Innovation, Technological Change

Forces that influence and determine technology development are discussed; government, university roles examined

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The German economist Gerhard Mensch advocates the view that innovation comes in bursts. He has developed a cycle theory based on the works of Kondratieff and Schumpeter. His prediction is that we are now in the beginning of a cyclic upturn.

But contemporaneous assessments of the long-range effects of new technologies have never been reliable. A study of the econometric models that have been developed clearly indicates their inability to predict the arrival or effect of breakthrough innovations or to take full account of the effects of such innovations once they have arrived.

This is understandable. The models try to explain and extrapolate past experience and to apply it on the future. But qualitative or breakthrough technical change introduces discontinuities and quantum jumps that no econometric macro model can predict. The same limitations exist on the effect of economic incentives on individuals and corporations.

Also, the tremendous implications of shift of values in society should be mentioned in this context. Suffice it to mention the shift in personal values and preferences among youngsters from the '60s and '80s.

In the U.S. we have seen the economic climate change to foster a highly entrepreneurial spirit. During the last 10 years, 20 million new jobs have been created in the U.S. During the same period 2 million jobs were lost in Europe and unemployment is soaring. If an economist in 1973 had seriously forecast that 10 years later there would be 30 million unemployed persons in the OECD countries, his credibility would have been seriously questioned. In 1982, growth in the OECD countries was heading toward zero, utilization of capacity was low, and profitability was depressed by high interest rates and saturated markets.

Since then we have seen some light in the tunnel. The U.S. economy has been a locomotive force for the other OECD countries since 1982. Inflation is down. Real interest rates are high, created partly by soaring budget deficits. The growth in the economy and the influx of money to the U.S. have sustained a high dollar value. These factors have made imports to the U.S. competitive and exports vulnerable. The trade deficit, especially toward Japan, has grown to worrisome dimensions. But if we look at the composition of the U.S. trade we will see a very strong and significant trend: The R&D-intensive manufactured products are increasingly important for the balance of payments. The economic outlook for Europe now seems a little healthier. But few large job-creating sectors of industry are currently planning to expand and increase capacity, apart from the electronics and automation industries that are expanding at an accelerating rate.

Now what about the future and our industrial and economic development? This question may be discussed in the light of four scenarios developed by Volvo and Shell.

Aggressive Structural Change

In order to achieve strong, long-term economic growth of the magnitude 4% to 5% per year — with society generally in balance — aggressive structural change is required within society as well as industry. Resources must be distributed efficiently among sectors, industries and regions. The resource-creating policy must be given priority over the resource-allocating policy.

A policy of this type has to be based on broad political support and perseverance beyond the artificial limits of the political mandate-term to govern.

Judging from the present election campaigns in Sweden and Norway such a policy is not in sight here.

Similar conditions are found in most European countries. On the other end of the scale we find the strategy-oriented economies of Japan, South Korea, Singapore, and France.

Fragile Compromises

It is more likely that the period of fragile compromises that we have had for a number of years will continue. The fragile compromises derive from a condition of indecisive parliamentary situations where substantial differences cannot be bridged. Minority governments, bloc policies, government crises, referendums, special interest politics, and conflicts in the labor market characterize this scenario. One manages to cope, but just barely.

The large organizations that dominate much of the countries' political life have been developed into instruments for negotiating about and preserving their shape of the pie.

If we cannot find effective political solutions to extricate us from these dilemmas, the next few years will see very severe strains. Open unemployment will increase to say 4% or 5%. Real unemployment in many countries may be 10 or 12 per cent. Young people with little theoretical or vocational training will find it hard to get jobs. Both the public sector and private industry will rationalize.

Health care and social benefits in industrialized coun-

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tries will suffer for two reasons: More elderly people and less money.

Continued high interest rates and excessive foreign debt in developing countries (Latin-American countries have a foreign debt of (US$ 360 billion) will foster reluctance to invest and to increase consumption in debtor countries. This is probably the most important political issue of our time.

Hard Times

If the fragile compromises become weaker or are sabotaged through political strikes or obstructions the country in question will meet hard times. The GNP will drop, the economy will enter a vicious circle.

