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PLACE MATTERS

Innovation Springs from Many Seeds, But Soil Is Equally Important

By Maryann Feldman

Economic restructuring over the past several decades has taken a toll on many places in America. The "new" economy has benefited certain regions while the economic standing of other places has slipped precariously. Globalization has not brought the promised benefits to everyone. Many communities are struggling to secure future prosperity, increase their standards of living, or more modestly maintain simple economic viability. The auto industry in Detroit exemplifies the interconnection between industry and community, the viability of individual companies and the fortunes of places—and the uncertainty that results when companies and industries are not innovative.

Many places search for a recipe for future prosperity, seeking to understand what the appropriate action is and what investments will yield the types of increasing returns that provide for economic growth. The key ingredients are a combination of entrepreneurs—individuals who see opportunity and go after it, and other individuals who are willing to invest in entrepreneurs' ideas with their money or their labor. Organizing these ingredients successfully has proven elusive. Many places struggle to define an economic future, despite the advice of highly paid consultants and the willing participation of state and local government, local institutions of higher education, and others.

This essay will provide four simple facts about technology-based economic development, and it should certainly not be considered the final word. These simple facts:

- Economic growth is local, complex, and beyond anyone's control
- Planning for the future is uncertain
- The role of universities is changing
- Innovation economies require preparation

CLARIFYING THE TERMS OF SCIENCE, TECHNOLOGY, AND INNOVATION

When an issue is significant, the popular discussion may easily become muddled. Terms may be used interchangeably and without precision, resulting in superficial debate. To avoid this carelessness, a series of definitions that discriminate between the components of science, technology, and innovation are in order to advance the discussion and enrich the policy options.

In daily conversation, terms such as invention and innovation, as well as science and technology, among others, are often used interchangeably. But for academics and policy makers, there are important distinctions among these terms, and these distinctions give each term a unique meaning and enrich the discussion. Invention is about discovery and the creation of something novel that did not exist previously. Innovation carried invention further with the commercial realization of the value of the invention or the receipt of an economic return. This is a subtle but important distinction. A patent, for example, provides legal protection of an idea and reveals an invention, while the marketing and consumer acceptance of a new drug are evidence of an innovation.

Science, in a broad sense, is the unfettered search for knowledge for the sake of understanding. That search is based on observed facts that may be replicated through experimentation or theory. Thus science begins with conventional preliminary conditions and searches for some unknown results to address fundamental questions related to hypotheses about the world. The process of investigation is known broadly as research and may be basic (with the intention of advancing science) or applied (with an orientation toward some practical end). These delineations are two ends of a continuum of problem solving, as basic research suggests avenues of inquiry that are advanced by applied research.

Similarly, **research** is enriched as applied work creates the need for more theoretical work and suggests new avenues for further basic research. In addition, and most critically, while science is classified by disciplines that define traditions of inquiry, and scientists are trained within these specific traditions, applied problem solving frequently creates the need for multidisciplinary teams or even creates new disciplines to colonize the frontiers of knowledge. Examples include the rapidly evolving fields of biochemistry and biomedical engineering or the emerging fields of nanotechnology in the physical sciences and genomics and proteomics in the life sciences.

In contrast, **industrial research and development** is the systematic augmentation or deepening of knowledge by applying it to some practical problem or new context with the idea of generating a commercial return. While science is typically conducted by universities and institutes of higher learning, R&D is typically conducted by private companies. An important distinction is that both public and private companies have a responsibility to earn returns for their shareholders and investors. In general, the more basic the science involved in a research project, the more difficult it is to earn the necessary returns. This is due to particular characteristics of the knowledge that research creates.

A variety of government incentives and public-private partnership programs have evolved over time from governments' desire to steer private investment toward more basic types of scientific activity, and to stimulate the development of new technologies that private companies would not consider attractive investments in the absence of some incentives. These incentives include direct grants, R&D subsidies, and other programs that encourage firms to conduct projects with universities or government laboratories.

A similar distinction may be made with regard to education and training. **Training** is task oriented and conforms to a set of skills, techniques, and practices. Typically, training is oriented to a job, occupation, or profession. While professional education is typically at a high level and its graduates command high salaries, curriculum has the well-defined outcome of conveying well-codified practices, such as being able to read financial statements in the case of business, being able to drill teeth in the case of dentistry, and being able to conduct and interpret a patient history in the case of medicine. Education has a broader goal of expanding knowledge and providing the capacity to create new knowledge.

