WHAT THE U.S. CAN DO TO MEET THE JAPANESE CHALLANGE IN HIGH TECHNOLOGY

Richard Florida, Assistant Professor of Public Policy and Management, School of Urban and Public Affairs
Carnegie Mellon University, Pittsburgh, Pennsylvania

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Introduction

The U.S. is losing ground to Japan in high technology. Large vertically integrated Japanese corporations are able to rapidly transform new technologies into downstream products and are moving upstream into new areas. American industry remains strong in breakthrough technologies but suffers from an inability to turn cutting edge breakthroughs into viable products or improved manufacturing processes. To meet the Japanese challenge U.S. industry must work to strengthen ties between research and manufacturing and in doing so to transform our leading corporations into "learning organizations."

Learning is a key to overcoming our serious competitiveness problems. Learning lies at the root of a new model for research and innovation that is increasingly taking hold in America's high technology startups and their large Japanese counterparts. Webster's New World dictionary defines learning as the act of "acquiring knowledge or skill, especially much knowledge in a special field." By learning, I mean something quite specific: the ability to generate, integrate and harness the detailed knowledge that emanates from different parts of an organization -- research, marketing, and manufacturing -- as well as outside of it. Companies that are able to do this can best be thought of as "learning systems."

The small innovative ventures of Silicon Valley and Route 128 are learning systems. The "hothouse" environment found in these companies allows them to rapidly propagate new technologies and products. These are research-driven enterprises which replace the overwhelming bureaucracy of established corporations with flexible and interactive environments. Young high technology ventures also interact constantly with outside entities -- suppliers, vendors, distributors, venture capitalists, universities, and the users of their products.

This new model for innovation is increasingly taking hold in Japan -- though in radically different forms. Corporations like Hitachi, Toshiba, Fujitsu, and NEC have dramatically increased their capacity to learn. They keep management lean and allow new ideas to bubble up from the shop-floor. Research and manufacturing are tied together in ways that create high levels of cross-fertilization. Japanese corporations also interact constantly with their suppliers who provide another source of new ideas. What we have only been able to do in entrepreneurial ventures, Japan has done in its large companies.

Japanese high technology extends learning to all the various stages of the production process from the research laboratory to the shop-floor. When all is said and done, this is the root of Japan's advantage and our worsening high technology dilemma. While the U.S. system truncates learning -- isolating it in the innovative domain, learning in Japan is more fully blown.

An Assembly-line Model of Innovation

In order to understand both the strengths and the limits of the U.S. system, it is first necessary to get a handle on what came before. The early part of the twentieth century saw the U.S develop a new form of mass production industrial organization based upon the assembly-line. Giant industrial factories combined taylorist ideas of scientific management with the mechanized flow of the assembly line. Massive management hierarchies grew up to supervise and direct work. By breaking down jobs into discrete components, mass production industrial organization took away workers' skills. In common terms, workers were paid to work not think.

Innovation was also shaped by the assembly-line model. As the great economist Joseph Schumpeter has shown, the rise of corporate research laboratories enabled large companies to internalize technological change and replace the innovative dynamism previously associated with independent entrepreneurs. With Edison's Menlo Park research laboratory as their model, hundreds of industrial corporations formed research laboratories in the first few decades of the twentieth century. During this formative period, research labs were located at or close to actual plant sites, allowing a near constant interplay between manufacturing and innovation.

The postwar era was a watershed for industrial research. Government became massively involved in the promotion of science and technology through increased Defense Department spending and the newly established National Science Foundation and National Institute of Health. Companies dramatically increased their own outlays on research as well. Total R&D spending grew from roughly $5 billion in the early 1950s to more than $70 billion in the early 1980s.

But, in time assembly-line innovation created obstacles to learning. The organization of industrial research was ultimately overcome by the rigidities of the assembly line model. In the years following World War II, corporate research became increasingly isolated and specialized. The various elements of the innovation process -- basic research, advanced development and manufacturing -- were gradually separated from one another.

