A Weakness in Process Technology

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Although the United States seems to be neither behind when it comes to research and development on new products or the willingness of its consumers to buy new products, the evidence clearly shows that it is behind when it comes to process technologies. Often Americans, even when a correction is made for wage differences, cannot produce goods at the price or quality levels achieved abroad. There is no one overriding reason for this lag in process technologies. An undereducated and trained labor force, too little savings and investment, a failure to see production as a central task, and a number of other factors have all contributed to the problem.

As Robert Solow demonstrated in the work that recently won him a Nobel Prize, technical change is central to productivity growth. If productivity has slowed down, as it has in the United States, and is not advancing at the pace of one's competitors, as it is not in the United States, then somewhere in the system something is probably going wrong with the processes that determine the pace of technical change. Where are the failures located and why are they occurring?

As I shall discuss below, the location of the problem is clear. The United States starts with scientific and engineering knowledge second to none. New scientific principles are quickly learned and incorporated into its thinking. The United States is in fact still the leader in generating the basic new ideas that drive technological change. And at the other end of the process it is equally clear that we have consumers who are almost by instinct leading-edge buyers. No consumer anywhere in the world is quicker to buy the new or the different.

If one looks at process technologies, however, U.S. firms too often are slow to adopt new technologies. Often they cannot produce products at the costs or quality levels achieved by their foreign competitors.

Still Ahead at the Beginning

When the chief executives of more than 200 European firms were asked to rank countries on technological prowess in nine fields—computing, electronics, telecommunications, biotechnology, chemicals, metals and alloys, engineering, manufacturing, and robotics—the United States had number one rankings in five fields and tied for number one in two others (electronics and manufacturing). In the remaining two fields (robotics and metals and alloys), America was ranked second.

These subjective judgments can be backed up with a wealth of hard data. When it comes to research scientists and engineers relative to the size of the labor force, the United States still has more than any other country, according to the National Academy of Engineering and the Organization for Economic Cooperation and Development (*1*). Research and development spending is a slightly larger fraction of U.S. gross national product (GNP) than in any other country, and because of its size the United States does far more research and development in absolute terms than any other country in the world.

Output measures of research confirm the pattern seen in inputs. Our receipts for the sales of technological licenses to the rest of the world far exceeds those of any other country. Americans write 35 percent of all of the scientific and technical articles published in the world (*2*). Given the importance of the U.S. market any major breakthrough will be patented in the United States regardless of where it was developed, yet Americans receive more patents than the citizens of all of the rest of the world combined (*4*). If one lists the basic innovations that have done the most to alter the nature of our world in the last 20 years—the transistor (Bell Labs), the semiconductor chip (Texas Instruments), the small computer (Apple), the video recorder (Ampex)—they are all American ideas. It is difficult to think of a recent foreign innovation that ranks with these in terms of importance.

If one lives in the great scientific research institutions of the United States, it is clear that even when new breakthroughs are discovered abroad, Americans know about them very rapidly and can quickly duplicate the results in their laboratories. The time lag for bringing knowledge back to the United States is very short.

Although it is clear that Americans are not slow to adapt to technical change in their laboratories, something important, however, has changed. The sources that show that America still leads in most measures of scientific or engineering accomplishment also show that the rest of the world is closing the huge gap that existed at the end of World War II. Americans write more articles than anyone else, but a smaller proportion than they used to write. America still has a lead in research efforts, but the lead is smaller than it used to be (*1*). Americans still get more patents, but a smaller percentage than they used to get (*2*).

In addition there is an aggressive, definite number two, scientific challenger, Japan, on the economic playing field. Where Americans do not rank first in a field, the first rank is always held by Japan; where Americans still rank first, the second rank is always held by Japan (*3*). American's scientific lead looks, and is, much less secure.

Behind in the Middle

Economists measure how well societies are doing at embedding technical change into their economies by looking at the growth of productivity. At what pace is the economy becoming more efficient? To raise productivity firms must understand new technologies, but they must also embed them in new capital equipment and create the

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skilled work forces that can effectively use them. Productivity growth is a measure of technical change but it is a broader measure of technical change than that found by measuring just what comes out of a nation's laboratories.