Knowledge has the characteristics of being nonrival, and nonexcludable, which classifies knowledge as a public good. Nonrival, in the economists' terminology, indicates that one person's use of knowledge does not impede another's use of it. Consider the example of a mathematical formula. Knowledge is created when the formula is first derived and formal proofs are demonstrated. The result is most likely a scholarly publication that codifies the knowledge, rendering it easy to diffuse and put into practice. Once the formula is known, one scientist using it does not diminish its usefulness or utility to other scientists. In fact, the value of the formula may actually increase as a result of its more diffuse use and acceptance. Knowledge, once created, is nonrival; many economic actors may enjoy it simultaneously.

Nonexcludability refers to the fact that, once knowledge is discovered, it is difficult to contain or to prevent others from using that knowledge commercially, since the returns to the discoverer are smaller than the returns to society. This is the traditional justification for government funding for basic research.

Intellectual Property defines specific bits of knowledge that are novel. IP can take many forms, including products and processes that are protected through patents, trademarks, or trade secrets, and authored works that are protected through copyright. Most governments consider certain kinds of creative endeavors as intellectual property and allow inventors legal recognition for these endeavors. Some forms of IP include software, databases, plant varieties and other biological materials, as well as "tangible research property." The latter includes items such as circuit chips, organisms, drug targets, formulations, and engineering prototypes.

It is up to the creator of intellectual property, however, to decide whether an invention, discovery, or new idea is to be legally recognized and protected. For instance, a researcher who immediately publishes a discovery has made the decision not to treat it as IP and to make it freely available to the public for use.

Commercialization is the process that turns an invention into an innovation. It involves defining a concept regarding who is willing to pay for the new idea, what attributes they value, and how much they are willing to pay for the added value. The ability to legally protect an invention therefore forms the basis for commercialization activities, as it precludes others from copying the invention, entering in the market, and competing for a share of the economic profit.

More important, if companies did not have the ability to protect their discoveries, then they would have no incentive to invest in many important R&D activities, such as clinical trials, thus interfering with the creation and diffusion of knowledge. As such, IP creation is a fundamental ingredient of the commercialization process and an important vehicle for the transfer of knowledge between legal entities and the public.

While patenting measures invention, commercialization requires the additional steps of translating inventions into consumer needs and product markets. At its earliest stages, before applications are easily described or generally appreciated, realizing the potential of an invention requires a sophisticated understanding of consumer needs, existing markets for product innovation, and factor inputs. Commercialization, even when ideas are abundant, may not be completed because outcomes are highly uncertain, risk aversion may cause projects to be delayed or abandoned, or the relevant organizations may not be able to collaborate.

Technology is information that is put into use to accomplish some task. This information may take many forms, including both hardware (physical, material objects) and software (digital material, procedures) or combinations thereof. As such, technology has a fairly broad definition and includes anything that helps to improve the efficiency and quality of daily life. Electronic and computer technology helps its users to share information and knowledge quickly and efficiently. Vitamins, new biochemical formulations, and drugs alter one's health and improve one's lifestyle, making up another important class of technology.

Using this definition, technology may often be considered a form of intellectual property. In general, technologies are often broadly classified based on their area of application, and therefore terminology such as information technology, biotechnology, and nanotechnology has become commonplace.

Technology transfer is the application of information. Technology transfer is therefore a distinct and important subset of knowledge transfer; knowledge transfer is a broader concept that encompasses a set of relationships. Technology transfer is often considered as a formal activity within or across organizations. Case in point: a discovery derived from research in a scientist's lab may be licensed to a company that will commercialize the technological innovation into a product or service to be sold in the marketplace.

Although commonly associated with commercial goals, examples of technology transfer may be found between non-profit organizations or institutions and even between groups within the same organization. Direct technology transfer is often treated as a function and handled by a specific office or department within an organization such as a technology transfer office, business development office, or research foundations.

The intention is to provide some guidance and to highlight some steps forward using these four facts as (contradictory but no less pertinent) policymaking guideposts. (The box on page 8 provides an introduction to the terms that we use in this essay and others contained in this edition of Science Progress).

