What industry expects from science

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At present, industry seems to expect much less from science in general and from its academic home base in particular than during the times of technology push, where industry itself was a major source of science. The volume of science for science sake has, in many fields, grown beyond its perceived utility. The reasons for this change are discussed in their historical context in order to derive ideas for improvements. Yet it is by no means certain, that the good old times of technology push will come back. The demand for existing technology in Asia is much larger than the demand for new technology in the saturated G7 countries. New technology has a comparatively small market, unless it is less expensive and less risky than existing technology. Industry must expect therefore that science listens to non-scientific input already in the planning phase. Funding authorities appreciate this. Creative scientists, who apparently had the freedom to do research for its own sake, were often the most successful innovators of the industrial society. They won their support. This is still the model for funding research and excellence in any field. © 1997 by John Wiley & Sons, Ltd.

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The four development periods

We will consider four periods in the relationship between science and industry: The initial period until the end of the 19th century, the market pull period during the first part of the 20th century, the technology push period until the fall of communism, and the new period just beginning and whose impact is still unknown to us.

The initial period was clearly dominated by the UK and its technology. It started with the steam engine and Adam Smith's 1776 vision of the wealth of nations, to be based on the division of labour, technical progress, accumulation of capital (stock), the legal frame, and perfect competition. This vision carries us well into the next century, where Asia will develop into a leading economic

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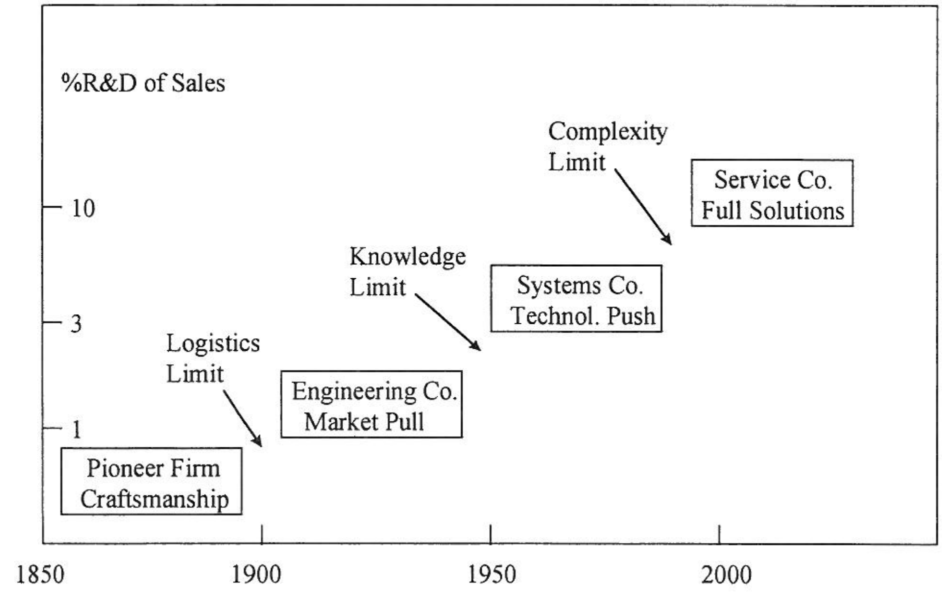

Figure 1.

region. We start with our relationship (see Figure 1) in the middle of the 19th century when the UK received its first continental competition. The relationship between academia and industry was nearly negligible. Only the chemical industry had established solid relations with academia. Most of industry still had a craftsmanship approach to innovation. Siemens and Halske was founded, just as Boulton and Watt a century earlier, by a business man and a fine mechanic. The US started to industrialize after the civil war which ended the dominance of the agricultural South and prompted the conversion of the land grant colleges to engineering institutions, led by the MIT. In France the Politechniques were founded.

From the beginning of the 20th century the demand for technology products required more professionalism in management and production. The first 45 years were dominated by market pull. Batch processing was extended to work flow processing. Ford's Model T was the first example of systems engineering, and of the change from custom-made systems into mass production. Consequently, the success story of industry–university interaction began with the engineering sciences. Every little kingdom in Germany opened its 'Technische Hochschule' where mathematics, physics and chemistry were considered, as in the French politechniques, to support engineering, not to do independent science as in the traditional universities. In Europe this interaction could have created a very prosperous period of growth, but two world wars destroyed this opportunity, and so the US took the lead, for this century at least.