American productivity, almost regardless of where one looks, is not growing at the pace of productivity abroad. In the private economy productivity has grown 0.8 percent per year in the past 10 years, 0.8 percent in the past 2 years, and 0.9 percent in the first 6 months of 1987 (*4*). Short- and long-term trends are consistent. During the same time period, productivity was growing at 4 times that rate in the rest of the industrial world. At one time this differential could be explained as a catch-up phenomenon. The rest of the world could adopt already proven American technologies and did not have to invent their own. But with per capita GNP approximately equal in Europe, Japan, and the United States, such an explanation gets more and more tenuous. It also does not explain why the U.S. productivity growth rate has fallen from the more than 3 percent per year level that existed in the 1950s and 1960s.

Service output has been growing everywhere in the world but only in the United States has service productivity failed to grow at a healthy rate. Higher unemployment rates might lead firms to keep workers on the payroll that they don't actually need, but unemployment has increased far more in Europe than it has in the United States in the last decade. U.S. firms can also lay off workers much more easily than their Japanese or European competitors and, therefore, there should be less disguised unemployment in the United States than abroad. Between 1979 and 1985, productivity was actually falling in mining, construction, transportation, finance and insurance, and real estate (*5*). Such declines are not found abroad.

Among industries, manufacturing is a relative bright spot—productivity growth averaged 3.1 percent from 1979 to 1985. But this was a rate of growth somewhat slower than that of France (3.8 percent), Germany (3.2 percent), Italy (3.7 percent), and the United Kingdom (4.2 percent) and far below that of Japan (5.7 percent). Here again long-run and short-run trends are consistent. In 1985, manufacturing productivity grew 4.4 percent in the United States but 5.0 percent in Japan and 5.6 percent in Germany (*6*). Productivity growth is cyclical, rising when sales and output rise; this should have led to a higher U.S. performance because growth rates in recent years have been higher here than abroad.

Specific industry studies reveal the same productivity growth gap. In 1986, U.S. steel mills required 6.4 hours of labor per ton shipped. The Japanese required only 6.0 hours (*7*). Japanese machine tool companies and auto companies seem to require just about half as much labor as their U.S. counterparts to produce the same output (*8*). Inside the United States the best Japanese assembly facilities require slightly less labor than the best U.S. assembly facilities and far less labor than the worst U.S. plants (*9*).

Productivity is one measure of performance; quality is another. When it comes to the quality of products, the United States definitely lags. In 1985, the best high precision U.S. robots had the ability to place something within 25 micrometers of where it belonged. The best Japanese had an accuracy of 5 μm (*10*). U.S. robots also had more down time for repairs (*11*). Quality indicators show that imported cars consistently dominate domestically produced cars (*8*). In a comparison of the quality of Japanese and U.S. air conditioners, the failure rates for the worst producers, all U.S., were 500 to 1000 times as great as those made by the best producers, all Japanese. The average U.S. manufacturer suffered 70 times as many assembly-line defects and made 17 times as many service calls in the first year of services as others (*12*). When it comes to high technology steels, U.S. firms cannot roll steel with the corrosion resistance, mechanical properties and dimensional tolerances found in top-of-the-line foreign facilities (*13*). American nuclear reactors suffer 5.5 emergency shut-downs per year, whereas the average Japanese reactor has only 0.3 shutdowns per year (*14*). America, of course, still leads in some industries, such as aircraft production, but more and more often it lags behind.

Trade flows between countries are influenced by variables other than technology, productivity, and quality—such as currency values and wage levels—but trade statistics point in the same direction. The U.S. trade surplus in high technology products has disappeared (*3*). American machine tool makers are rapidly losing their markets at home and abroad (*15*). Japan's market share for semiconductor chips has risen 50 percent in the last 8 years while the U.S. market share has shrunk 20 percent (*16*). America's export market share in high R&D intensive goods has shrunk more (4 percentage points between 1970 and 1984) than that in low R&D intensive goods (2 percentage points) (*17*). The losses in competitiveness are not just in low-tech rust-belt products. The United States seems to be losing its comparative advantage at the front end of the product cycle in new goods and not just at the tail end of the product cycle in old goods.