Protection and Retreat

In the worst case developments get out of hand for the politicians and a depression causes people to lose confidence in institutions and politicians. This scenario is characterized by protectionism and retreat, with each country feeling itself forced to protect its own employment and its own industry.

Established values are eroded and international tensions are unleashed as a consequence of the protectionist trade policies.

We know of no way out of these problems except through economic growth. It is important to leave the marshland of fragile compromises and stubbornly carry through the aggressive structural change that is needed.

The Technology Factor

New technologies and technological innovation are the major driving forces behind productivity increases. This can best be illustrated by showing the results of a study by the Brookings Institution.

The study indicated that 44% of the productivity increase in the U.S. since the War could be related to technological innovation, about 16% to tangible capital investment, 16% to economies of scale, 12% to improved education and 12% to better allocation of resources.

Of course there is a strong interaction between each of the factors mentioned. None of the factors can be neglected without impairment to productivity in the long-run.

The general findings were also that economic growth results from slow, but steady improvements in technology and knowledge, as well as from breakthrough innovations.

The Breakthrough Innovation

A breakthrough innovation is the kind of happening that:

—Changes the direction of whole industries.

—Creates new industries.

—Changes the growth rate of the economy significantly.

The breakthrough innovation is basically unpredictable and certainly unforeseen as to scope, dimension and economic effects.

Typically, the breakthrough does not immediately displace an older technology. Advantages with the new technology may be marginal in the beginning. But then competition will widen the advantage.

Table 1 depicts some characteristic breakthrough innovations.

RECENT BREAKTHROUGH INNOVATIONS

Pharmaceuticals
- Antibiotics
- Birth control pills
- Recombinant DNA technology

Chemicals
- Herbicides
- Synthetic fibers
- Plastic films for packaging

Electronic Devices
- Transistors
- Integrated circuits
- Lasers
- Microchips

Computers
- Mainframe computers
- Minicomputers
- Microprocessors
- Software systems

Communication
- Optical fibers
- Digital switching

Transportation
- Jet airplanes
- Space vehicles

Reproduction
- Xerography
- Instant photography

Materials
- Plastics
- Ceramics
- Powder metals

Factory Production
- Tape controlled machine tools
- Robots

Table 1

Now, could we accelerate the process of achieving breakthrough innovations if the economic climate and other environmental conditions were right? The answer is definitely yes.

Today marks the leading edge of a revolutionary change in technology that began only a little more than a quarter of a century ago. That technology is drawn from an entirely new scientific base that bears little resemblance to the science that engineers and scientists learned even three decades ago. Today, one deals with phenomena that were inconceivable and impossible in the world of Newtonian mechanics. New industries are arising out of wave mechanics, quantum electronics, and the new physics of solids. Their products are revolutionizing older technologies in efficiency and in function.

The rest of this century may well become the age of telecommunications and telematics, leading to radical social changes. Robots are arriving rapidly in the factories. Fusion energy is making headway. Perhaps a breakthrough will come in this century, opening limitless horizons for energy supply. New materials are constantly being developed, in ceramics, metals, plastics, crystals, polymers, etc. The biological revolution looming over the horizon will of course have major impact on pharmaceuticals and health, but it will ultimately extend much further to agriculture, aquaculture and food preparation on a greatly modified basis.

JOB CREATION

It is important to be sensitive to those who are now employed, but who are concerned about future employment in a high-technology society. Educational systems must undergo major transformation to train the productive workers of tomorrow and retrain those of yesterday. But even so, can the winner in the pit be retrained to assemble silicon chips?

Jobs are certain to remain a key public policy issue for the foreseeable future.

In 1983 David Birch and Susan MacCracken of MIT published some important statistics related to job creation. They found that about 10% of the 19 million new jobs created in the U.S. in the 1970s were produced by companies with fewer than 100 employees. The net increase in the Fortune 500 companies was very small.

The data of Birch and MacCracken suggest clearly that the creation of new companies seems to be a key requirement for job growth. Out of the small companies some will experience explosive growth and create a large part of the new jobs.

So policies to foster entrepreneurial ventures are at least as important for job creation as policies that nurture existing companies. And both sets of policies should stress the implications of changing technology. Government management and labor must recognize that a high-wage economy requires a very high capital investment per employee.