The Manhattan Project marked the beginning of 'Big Science' and the technology push period. AT&T's Bell Laboratories, for more than one generation the Mecca of industrial physicists, was responsible for two major advances in 1947, Shockley's transistor and Shannon's information theory. Chemists had always had their own industry and were very successful without much publicity. Now physicists were getting the full attention from cold-war governments, funding agencies and the public. Huge government laboratories were established in all leading countries except Japan. Industry built large central laboratories in virgin land (as secluded and well kept as their government's). The natural science and engineering departments of universities had to produce the necessary volume of scientific staff within a very short time. The postwar economic boom (the 'golden years') with real growth rates of 5% to 7% per year allowed for an unprecedented extension of the relevant university departments, specifically mathematics, physics, chemistry, engineering and economics. In many cases, quality could not keep pace with quantity. With a short delay, but with even more drive, Japan followed the lead and excelled in manufacturing the most demanding components.

The technology push era ended with one of its best side effects, the fall of communism. In terms of GDP per capita, Adam Smith's industrial society gained the G7 countries two orders of magnitude in the last 250 years, and an end is not in sight. In terms of the real growth rate per capita, however, all our great innovations gave us only 1.3% per year. This is the result if we take the industrial society at large, the (virtual) state-of-the-art of society with the highest GDP per capita at any time: i.e. the UK's GDP from 1750 to 1910, then the US's GDP, and now Japan's GDP. The later a nation committed itself and had the full opportunity to industrialize, the higher was its growth rate, specifically after a severe breakdown: we have mentioned the golden years after the Second World War with 5% to 7% per year. Now Korea and China grow at 9% to 11% in real terms per capita per year. Eventually all countries which manage to close the gap to the state of the art must make the transition from their catching up growth rate to the state-of-the-art growth rate of 1.3%. Once at the top, no country can grow faster than the industrial society at large, unless it innovates at a pace the whole of industrial society has not seen since its beginnings 250 years ago.

This fact is at the origin of the G7's structural problems: the downsizing of industry, the persistent unemployment, the reduction of science and technology in industry and, with some delay, also in government. The G7 countries have their infrastructure essentially built up, worth approximately \$73 000 per capita (capital stock), requiring about \$5 000 per capita per year for maintenance. If we include our private infrastructure (housing, cars, equipment), education and social benefits, the G7 maintenance charge approaches the GDP per capita (\$30 000). We can say now there is a maintenance mentality with not enough money and spirits for new growth. Or we can say there is no way to grow beyond the point where the gap is closed, and the level of wealth possible at the top with the state-of-the-art growth (1.3% per year) has been reached. In the long run the second interpretation is correct, the first is wishful thinking.

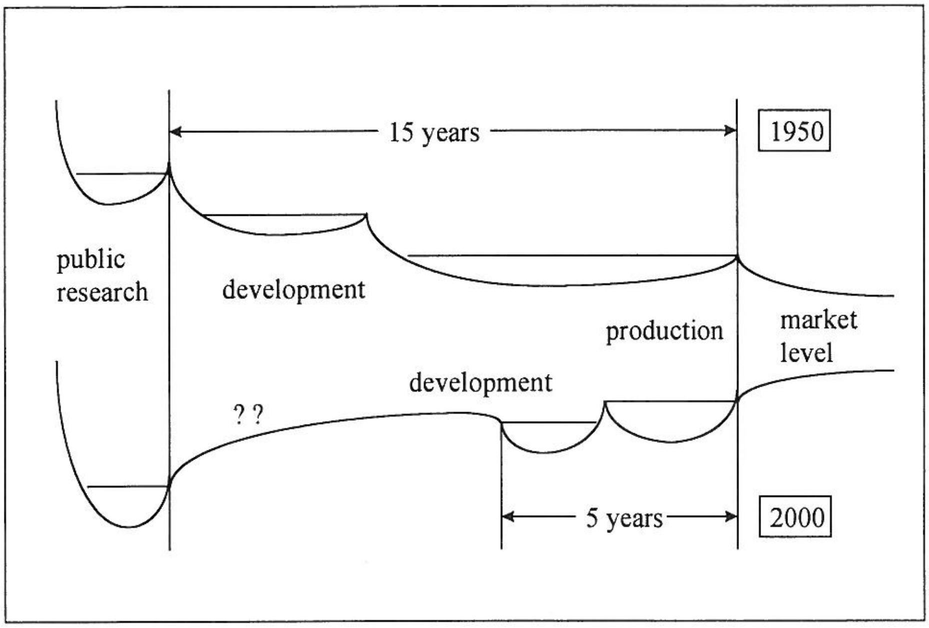

Figure 2.

In contrast to the mature industrial societies, East Asia's growth rates combined with its huge population makes Asia the centre of industrialization for the next two generations. It needs existing technology; Asia cannot wait for very new developments. There are good scientists and engineers: When Asia can afford even better technology than the present state of the art, they can provide it. For the time being, however, our industrial potential is welcome, and we must make the best of it by establishing long lasting relations. This is the beginning of the new period.