The prime reason for America's poor productivity, quality, and trade performance is easily isolated. When it comes to process technologies Americans are slow to invent and slow to adopt. In industry after industry if one plots the speed with which new process technologies are first adopted and the speed with which they are put in place, U.S. firms lag behind foreign firms. A study of the adoption of robots illustrates the problem. In absolute terms the United States has less than one-third as many robots as Japan. Per worker it has less than one-sixth of Japan's robots, many fewer robots than Sweden, and substantially fewer robots than Germany or Belgium (*10*, p. 20a). Numbers also exaggerate the use of robots in the United States. Here the big three automobile makers and IBM employ 60 percent of all robots (*10*, p. 25). In Japan and elsewhere their application is much more widely spread. If one plots an adoption curve for robots, Americans actually start to use robots earlier, but by the late 1970s are lagging far behind the adoption curves for either Japan or Sweden.

When it came to adopting the oxygen furnace or continuous casting the U.S. industry lagged years behind those in the rest of the world and even to this day have failed to catch up (*18*). Basic oxygen furnaces account for 60 percent of U.S. steel production but 71 percent of Japanese steel production. Forty percent of U.S. steel is continuous cast; 90 percent of Japanese steel is continuously cast (*19*).

Numerical machine tools account for a much higher fraction of total metal cutting tools in either Japan (67 percent) or Germany (49 percent) than they do in the United States (40 percent) (*15*, p. 17a). If one looks at flexible manufacturing systems, the average American system makes 10 parts while the average Japanese system makes 93 parts (*20*). The Japanese flexible manufacturing systems also achieve much greater uptime and use much less labor, direct and indirect (*20*, p. 27). When it comes to installing such systems, Americans take both more time (2.5 to 3 years versus 1.25 to 1.75 years) and more labor (25,000 manhours versus 6,000 manhours) than the Japanese (*21*).

When it comes to low-tech industries the same slowness to buy and use new processes is apparent. When stone cutters in Europe were able to cut marble and granite panels for buildings to thickness of less than one-half inch, the best American cutters had yet to break through the two inch barrier (*22*).

What is true in process quality also seems to be true in process speed. The rest of the world has become faster to move products from their laboratories to the market place. American auto companies require 62 months from inception to delivery of a new car; Japanese companies only 43 months (*9*, p. 6).

Americans also seem strangely uninterested in improving the quality of their processes. In one study of German and American companies, the Germans spent 8 to 12 percent of their annual sales on plant and equipment to enhance the quality of their manufacturing performance. Their U.S. counterparts spent two to three times less and then primarily to expand capacity or cut costs (*23*). Japan has outspent the U.S. two to one on automation in the past 5 years and a much higher fraction of its new machine tools (55 versus 18 percent) were computer controlled (*21*, p. 28).

What Is Going on in the Middle?

While the lag in process technologies is clear, the reasons for it are not. Or perhaps more accurately there are a variety of reasons and none stands out as the dominate reason. In my opinion, the search for a dominant cause is misplaced; all of the reasons that I enumerated below are part of the answer, but it seems to be in the American character to argue that a problem has not been solved if one overriding cause has not been isolated. This search for the prime cause is perhaps the dominant reason why Americans have done so little to address their defects in process technologies. What can one do until one knows the prime cause?

Correcting each of many small causes is not part of the American style, but such small improvements are at the heart of large aggregate improvements in process technologies. Seldom is there a major breakthrough. Progress is made by making thousands of incremental improvements.