Experience indicates that venture groups in bigger enterprises should be organized rather independently from the parent organization in order to be successful. Otherwise bureaucratic routines and the rigid ways that may be dominant in the company culture, may stifle the creativity and the freedom that entrepreneurs need to stimulate their enthusiasm and drive.

About five years ago American microelectronic manufactures were caught unprepared for the rapid expansion of the market for 64K RAMs. Made wary by a recession in the late 1970s, American manufacturers delayed investing in new facilities. But the Japanese went ahead. So when the market suddenly blossomed in the early 1980s Japanese companies captured most of the initial market.

American newspapers and periodicals were seriously concerned that their industry was forced to concede the RAM industry to Japan and perhaps leadership in microelectronics as well. But at the same time AT&T was getting ready to produce the next generation of memory chips — 256K RAMs. In 1981 the phone company was already installing those 256K RAMs in their switching equipment. Since then U.S. companies have been in the lead, and they talk about 100 million transistors per square centimeter by the turn of the century. But many industries — traditional and new — are being challenged. Competition is going to be there in virtually all industries from one ambitious country or another. We have entered a different industrial climate, one in which we have to reorient our thinking from traditional national markets to increasingly international arenas.

INNOVATION BY SMALL AND LARGE COMPANIES AND INDIVIDUALS

The contribution to innovation and technological development of large corporations, small companies and individuals is often misunderstood.

It is a fallacy to believe that innovation comes primarily from any one of these three primary groupings. They all innovate, each in its own way. The large companies have the cash flow and staff to implement the really large projects. They can take significant risks and often succeed in launching innovations by brute force.

Small companies and individuals are, however, equally important. Traditionally, they are the original sources of a disproportionate number of breakthrough innovations.

In the U.S. more than 50% of the founders of new firms came from well-established companies where they could not sell their ideas or found resistance to change. Such new companies play a critical role in keeping a steady state dynamic equilibrium in motion. As long as new firms are entering an industry, the rate of progress will not decline. But once entry slows down the rate of progress will. Venture capital plays a very important role in the financing of individuals and small companies that are essential for renewing and restructuring industries, create new products, and secure their success in the marketplace.

COMPETITIVE ABILITY AND EDUCATION

In the long run, competitiveness depends on the productivity and creativity of the work force, and that runs throughout an organization, from the managers to the engineers to the production supervisors to the people with their hands on the machinery.

Moreover, most economic scenarios predict a heavy and increasing demand for technical personnel before the end of this decade. In all likelihood our rate of economic growth is going to depend directly on the supply and on the quality of technically trained personnel across the board — PhDs and technicians in industry, researchers in labs, teachers in schools.

It is clear that countries wishing to be in the top league will have to strengthen their national scientific and technical personnel base. Our first priority must be for immediate emphasis on training people in those areas of science and technology likely to have the greatest impact on industrial growth. That is, we have to address the immediate problem of enough professional scientists and engineers.

That means concentrating on university training, where we can quickly capitalize on an existing mechanism that we know works well — the participation of graduate students in research projects as an integral part of their schooling. Universities are clearly important, both in terms of producing the new knowledge that stimulates technology and in terms of producing the people who drive the innovative process in society.

We presently experience a strong shortage of engineers in Norway. The shortage is general, but is most strongly felt in areas like EDB, telecommunications, etc. Also the number of PhDs trained every year is going down. Even if the shortage can be ameliorated by sending students abroad, that is no long-term solution.

Less than 15% of our student population are technical students. In Sweden and Finland the figure is more than 20. And I understand that this figure will be increased.

Now we also face a large problem than university education. That is the alarming lack of emphasis on science, mathematics and languages in our primary and secondary schools.

It is alarming when a Norwegian student examination is no longer automatically accepted as basis/or university studies abroad. The only lasting solution is for us citizens to restore school teaching to a profession of importance by giving teachers not only recognition, but also fair compensation.

PARTICIPATION BY FACULTY MEMBERS IN INDUSTRY

In the U.S., college and university professors have long been active in private business. We have, however, seen an increase in their participation in recent years. The growth of commercial interest in electronics and in biological research have spurred these developments.