ECONOMIC GROWTH IS LOCAL, COMPLEX, AND BEYOND ANYONE'S CONTROL

All economic activity must be grounded somewhere. The idea of a flat world benefits corporations who move their operations to exploit wage differentials. But labor is less mobile, and people as physical beings provide the nexus for economic activity, either as workers or consumers. Even as the Internet eases long distance collaboration, creativity resides within individual people and that creativity is enhanced by local context and connections between people. Former Speaker of the House Tip O'Neil was fond of saying that all politics is local; by the same logic all economic growth is local.

Economic activity has a pronounced tendency to cluster spatially in locations rich in the factors that promote productivity and exchange. The 19th century British economist Alfred Marshall wrote about the spatial cluster of industries in 1890, noting that easy access to pools of skilled workers and specialized suppliers, localized competition, and the ability to benefit from knowledge externalities provided an advantage to local companies. This is well known today due to the prominence of modern technology-based clusters, such as Silicon Valley and Route 128 in Massachusetts. Manufacturing and productivity activity benefit from spatial concentration. Creativity and innovative activities, however, benefit most from the geographic concentration of resources due to increasing returns to the application of knowledge. The tendency of innovation to cluster both spatially and temporally is a regular occurrence. Consider Florence under the Medici family, Vienna during Mozart's career, Manchester during the Industrial Revolution, or Paris in the 1920s—all places where creative activity flourished.

New technologies and new industries display similar tendencies even as they begin rather humbly as entrepreneurial ventures. Translating entrepreneurs' dreams and realizing their economic potential involves building an appreciation of what is possible among potential investors, customers, and employees. Increasingly there is recognition that what matters for place-specific industrial development is not necessarily resources or initial conditions but the social dynamics that occur within a place and define a community of common interest around a nascent technology or emerging industry. Community building—as opposed to planning—can be essential to regional industrial development by constructing a shared understanding and appreciation of an emerging industrial activity.

Geography and place-specific interactions shape industries. If you enjoy coffee or fine wine, then you know that there is something about the soil, the climate, the angle of the sun, the age of the trees, and the growing and harvesting traditions that creates something very unique. Even the best vineyards experience different vintages, reflecting the myriad of variations that determine quality. While quality winemaking is diffusing around the world, with product now exported from Chile, Argentina, Australia, New Zealand, and South Africa, wines have become more complex and differentiated rather than homogenous. Connoisseurs talk about *terroir,* a French term used to denote the special characteristics that geography bestows. The term can be translated literally as "dirt" but more poetically as a "sense of place." The term captures the total effect that the local environment has on the product, when the total effect is more than the sum of its parts.

Location is a geographic platform that provides a means to organize human activity and that is essential to the creation of innovation and the production of knowledge. Companies are one well-known way of organizing productive activity. Geography, spatial proximity, and collocation are another. As technology allows greater communication at long distance, we experiment with distant collaboration and knowledge sharing. But sometimes there is simply no substitute for just being there—being at the place where exciting work is taking place, where high-content unstructured conversations take place, and where the unexpected may be explored and spark something new.

The essence of strategic advantage is being able to do something well that will not be easily replicated by others. Companies understand this, but unfortunately places seem to try to attract and grow the same glamorous sectors. Unfortunately, by the time an industrial activity is well understood and appreciated and easy to target, it is too late. The first movers have already captured the market, and as the process become self-reinforcing it is impossible to catch up.

Consider the example of Boston's biotech industry (see box on page 12), arguably the most successful biotech cluster in the world. It is most relevant that biotech was never an economic development target. The industry simply evolved organically, growing up at a time when few people understood biotech or its economic potential. By the time other communities jumped on this bandwagon, Boston was far ahead in its lead.

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PLANNING FOR AN UNCERTAIN FUTURE

Our difficulty comprehending the complexity of future growth underlies faith in market mechanisms. Recently this reliance on the market has diminished the role of government in many people's minds. Yet government at its best is the vehicle for collective action. Government ensures that markets work well, that competition is fair, and that all citizens are able to participate in the economic future. When government works well, communities are viable.