While America has as many research scientists and engineers as the rest of the world, when one steps beyond research, one discovers that America is an underengineered society. It graduates fewer engineers and scientists than its competitors, puts slightly more into research, puts many more into defense, and as a consequence is left with many fewer production engineers than its foreign competitors (*2*, pp. 193 and 216). In the end the weight of numbers makes a difference. Having five engineers makes it possible, for example, to staff flexible manufacturing systems with more technical people but many fewer total people in Japan than in the United States (*21*, p. 30).

There also seems to be widespread anecdotal evidence that at least until very recently, firms tended to put their best engineers into research and design and to put their second-best engineers in production. Individual career choice seemed to point in the same direction since pay and promotions for those in production systematically lagged behind those of engineers in design and research.

With less total engineering talent, top managers are also much less likely to have technological backgrounds—two thirds abroad, one-third here (*24*). As a result, when major technical breakthroughs occur, top managers tend to sit back and wait for the financial numbers to prove that the necessary investments are profitable. Who wants to make major investments in a technological black box that one does not personally understand? But to wait for the numbers is to wait until someone else has already pioneered the development and gotten a head start in production.

The lack of technical knowledge among top managers is compounded by the fact that production is not the route to the top in American industry, and few chief executive officers have ever run a production facility. When asked to rate which functional area was the fastest route to the top, only 4.6 percent of Fortune 500 executives ranked production or manufacturing as the route of choice. In contrast, 34 percent cited marketing, 25 percent finance, and 24 percent general management (*25*).

The two cultures' idea (technical people cannot understand human beings; humanists cannot understand science) is peculiar to the Anglo-Saxon world and leads to a bias in backgrounds that handicaps both U.S. education and U.S. industry. People do not attempt to learn both skills because they are told that it is not possible. Japanese managers almost always have a technical education, yet people skills are noted by outsiders as the "art of Japanese management."

While scientists and R&D are admired in the United States, production engineering ranks much lower and important industrial disciplines like welding are respected hardly at all (*26*). Welding, however, has become a high-tech science, and not surprisingly, it is one where the rest of the world leads.

But a lack of engineering talent is merely the tip of the iceberg. High school vocational and technical education is both less prevalent and of poorer quality than that found abroad (*2*, p. 217). Both the machine tool and semiconductor industries have suffered from a lack of intermediate skills, such as those of machinists, tool and die makers, and electronic technicians. Americans lack the math skills to compete in an increasingly mathematized production process (statistical quality control and computer programmed machine tools) (*6*, p. 20).

American firms also do much less investing in the skills of their own work forces. The time spent training to upgrade the skills of those expected to work in flexible manufacturing systems, for example, was three times as long in Japan as in the United States (*21*, p. 28). American firms do not invest since they cannot capture the benefits of their training. Their workers leave too quickly (in electronics the U.S. labor force turnover rate is four times that found in Japan) to recoup the costs that have been incurred (*27*).

When it comes to formal education, the United States used to have a better educated work force, but it now has a higher functional illiteracy rate and high school drop-out rate than those of all its major competitors.

The bottom line is a less well-trained labor force. The result is lower productivity and quality. Modern industrial armies require good privates and corporals as well as good generals. America does all right when it comes to producing technological generals, not so well when it comes to producing privates. The bottom half of the U.S. labor force simply compares poorly with the rest of the industrial world when it comes to both education and skills.

There may also be a problem in that less job security in the United States leads workers to resist technical changes more than those in Europe or Japan who know that new process technologies will not automatically lead to their unemployment. Negotiated restrictive work rules are much more prevalent than they are on the European continent or in Japan.

America's research is also differentially focused. Whereas total R&D efforts have kept pace with those in the rest of the world, nondefense R&D has lagged. In 1984, Japan spent 2.8 percent of its GNP on nondefense efforts, the United States only 1.9 percent (*28*). Business spending on R&D is also greater in both Japan and Germany than in the United States (*17*, graph 3). In America, government fills the expenditure gap with defense research.