According to a recent unpublished survey by the National Science Foundation, some 3,000 full-time science and engineering faculty members in the U.S. own or are major shareholders in outside companies. That is more than 4% of the total faculty. In the late 1970s, the figure was a little more than 1%. Many see these new-style professors as a vital force in speeding up the transfer of new ideas from the university to industry. But there is also increasing concern that such external interests may impair the faculty's drive to pursue their main missions of teaching and research.

Stories about university researchers becoming millionaires overnight may have led some of them to regard students and teaching as a nuisance. But it should be remembered that before Herbert Boyer could form Genentech Inc. he had to work very hard and break much new ground as a biochemist. His economic success has certainly inspired university faculty to hard and creative work in their labs. And I believe that many students have also been strongly motivated by such success stories.

We all know about the tremendous impact Stanford and Massachusetts Institute of Technology have had on commercialization of new technologies. And few will maintain that this sponsoring of entrepreneurship has led to reduced quality of teaching or research at these institutions. Other universities, in the U.S., in Europe and in Asia, are now trying to copy what Stanford and MIT have pioneered.

Science Parks have been established close to universities, investment grants, tax concessions and other incentives are being provided. Governments have started to view academic entrepreneurs as a source of hope for older industrial communities.

These developments have many positive side effects for the universities. But there are a few conditions to be observed. Academic and basic research have as their objective to understand scientific phenomena. Clearly, university researchers who want to exploit their academic work for profit, have to be very careful about their integrity and the potential for conflicts of interest.

All experience indicates that universities with proper funding of basic research projects attract highly-qualified faculty, and turn out creative students and knowledge of great value to commercial enterprises. Entrepreneurs with good ideas for commercialization are few and far between. A high level of entrepreneurs spinned off from the universities will therefore not represent a threat to their academic achievement, but rather an efficient means of technology transfer to industry.

ORGANIZATION OF RESEARCH AND DEVELOPMENT

I have dealt briefly with university research and its importance to industry. Over time many different types of relationships have evolved between universities and industry, such as:

1. Faculty members entering into individual agreements with an enterprise to provide consulting services in the field of their expertise.
2. Research grants and contracts between a university and a company. Some very big contracts in the U.S. have spurred the debate about the university's potential loss of its basic academic values.
3. Affiliate programs where several companies share the cost and get new insight in a special research area.
4. Industry cooperatives where an entire industry perceives a need for more educated professionals and more basic research, and together initiate the universities to take action.
5. Exchange of people where people from industry deliver lectures on campus and faculty members spend their sabbatical year working for a company.

The technology-transfer system between university and industry described above is based on the understanding that the companies are organized with research and development groups that are strong enough to be able to define their problems, contribute to their solutions and to know where to find specialized knowledge that go beyond their capability.

Most smaller firms at least in this country have missed this innovative force and have therefore lacked the ability to make use of the extensive system of research institutes.

For many university professors the opportunity to make new product contributions per se is important. They find the impact of their campus research greatly enhanced by moving into product development.

Most smaller firms, at least in this country, have missed this innovative force and have therefore lacked the ability to make use of the extensive system of research institutes that we have established during the last 40 years. Until fairly recently the rate of spinoff of high-tech companies from the institutes was fairly low. Most of their efforts was directed toward the bigger Norwegian companies who have their own R&D staff that could utilize the research potential in universities and institutes.

In recent years we have had a gradual shift in policy, and research grants have to a larger extent been directed to small and medium companies. This kind of seed money will undoubtedly enhance the smaller companies' potential to improve and develop their technological base.

Still more important is the need to have this technological base coupled to the marketing group within the smaller company. A survey of Norwegian high-tech companies showed that more than 70% of their international marketing executives had a technical background.

THE JAPANESE EXPERIENCE

The Japanese have demonstrated how by mobilizing human resources and by investment in human capital, in software and hardware they have assailed American preeminence in areas where they seemed to be undefeatable. Suffice it to mention robotics, laser technology, CAD/CAM, and other software.

Only in areas where Japan has great structural disadvantages as in military endeavors or where the cost of raw materials or energy are prohibitively high, does Japan trail far behind. But again the Japanese do not regard such barriers as not being changeable. Japan is upgrading the quality of research at its universities. The Japanese labor market has less resistance and structural rigidity than most adapting to the functional requirements of high technology.