The decentralization of manufacturing operations during the 1960s and 1970s only made things worse. Older plants in the industrial heartland were replaced with new ones in growing regions like the sunbelt and in third world countries. Research functions which had traditionally been located at or near these older plants were then relocated to suburban campuses. Initially, it was thought that separating research laboratories from manufacturing would provide the insulated environment needed to achieve important breakthroughs. But, this only increased the physical and social distance between innovation and production, and technological change suffered. Divorced from actual manufacturing, research got out of sync with the demands of operating divisions, and operating divisions found there was little they could do with the discoveries made in research centers.

The Re-emergence of Entrepreneurial Innovation

By the late 1950s and early 1960s, important changes were beginning to take hold on America's technological landscape. Most notable among these was the rise of a series of important high technology industries like semiconductors and computers. While the genesis of these new industries began inside large companies and universities, small companies frequently became the vehicle for catalyzing new breakthroughs. The basic technology used in semiconductors was developed at Bell Laboratories, but it was the emergence of Fairchild in the late 1950s that got the semiconductor industry going. Similarly with computing. While universities were important at the outset, initial commercialization through startups like computer pioneers, Eckert and Mauchly's, University of Pennsylvania spinoff and Engineering Research Associates, which were founded well before IBM's entry into the field. The founding of three important new companies, Fairchild Semiconductor, Digital Equipment Corporation, and Control Data, in 1957 signalled the re-emergence of entrepreneurial innovation.

The roots of this entrepreneurial renaissance are easy to understand. By the 1950s, the assembly line model had created obstacles to innovation. Researchers often faced sizeable barriers getting companies to move forward with their ideas. Even when new technologies were developed, with manufacturing far removed from research centers, large corporations were unable to mesh new technologies to existing manufacturing capabilities or to their longer run strategic objectives. There was no way out. Gradually, researchers and other personnel began to create their own alternatives.

The basic vehicle for this was the entrepreneurial startup.
Small high technology companies developed a new kind research environment. Innovation was typically organized in ad hoc and informal ways. Ph.D. scientists were thrown together with blue collar workers and encouraged to become involved in actual production. Hewlett Packard, for example, actively promoted a policy of "management-by-walking-around" and encouraged researchers to interact with factory workers. In most entrepreneurial companies, top researchers and other key employees were given stock options and other ownership stakes which tied them closely to the success of the business. The stifling bureaucracy and mundane work environment of large corporations was replaced with a flexible and interactive research milieux.

Research and manufacturing took place under the same roof. When I recently spoke with the venture capitalist Eugene Kleiner, who was Fairchild's original director of manufacturing, he emphasized that Fairchild was fully integrated from research through manufacturing. Fairchild not only invented new chips, it invented new processes for making new chips, manufactured those chips, and made the equipment used to manufacture them.

This organizational synthesis enabled small high technology companies to attract extremely motivated researchers and become the focal point of important breakthroughs. These were the places that "high energy" researchers could make their new ideas happen. So, for example, 11 of 18 major semiconductor innovations made during the 1970s came from small startups. The more recent custom chip revolution has occurred almost exclusively through the vehicle of entrepreneurial ventures like LSI Logic, Cypress Semiconductor and a host of others. Entrepreneurial computer firms such as Apple, Cray and Sun pioneered critical breakthroughs in the areas of personal computing, supercomputing and computer workstations respectively. The rapid transformation of biotechnology from university science to a nascent industry was premised upon the action of venture capital backed startups like Genentech, Cetus, Amgen and Integrated Genetics.

Small technology-based companies interact frequently with each other -- and this provides another source of learning. Innovation complexes like California's Silicon Valley and Boston's Route 128 area are home to tremendous concentrations of high technology businesses. These dense clusters of high technology firms, venture capital and other support services allow independent agents to synchronize their activities and act as a workable whole. In a recent conversation, Luigi Mercurio, a Silicon Valley entrepreneur, used the term "virtual corporation" to refer to the complex interactions that occur among that region's many independent companies.