Within our public research effort there is a much greater concentration on high tech. Whereas the United States spent 88 percent of its public R&D effort on high R&D intense industries, 8 percent on medium R&D intense industries, and 4 percent on low R&D intense industries, the corresponding Japanese division of expenditures was 21 percent, 12 percent, and 67 percent—exactly the reverse of the U.S. pattern. The Germany division was 67 percent, 23 percent, and 10 percent—a much less concentrated effort (*2*, p. 194). (A high R&D industry was defined as one with R&D expenditures relative to sales of more than twice the manufacturing average; a medium R&D industry fell between twice and half the national average; a low R&D industry spends less than half the national average.)

In some industries, such as machine tools, the defense involvement has led to tools so complex and sophisticated that they are too costly to buy and too complex to use in civilian applications (*15*, p. 71). Defense research is often defended as resulting in civilian spin-offs, but in recent years these spin-offs have been hard to find. As defense has gone into space the spin-offs either do not exist or take much longer to work their way into civilian applications. In fact, there have been more spin-ins than spin-offs. It is easy to cite recent civilian innovations that have had great military applicability (the transistor, the semiconductor chip, and the small computer); it is hard to cite the reverse.

The organization of R&D and production is also different abroad. Collaboration is much greater (*29*). Instead of developments taking place in a sequential line from research, to development, to production, to sales, the processes overlap leading to much shorter periods of time to bring products to market (*30*). Research engineers often go with their new products to form production teams.

But why should development systems be better abroad? Part of the answer may be found in the inability of technical people to communicate with nontechnical people and in the low prestige of production. No one wants to slow down a career by getting involved in production if it is not a route to the top.

In the United States, resistance from plant managers to process innovation is also common (*31*). This comes about because of the widespread use of narrow profit centers to determine promotions and bonuses (*32*). Managers do not want process R&D experiments made in their plants because they reduce plant output and thus annual bonuses (*33*). Yet process experiments usually cannot be carried out in a company's laboratories.

The cost of capital may also play a role. In theory with a world capital market, the long-term real rate of interest should be the same everywhere in the world regardless of whether a country's citizens are high or low savers. In fact there is a strong empirical correlation between high local savings rates, low real interest rates, and high levels of investment in plant and equipment. The world capital market moves savings around the world, the differences would be larger without it, but it does not move enough savings to equalize rates of interest.

In early November 1987, for example, real corporate bond rates (the rate of interest on corporate bonds minus the rate of inflation) were 8.2 percent in the United States and 6.0 percent in Japan. Low U.S. personal savings rates (expected to be about 3 percent in 1987) are compounded by a high U.S. federal deficit. Too much of what savings there is must be siphoned off to pay for public consumption.

When local savings is lacking, savings must be attracted from abroad with high interest rates, but these capital flows in turn raise the value of the dollar (to move money into the United States one must sell the local currency and buy dollars) and make U.S. products less price competitive at home and abroad. Knowing the handicap of a high valued dollar, firms are less willing to invest in new process technologies.

Having lower rates of interest allows foreign firms to aim for, and accept, lower rates of return on investment. This means that foreign firms can profitably invest in technologies that would be unprofitable in the United States. The result is higher capital-labor ratios and often newer technologies since these technologies must be embedded in new equipment.

Some of the problems in the United States can be cured with higher taxes or lower spending to reduce the federal budget deficit and with restrictions on consumer credit to raise personal savings rates. But both tactics reduce consumption and what American wants to consume less?

There may also be something to the idea that short-term pressures to have ever rising quarterly profits are more intense in the United States than elsewhere. One certainly sees patterns that make little sense on any other hypothesis. R&D spending in the United States is, for example, cyclical—falling in recessions and rising in booms. This is a pattern not observed abroad and it does not make economic sense. If a project is a bad project it should have been killed before the recession began; if a project is a good project it should not be killed simply because of a few months of negative sales. Cutting R&D is the easy way to make those quarterly profits rise while sales are falling since this has no short-run negative effects on sales. During recessions, plant expansion is also cut back more radically in the United States than abroad (*34*). Often, such as was the case in the semiconductor industry, this has given foreign competitors a chance to grab market share when demand expands at the end of recessions, since their U.S. competitors do not have the capacity to immediately service expanding demand and have fallen behind on developing new products or processes.

