.

I. Feller, “Universities as Engines of R&D-Based Economic Growth: They Think They Can,” *Research Policy* 19 (1990), pp.335-48.

I. Feller, “S&T-Based Economic Development and the University,” *Economic Development Quarterly* 18 (2004), pp.138-50.

R. Florida, “The Role of the University: Leveraging Talent, Not Technology,” *Issues in Science and Technology* (1999), pp.67-73.

R. Florida and W. Cohen, “Engine or Infrastructure? The University Role in Economic Development,” in L. Branscomb et al. (eds.) *Industrializing Knowldege: University-Industry Linkages in Japan and the United States* (The MIT Press, 1999), pp.589-610.

M. Fogarty and A. Sinha, “Why Older Regions Can’t Generalize from Route 128 and Silicon Valley: University-Industry Relationships and Regional Innovation Systems,” in L. Branscomb et al. (eds.) *Industrializing Knowledge: University-Industry Linkages in Japan and the United States* (The MIT Press, 1999), pp.473-509.

C. Goldin and L. Katz, “The Shaping of Higher Education: The Formative Years in the United States, 1890 to 1940,” *Journal of Economic Perspectives* 13 (1999), pp.37-62.

H. Goldstein and C. Renault, “Contributions of Universities to Regional Economic Development: A Quasi-Experimental Approach,” *Regional Studies* 38 (2004), pp.733-46.

G. Graff, A. Heiman, and D. Zilberman, “University Research and Offices of Technology Transfer,” *California Management Review* 45 (2002), pp.88-115.

K. Hill, “Universities in the U.S. National Innovation System,” Center for Competitiveness and Prosperity Research, Arizona State University, March 2006.

K. Hill, D. Hoffman, and T. Rex, “The Value of Higher Education: Individual and Societal Benefits,” Center for Competitiveness and Prosperity Research, Arizona State University, October 2005.

J. Jacobs. *The Economy of Cities* (Random House, 1969).

A. Jaffe, “Real Effects of Academic Research,” *American Economic Review* 79 (1989), pp.957-70.

A. Jaffe, M. Trajtenberg, and R. Henderson, “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations,” *Quarterly Journal of Economics* 108 (1993), pp.577-98.

A. Jaffee and M. Trajtenberg. *Patents, Citations, and Innovations: A Window on the Knowledge Economy* (The MIT Press, 2002).

R. Jensen and M. Thursby, “Proofs and Prototypes for Sale: The Licensing of University Inventions,” *American Economic Review* 91 (2001), pp.240-59.

A. Klevorick, R. Levin, R. Nelson, and S. Winter, “On the Sources and Significance of Interindustry Differences in Technological Opportunities,” *Research Policy* 24 (1995), pp.185-205.

E. Malecki, “The R&D Location Decision of the Firm and “Creative’ Regions—A Survey,” *Technovation* 6 (1987), pp.205-222.

E. Malecki and S. Bradbury, “R&D Facilities and Professional Labour: Labour Force Dynamics in High Technology,” *Regional Studies* 26 (1992), pp.123-35.

E. Mansfield, “Academic Research and Industrial Innovation,” *Research Policy* 20 (1991), pp.1-12.

D. Mowery, R. Nelson, B. Sampat, and A. Ziedonis, “The Growth of Univesity Patenting and Licensing by U.S. Universities: An Assessment of the Effects of the Bayh-Dole Act,” *Research Policy* 30 (2001), pp.99-119.

D. Mowery and A. Ziedonis, “Academic Patent Quality and Quantity Before and After the Bayh-Dole Act in the United States,” *Research Policy* 31 (2002), pp.399-418.

R. Nelson, “Institutions Supporting Technical Advance in Industry,” *American Economic Review* 76 (1986), pp.186-9.

M. Orlando and M. Verba, “Do Only Big Cities Innovate? Technological Maturity and the Location of Innovation,” Federal Reserve Bank of Kansas City *Economic Review*, 2nd Quarter 2005, pp.31-57.

E. Rogers and J. Larsen. *Silicon Valley Fever: Growth of a High-Technology Culture* (Basic Books, 1984).

N. Rosenberg and R. Nelson, “American Universities and Technical Advance in Industry,” *Research Policy* 23 (1994), pp.323-48.

A. Saxenian. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Harvard University Press, 1996).

U.S. Patent and Trademark Office, “U.S. Colleges and Universities: Utility Patent Grants 1969-2003,” September 2004.

A. Varga, “Local Academic Knowledge Transfers and the Concentration of Economic Activity,” *Journal of Regional Science* 40 (2000), pp.289-309.

L. Zucker, M. Darby, and M. Brewer, “Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises,” *American Economic Review* 88 (1998), pp.290-306.

L. Zucker, M. Darby, and J. Armstrong, “Geographically Localized Knowledge: Spillovers or Markets?” *Economic Inquiry* 36 (1998), pp.65-86.

L. Zucker, M. Darby, and J. Armstrong, “Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology,” *Management Science* 48 (2002), pp.138-53.

THE PRODUCTIVITY AND PROSPERITY PROJECT

The Productivity and Prosperity Project: An Analysis of Economic Competitiveness (P3) is an ongoing initiative begun in 2005, sponsored by Arizona State University President Michael M. Crow. P3 analyses incorporate literature reviews, existing empirical evidence, and economic and econometric analyses.

Enhancing productivity is the primary means of attaining economic prosperity. Productive individuals and businesses are the most competitive and prosperous. Competitive regions attract and retain these productive workers and businesses, resulting in strong economic growth and high standards of living. An overarching objective of P3's work is to examine competitiveness from the perspective of an individual, a business, a region, and a country.

THE CENTER FOR COMPETITIVENESS AND PROSPERITY RESEARCH

The Center for Competitiveness and Prosperity Research is a research unit of the L. William Seidman Research Institute in the W. P. Carey School of Business, specializing in applied economic and demographic research with a geographic emphasis on Arizona and the metropolitan Phoenix area. The Center conducts research projects under sponsorship of private businesses, nonprofit organizations, government entities and other ASU units. In particular, the Center administers both the Productivity and Prosperity Project, and the Office of the University Economist.

CENTER FOR COMPETITIVENESS AND PROSPERITY RESEARCH
L. WILLIAM SEIDMAN RESEARCH INSTITUTE
W. P. CAREY SCHOOL OF BUSINESS
AT ARIZONA STATE UNIVERITY

P. O. Box 874011 – Tempe, AZ 85287-4011
Phone (480) 965-5362 – FAX (480) 965-5458
wpcarey.asu.edu/research/competitiveness-prosperity-research

ASU W. P. CAREY SCHOOL of BUSINESS
ARIZONA STATE UNIVERSITY
wpcarey.asu.edu

P3 | PRODUCTIVITY AND PROSPERITY PROJECT
economist.asu.edu