Frequently, policy is based on a linear model of innovation whereby innovation emerges from increasingly practical applications of new fundamental knowledge. This type of policymaking is wrongheaded. On the contrary, technological change must be conceptualized as a process whose outcome is not determined but is rather open. It is impossible to discover a sequence of clearly delimited stages that have to be passed one after the other.

Instead innovation is more accurately described as a complex, self-organizing process that covers a much wider range of small- to medium-sized enterprises, large multinational corporations, universities, the public sector, competitors, and collaborators alike. Innovation policies need to provide the infrastructure so that creativity and innovation flourish.

There is an equal danger that places become too inward-looking, depending too much on local resources, local collaboration, and local markets. The most successful economic entities are also globally connected, benefiting from local buzz and

REGIONAL INNOVATION: BOSTON AND MIT

The Boston area is a hotbed of entrepreneurial companies spinning out of the region's universities and research hospitals, with the Massachusetts Institute of Technology leading the way—but with many other research institutions and institutions of higher education participating. Why has it happened in Boston? And what can other cities do to promote entrepreneurial clusters?

By many accounts, Boston has developed the most successful concentration of biotech companies in the world. The development of the "biotech cluster" in the region during the past two decades has highlighted the entrepreneurial ferment. It is instructive, then, to consider the development of the complex Boston ecosystem from an MIT perspective, since MIT was the earliest and is still the most active university player in the eco-system. This story has been told before but not from the perspective and history of the university.

History is relevant. MIT is not the typical university in that it was originally formed as a "school of industrial science" to aid "the advancement, development, and practical application of science in connection with arts, agriculture, manufactures, and commerce," according to the 1861 MIT Charter from the Commonwealth of Massachusetts. Thus, its commitment to technology transfer to industry (an unknown term at the time, but clear in concept) was there at its beginning.

While the educational philosophy of the early Institute centered on mastery of basic concepts, practical problems were also attacked. In 1903, for example, a Sanitary Research laboratory was founded devoted to year-round research in special problems relating to sewage disposal and its bacteriology and chemistry, noted Samuel Prescott in his 1954 essay "When M.I.T. was 'Boston Tech.'" Or consider MIT's Division of Industrial Cooperation and Research, which was founded in 1921, through which "the resources of the Institute [were] made available to American industry," according to MIT's 1921 yearbook, with companies able to contract with the Institute for consultation by faculty and research projects. M.I.T. noted at the time that "through real cooperation and closer contacts between the two greatest factors of industrial life—the training school and the manufacturing plant—there should be no limit to the development and reach achievements which result."

In the two decades following World War II, MIT evolved into a full university, but "a university polarized around science," as Julius Stratton, president of MIT, described the institute in 1961. Research grant volume and the number of graduate students both began a rapid rise that has continued to this day. The research focus evolved from mostly "practical" to basic research, both in engineering and science. MIT's reputation as a first-rank engineering school began to be matched by its standing in the "basic sciences:" physics, chemistry and biology. But importantly, the interaction of industry with the university continued. Many of the faculty consulted with companies, using their "20 percent of time allowed for outside professional activities" (standard policies in many universities) to spend time in company laboratories.

During this period, a number of faculty members and MIT researchers started companies, many of which grew into major corporations. Examples include: EG&G, founded in 1947; Digital Equipment Corporation, founded in 1957 (and initially financed with a $75,000 investment by American Research and Development, "the first venture capital fund"); Amicon Corporation in 1962; Bose Corporation in 1964—and many others.

Quite naturally, the majority of the companies were in the Boston region benefiting from geographical closeness to their founding faculty scientists. Indeed, MIT has a rule that faculty firms should be near the university. Many community hospitals have similar rules that require house staff to live in close proximity. This not only makes commuting easier, it also has the positive effect of locating staff and their families in the community.

global pipelines. Leaders, while certainly important, required dedicated followers. The most successful places forge a consensus or shared understanding about what is possible, what needs to be done, and even how to best organize an activity and realize value. The most successful places do not stop, but instead constantly look for improvement and new opportunities.

THE CHANGING ROLE OF UNIVERSITIES

Universities are important actors in local economies. Their relationships with for-profit activities are becoming more direct and focused. Institutions of higher education seek to create effective transfer mechanisms that efficiently increase the stock of knowledge, promote social or economic development, and increasingly enhance economic competitiveness. Yet formal technology transfer is certainly less important than teaching, research, and public service—the traditional activities of universities.