American firms are also much less willing to invest in new equipment to promote either the safety of the work force or the quality of the product. Both played an important role in the Japanese decisions to adopt robots faster than their American counterparts (*10*, p. 26). Auto welding is demanding, dirty, monotonous, and dangerous. Few workers can do a high quality job hour after hour, day after day. The Japanese thought that the long-run payoffs from higher quality cars were so great that in the short run they were willing to make noneconomic investments that did not meet their own rate of return on investment criteria. American firms were not willing to pay a premium for quality and waited for those rates of return on investment to reach the right economic levels before they invested in robots.

Although the high cost of capital is probably part of the answer as to why less is invested in process technologies here, it is clearly not the sole answer that it is often portrayed to be. When investments are going to be made and the only question is whether to invest in high capital-labor technologies or low capital-labor technologies, it is not the cost of capital that counts, but the relative cost of capital and labor. While U.S. interest rates have been higher than those abroad, so have U.S. labor rates. The World Bank study of slow robot adoption in the United States came to the conclusion that higher capital costs did not seem to play a role because of this factor (*10*, p. 47). Interest costs were twice as high but so were wages.

Higher capital costs cannot also explain why U.S. firms invest later and do not operate their existing equipment at the same level of performance. And it certainly cannot explain why Americans were investing in open hearth furnaces after the rest of the world had started to build oxygen furnaces since open hearth furnaces were more capital intensive than oxygen furnaces.

Active government industrial policies abroad have been used to push process technologies. In Japanese machine tools, for example, the Ministry of International Trade and Industry (MITI) encouraged firms to obey a 5 and 20 rule—they should not manufacture a particular product unless they had a 5 percent Japanese market share and that product accounted for 20 percent of the firms output. One company (FANUC) was encouraged to be the dominant supplier of control units for all machine tools and a 10 to 15 percent R&D subsidy was provided to the industry (*15*, p. 24).

The dominant view among American economists, although not my view, is that foreign firms succeeded in spite of government intervention (good intentioned help is really a hindrance) and not because of it. If so, then the success of industries such as Japanese machine tools has to be found among the failures of U.S. managers and labor and not in skillful policy interventions abroad. In contrast, I would argue that Japanese industrial policies have played a role in their industrial success in machine tools, but I would not want to argue that government aid was the dominant cause of their success.

Effective industrial policies are just one of the many ways that a firm can gain a competitive edge.

Ahead at the End

Those products (digital tape recorders, stereo television, the French interactive telecommunications system, many new drugs, and four wheel steering) where Americans do not have the fastest consumer adoption curves are the exceptions that prove the rule (*35*). Almost never is the slowness attributable to consumer resistance to new products. Almost always it is attributable to legal delays or backward U.S. process technologies.

The American recording industry has successfully blocked the introduction of digital recorders, and time-consuming drug testing laws have led new drugs to first be introduced abroad even if they are developed by U.S. firms (*36*).

The French got their interactive telecommunications system started fast because the French government gave (buried in the monthly charges) each telephone user the necessary equipment. American broadcasters have been slow to shift to high resolution stereophonic television transmissions. Four wheel steering is just one of many post–World War II innovations (radial tires, turbocharging, anti-skid braking systems) where American firms have been slow to innovate.

When the product is available, however, regardless of whether it comes from domestic or foreign producers, market penetration seems to occur as fast here as anywhere else in the world.

Conclusion

Process technologies are a U.S. logjam. Given an identifiable problem, what are the options. Wisdom starts with recognizing that there is no "silver bullet" solution. No one action—no matter how major—is going to cure the problem. The solutions essentially involve changing many of the organizational details of the U.S. economy, the U.S. education system, and the U.S. firm. If done together, each of these small changes in organizational detail can produce a structural revolution in standard U.S. operating procedures that will lead the United States to become competitive in process technologies.

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