Innovation complexes are more than the sum of their parts. They provide an environment where human resources can continuously be upgraded, where researchers circulate constantly among companies, and where very specialized labor pools develop. Dense linkages and networks among companies create important technological synergies -- giving workers, firms and entire complexes the capacity to respond quickly to new technologies and changing market conditions. As companies learn from one another, new ways of doing things become assimilated into the complex. Innovation complexes are broad learning systems which continually recreate the conditions for their own growth.

A Breakthrough Economy

The rise of this new model of high technology innovation creates some vexing dilemmas. Entrepreneurial small firms have made the U.S. very good at breakthroughs innovations; yet these companies often lack the capability to follow through and capture the full economic rewards of their innovations. America's entrepreneurial system of technological development is gradually turning us into a "breakthrough economy" -- an economy where new technological frontiers are all that matter, where manufacturing is neglected, and where innovation is increasingly separated from production.

While entrepreneurial innovation provides a catalyst for rapid technological change, it can be quite disruptive. Most startups are formed by defections of key researchers or even research groups. This kind of turnover can seriously weaken existing companies. And, swarms of "me-too companies" in emerging areas can over-crowd emerging areas and lead to numerous business failures. Given this chaotic environment, some companies may actually reduce their commitments to research. The long term performance of American high technology suffers.

Entrepreneurial innovation is causing the fragmentation or splintering of high technology industry. Splintering makes it hard to build stable companies which are competitive over the long haul. Entrepreneurial startups focus on high end innovation where the biggest financial rewards can be gained. With their focus on breakthroughs, fledgling companies may overlook important incremental improvements in products and process. Manufacturing is frequently contracted out -- often to offshore facilities. Innovation and production are once again separated. In a recent conversation, Donald Valentine, the original venture capital backer of Apple and other important high technology companies put it this way:

> Silicon Valley and Route 128 are worlds of intellectual property, not capital equipment and production. Most of the employees of U.S. high technology live in southeast Asia.

In our premier high technology fields, manufacturing is afforded a second class position, with learning confined to high end innovation. Our system of high technology innovation cuts learning short.

The Japanese Challenge

Japan has become a potent competitor in high technology -- challenging the U.S. for world leadership in numerous fields. Japan has increased its share of the world market for high technology products from just 7 percent to roughly 20 percent over the past two decades. It has taken the lead in semiconductors and robotics and is quickly catching up in computers and biotechnology. Japanese patents in the U.S. system outnumber those of Britain, France and West Germany combined and are highly concentrated in key commercial areas like semiconductors and computers. The 1980s have seen our high technology trade deficit with Japan grow from under $4 billion to more than $20 billion dollars.

Beyond the Assembly-line Model

Much of the reason for Japan's rapid ascent in high technology lies in the way Japanese industry is organized. The rise of this new model of industrial organization was not implemented by managerial fiat or through unbridled government power, but rather was the outcome of bitter postwar industrial conflicts and political struggles. As in other industrial countries, neither business nor labor was able to impose its will entirely on the other -- a relatively stable set of accommodations or "social compact" being the result. Japanese workers received long term employment security as their part of the bargain, while Japanese corporations got great flexibility in organizing production. The nature of this compact opened up a series of important pathways beyond those of the American assembly line system.

Long term employment tied workers to individual companies and caused them to equate their own economic security with that of the enterprise. It reduced workers' fears of technological displacement or new forms of work organization. It also enabled firms to internalize and reap the full rewards of their investments in human resources.

Japanese corporations developed new methods for organizing work. These were similar in some respects to the ways that American high technology startups had organized research and innovation, but in Japanese companies they extended down to the shop-floor. Workers were given a great deal of autonomy in doing their jobs and heavily involved in manufacturing decisions. Management was kept quite lean. The differences between this and the assembly line model of industrial organization are neatly summed up by Konosuke Matsushita head of one of Japan's leading high technology companies.