Universities exist for the very purpose of creating, augmenting, verifying, and diffusing knowledge—the most important resource in the modern economy. Knowledge is an ethereal concept that is perhaps best considered as embodied in what economists call human capital, or individuals who have received the benefit of education and who are able to appreciate, integrate, and augment knowledge and engage in innovative activity. In practice, education is a human cognitive activity, a relational process in which questions, answers, clarifications, and other information flow. Innovation is predicated on the creation and application of knowledge.

Appreciation of academic discoveries requires a shared vision of what the potential might be and how best to move the technology forward, and often requires devising a terminology and a conceptual schema even to talk about the discovery and its market potential. By constructing a common, shared meaning of the technology through frequent interaction with academia creates questioning, skepticism, and creative playfulness—what the literature describes as the transmission of tacit knowledge.

Places look to their local universities as driving forces in the knowledge economy, yet universities are part of a local context. The benefits of the university may be absorbed by the local community and take root or may simply slip away. Universities, like other economic entities, require complementary assets to realize their potential and supply chains to provide them with resources. The complementary assets are companies with absorptive capacity both to employ skilled labor and to use research findings. If receptor businesses do not exist locally, then anything a local university produces will become an export to other places: Graduates will leave for employment elsewhere and research results will benefit distant companies.

The supply chain for higher education certainly involves significant continuing investment in physical plant and equipment. While it is possible to conduct some activities virtually, thus saving the cost of a physical plant, universities are important social spaces, and a university's infrastructure has important symbolic value. Moreover, universities require a steady supply of students who have the requisite background to be able to engage in higher education.

PREPARING FOR INNOVATIVE ECONOMIES

Innovation has become recognized as the foundation for all types of places to succeed. The ability to create economic value by exploiting technological progress, introducing new products to the market, redesigning production processes, or reconfiguring organizational practices is critical to productivity for companies, industries, and places. Innovation, however, is not limited to new science-based or high-technology industries. Innovation is equally transformative in existing mature industries and provides a means for competitive advantage.

When considering the development of industrial clusters there are two broad and diametrically

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opposing models. One model, practiced in East Asia, relies on government dictating the growth of designated science cities. This is a very top-down approach to economic development that has been successful in Singapore and Taiwan: The central government dictates that a specific location will have a concentration of R&D and it accomplishes this in a relatively short period of time. The verdict is still out as to whether these locations will be successful at creating a sustained competitive advantage given that innovation is more complex than simply conducting R&D.

The other model occurs in the United States, and to varying degrees in other market economies, and it relies on self-organization and local initiative. In market economies the central government cannot dictate the actions of private companies, but may only offer incentives to encourage companies to locate and invest in local research and development. The closest the United States has to a government-induced cluster is Research Triangle Park in North Carolina, which was the result of state and local government actions. Research Triangle Park, however, was a very long undertaking beginning in the 1920s, and it is now the largest and most successful research park in the world. While there are many other examples of government trying to build clusters in market economies (see article on page 35), the results typically look very different from what was originally intended.

While economic development officials and government planners want to define long-term strategies, it is difficult—if not impossible—to predict scientific discoveries, new technologies, and new opportunities. IBM, Inc., a mainframe computer industry leader in the second half of the 20th century, famously underestimated the potential of the personal computer industry, creating an opportunity for new companies to create entirely new information technology hardware and software industries and companies—think Dell Inc., Apple Computer Corp., and Microsoft Corp. But then these and other industries and companies largely failed to predict the potential of the Internet and how it would change the way we access information and communicate—something IBM used to its advantage to reinvent itself as a largely Internet-driven IT services company. Policymakers couldn't possibly have predicted any of this, but they could and did till the soil that allowed all this innovation to flourish.

Successful entrepreneurs make and remake their own luck, adjusting and adapting to survive. Instead of wisely considered, far-sighted solutions, entrepreneurial activity is by necessity messy, adaptive, and unpredictable. Economic development strategies need to be equally adaptive.

Maryann Feldman is S.K. Heninger Distinguished Professor of Public Policy at the University of North Carolina, Chapel Hill.