The Japanese government and MITI are active in defining and sponsoring ambitious national research projects in areas like new materials, optoelectronics, etc. Japan has mobilized an extensive campaign to upgrade its capabilites in selected future-oriented technological areas and is now spending 2.4% of an ever-expanding GNP on research and development. The figure is expected to be 3% by 1990.

The number of researchers has increased from 18 to 27 per 100,000 population. Popular opinion is that technological innovation in Japan depends very much upon centralized industrial policy targeting. But the government's share of total R&D is smaller in Japan than in the U.S., West Germany, England, and France. On the other hand, MITI has assisted extensively in coordination and consensus building.

Japan's educational system is excellent when it comes to turning out students with high performance in mathematics and sciences. But the system seems to stress memorization over creativity or critical analysis. Japanese students, even at the doctoral level, shy away from attacking research problems that require them to build new theories. Their preference seems to be to research topics with known parameters and which can be solved by using existing theories.

Japan's whole R&D system is oriented strongly toward applied research and rapid commercial development. Little attention has been paid to basic research. If Japan shall be able to progress in, for instance, biotechnology and pharmaceuticals, Japanese universities have to make agonizing reappraisals of their attention to basic research in biology, biochemistry, chemistry and other natural science fields.

Japan's laser industry is lagging behind America's largely because university basic research in applied physics has been undernourished.

CONCLUSION

1. All parties seem to agree that our societies shall pursue policies to foster technological innovation and the application of new technologies to mature industries as well as to new high-technology enterprises.

2. The entrepreneurial spirit has been encouraged in the Scandinavian countries. Venture capital is available, chasing good projects and qualified people to run them.

3. The political system in the Scandinavian countries seems to give priority to the resources — allocating policies rather than to the resource-creating policies.

4. In order to stimulate innovation and growth in our Scandinavian enterprises, in a high-wage economy, increased emphasis on technological education is needed. Improvements should start with greater emphasis on sciences, mathematics and languages in primary and secondary schools.

5. Fundamental and long-range research in our universities should be strengthened in order to attract and develop highly-qualified faculty and students, and to push the frontier of our knowledge.

6. Every company, independent of size, should establish and nurture market-oriented technological awareness functions.

The density of engineers and technicians in new high-technology companies may be 40% to 50% as compared to the 5% to 12% in more traditional companies. With frequent product change, strong market-oriented development groups with applied research capabilities are necessary in future-oriented companies. Such groups are essential for efficient transfer of technology from universities and applied research institutes to companies.

7. We should encourage young scientists and researchers to regard their terms with basic and applied research institutions as a spring board for establishing new enterprises. Maybe we should even start university training in entrepreneurship, as we have seen demonstrated for instance at Babson College in the U.S.

8. There is a big but unutilized technology potential of great commercial value in our universities and applied research institutions. Ways and means to stimulate technology transfer between enterprises and research institutions in order to utilize existing knowledge is as important as creating new knowledge.

A couple of years ago the *Economist* gave the following comments on technology:

"Policy makers keep hoping that technology can rescue their economies. Actually it is the economies that need to be got right first. Technology needs economic policies that lead to expectations of high growth and profits, low interest and inflation rates. What is good for investment is generally good for technology. Purchasing promotes innovation best when the purchaser is pursuing self interst.

"Setting the right regulatory climate is another way governments can help innovation.

"Setting high standards can help to make an industry more competitive by forcing it to deploy modern technologies. This should be a trust-busting climate that discourages monopoly (allowing bright young companies to compete) and avoids inordinate delays in letting technology be implemented, e.g. by imposing realistic standards."

And as Brian Quinn comments:

"These are excellent guidelines if coupled with a true vision of a better tomorrow and a commitment to maximum human resource development supporting that vision. Today most of the limits as to what can be done are set by imagination and institutions. Never in history have science and technology offered so many options to improve living standards and lifestyles for humans. Somewhat like politics, engineering is the science of the possible.

"The challenges are firstly to release scientific, engineering and managerial imaginations and secondly to eliminate institutional barriers to meeting future demands.

"If these can be accomplished, there need be no insurmountable limits to potentials of manufacturing and its compatriot service sectors in satisfying world needs for production goods, life quality and environmental protection."