> Your firms are built on the taylor model. ... For you the essence of good management is getting the ideas out of the heads of the bosses and into the hands of labor. We are beyond the taylor model. Business is so complex and difficult ... that continued existence depends on the day-to-day mobilization of every ounce of intelligence.[1]

Learning in Japanese High Technology Industry

Japanese high technology took its shape from this broader pattern of industrial organization. In contrast to the U.S., large diversified companies play a central role in Japanese high technology. Corporations like Fujitsu, Hitachi, Matsushita, Mitsubishi, NEC, Sony, and Toshiba make everything from semiconductor chips and computers to televisions and consumer goods. These companies use many of the new technologies they develop in their downstream products and benefit from economies of scale and cross-fertilization in their research efforts.

Large Japanese high technology companies are supported by tiers of subcontractors and suppliers. Hitachi, for example, is served by more than 700 suppliers. Close relations with suppliers provide another source of learning. On the one hand, suppliers share information with anchor corporations and are involved in the development of new products and processes. On the other hand, new technologies can be handed over to primary suppliers or spun out in new subsidiaries. Large Japanese corporations actively can use their supplier networks to avoid the problems associated with bigness and develop semi-autonomous satellites which may be better suited to develop new products or technologies. Supplier networks provide many of the same functions found in American high technology complexes but in a more organized fashion. In this sense, Japanese industrial organization gets the benefits of structure as well as flexibilty.

Learning is significantly enhanced by close links between research and manufacturing. Research is carried out by multidisciplanary teams rather than specialists. Researchers are rotated within research centers and between research facilities and operating divisions. At NEC, for example, more than 80 percent of research personnel are rotated to applied labs or manufacturing plants where they function as "carriers" of particular projects and technical knowledge. The combination of long term employment and rotation allow Japanese companies to constantly throw together new combinations of researchers and at the same time to develop strong institutional memories.

The relationship between research and manufacturing is also quite important. In contrast to the U.S. where projects are handed "over the wall" from research to product development and ultimately manufacturing, product development moves along gradually and functions overlap. The basic mechanism for this is the "self-organizing" project team which adds and subtracts members whose skills conform to the different phases of the development cycle.

In addition, research laboratories are located in the vicinity of manufacturing plants and focus on commercial projects as well as long term research. This eliminates many of the distinctions separating research and manufacturing and creates powerful technological synergies. Close links between research and manufacturing enable each to learn from the other.

Japanese high technology shares many of the most powerful aspects of U.S. high technology but embeds them within a more structured institutional framework. Learning becomes systemic and extends from innovation through manufacturing.

Where Do We Go From Here?

Learning is a fundamental aspect of high technology innovation. New high technology organizations in both the U.S. and Japan can be thought of as learning systems. Any attempt to bolster the competitive position of U.S. high technology must recognize this.

The U.S.-Japan competition in high technology is a subject much concern to industrialists, technologists and government officials. This is typically portrayed as a battle between the innovative dynamism of small U.S. firms and the manufacturing

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[1] As quoted in Myron Tribus, "Applying Quality Management Principles," Research Management 30 (November-December 1987), pp. 11-21.

prowess of Japan's industrial titans. While some commentators see entrepreneurial startups as the basic strength of the U.S. economy, others see them as part and parcel of our vulnerability. These explanations make far too much of obvious differences in firm size. The issue is not size per se but structure -- in particular, the way that organizational structure affects learning.

The managerial implications that flow from the current debate also come up short. We will not solve our problems simply by stimulating more entrepreneurship or by somehow turning a handful of small high technology companies into bigger ones. If we are to succeed, the learning capabilities of high technology firms -- both large and small -- must be enhanced. For large firms, this means moving decision-making down to the lowest possible levels, encouraging communication between research and manufacturing, and forging better linkages to customers and suppliers. For small firms, it is necessary to extend the benefits of learning into manufacturing. This may prove to be a bigger problem since many of these firms have lost their manufacturing capabilities.

These are difficult problems, but they can be solved. A crucial first step is to make learning a clear priority of management strategy.