Industry has had to adapt to this change by reducing its volume in the G7, streamlining its operations to be globally competitive with the best, in order to win some share in the development of Asia. Industry expects that science in the G7 countries understands this need for change as well, to reduce its volume and to streamline its operations. This must not only be achieved without damage to the best performers in science, but must be understood as an opportunity to strengthen excellence and effectiveness, when industry's example is accepted. In many ways we are back in the second period of market pull, but at a much higher level.

The change for science

The meaning of excellence and effectiveness can be different for scientists and industry. In order to show this, Figure 2 compares the changes which took place in academia, industry, and the market between the technology push period and the new period.

In the technology push period we had so many excellent inventions, and such a low market position, that innovation was nearly effortless. This is indicated in the upper series of 'lakes' full of good product ideas. Industry's product generation time was of the order of 15 years (the military product cycle). This provided enough time for science to discover, for central laboratories to develop, for factories to produce, and for sales to market the products in sequence. The industrial laboratories in their thoughts and timing were close to academia.

Today academia has dug much deeper because the easy discoveries came naturally first, the number of researchers has multiplied, and the number of natural secrets to be discovered did not multiply accordingly. The market level is very high and fully competitive on a global scale. Product generation time has shortened to 5 years average. Consequently, industry has had to bring development much closer to production and to organize all functions in parallel. Two changes are apparent: instead of just falling downstream, innovations must be skilfully lifted to the market level; and the gap between academia and industry, between invention and innovation, has widened dramatically.

This separation between academia and industry has taken place in all disciplines and in all countries, although to a different extent. The largest separation took place in economics in Germany, the smallest in physics in France (according to the author's observations). If any interpolation is allowable, centralistic countries tend to show smaller gaps, and the gap widens with the number of supported scientists outside industry.

In the rich countries, the most effective way to bring science and industry together is to reduce the funding level. But industry is in no way free of guilt with respect to the gap. Its present short-term return on investment policy is not conducive to endogeneous growth, and the continuing consolidation still offers productivity gains in research and development. Furthermore, the resource research and development has become nearly as mobile as capital in today's world. This is particularly true for the development of software and simulation, which have replaced hardware research to a large extent.

Some recommendations

It is important that science should understand the changes that have taken place in industry and society, and which have been described in the preceding sections. The following recommendations will then be understood better and implemented in the correct way.

Risk taking and surprising results

Sell or perish is industry's equivalent to academia's publish or perish. Industry expects therefore, that at least 10% of science takes high risks, pursues the unlikely, and gets startling results. For some fields this may mean funding projects which would not pass the scientific establishment (some peer reviews). Therefore, industry supports courageous programme managers in funding agencies.

Industrial technologies

Most of the leading industrial societies publish their list of important future technologies and some 'road maps'. They overlap of course, considerably. Industry updates those lists continuously. It expects science to know them and to contribute freely to their development. Funding agencies make sure that science cooperates within this framework of future needs, as in the case of the European Framework Program.

Me too's

All the research activities not belonging to one or both of the preceding categories shall be scrutinized carefully. There should not be so much *l'art pour l'art* in science as there is in some traditional fields.

Critical mass and quality

In the information society there is little sense in financing critical mass and excellence at many places and in different times.

Assessment of impact

When governments were still humble and poor, they had little money to spend for the people's benefit. Consequently, all the administrative efforts were focused on the selection process for the recipients. That is the essence of 'cameralism'. Today governments are less humble and have a lot more money to spend. Consequently, they ought to shift their emphasis to the assessment of the results of their beneficial operations. This means the evaluation of the impact of each project several years after completion. The result will be that recipients will immediately shift their efforts from getting the money to achieving impact.

Joint project definition

Technology transfer is outdated. Probably it never worked, because we saw with Figure 2 that the real success of the technology push period, supposedly the model for technology transfer, was due to a 'waterfall' phenomenon. Today we need agreement on the goals of a research project between academia and industry, already in the planning phase, to ensure innovation, i.e. a market success. The probability that a spontaneous research project will fit the need in time, and with the available manufacturing technology, is too small to warrant the effort.

Science as tutor

A final word might be said concerning the added value of science in education. Clearly industry is interested in excellent graduates, but only 3% will find a good job in research. Yet it seems that research is the major purpose of higher education. In order to correct this, it is quite helpful to consider the human capital value given into custody at our universities. Six to eight years of the most valuable time of young people means, in terms of lost earnings, $0.5 to 1 million per student, not counting future income and higher responsibilities. Since on average we have 30 to 50 students per professor, each of them is entrusted with a capital of the order of $30 million. Whether each professor really perceives this and performs accordingly is a good question. It should convince him or her that the development of personal qualities is the real educational challenge, *not* his or her research projects.

Author's biography

Hans Günter Danielmeyer was Professor of Experimental Physics, President of the Technical University of Hamburg 1978–86 then member of the board of Siemens A.G. Policy Board German Industry Association. Vice President European Science & Technology Assembly.