SEWPS

SPRU Electronic Working Paper Series

Paper No. 98

Policies for Developing New Technologies

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August 2003

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This paper has been prepared for the 3rd Edition of *Claves De La Economía Mundial*, published in Madrid.

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Abstract

Section 1 of this article identifies a central feature of technology policies pursued during the second half of the twentieth century. This was the very widespread concentration on policies to promote the creation, dissemination and application of information and communication technology (ICT). Section 2 asks whether this heavy concentration on one technology is likely also to be a feature of technology policies in the next half century for some new general purpose technology, such as biotechnology. Section 3 examines the potential of biotechnology and concludes that it does not possess that special combination of characteristics which made ICT such a uniquely strong candidate for supportive policies everywhere. Finally, Section 4 reviews the economic and social climate in which new technologies are likely to be further developed in the twenty-first century and concludes that this will probably not be so favourable to a renewal of high growth. However, the development of a combination of several new technologies with ICT and a strategy designed to promote their application in the poorer countries of the world does offer some hope for a more favourable outcome.

Policies for Developing New Technologies

1. Introduction

The last quarter of the twentieth century witnessed a remarkable convergence of policies for new technologies. Almost every country, whether in Western or Eastern Europe, whether in North or South America, in Asia, Africa or Australasia, has pursued policies for the development of Information and Communication Technology (ICT). Some of these were concerned mainly with the private sector, some with the public sector, in most countries with both, the precise mixture depending on the political regime, the structure of industry, ownership of the telecommunications infrastructure and so forth. These features were themselves changing fairly rapidly in many countries, most notably in Eastern Europe. But whatever the political and social regime, the preoccupation with ICT was observable everywhere and identified in numerous surveys by international organisations.

This common endeavour could no doubt be attributed to the widespread conviction that ICT was an extraordinarily pervasive technology which could be fairly characterised as a “General Purpose Technology”, i.e. one which could and would be used in most sectors of the economy and many different activities. In manufacturing industry almost every technique offered some possibilities for process control through computerisation, whilst office functions offered even greater possibilities.

It would be true to say that just after the Second World War, the ICT enthusiasts were relatively few in number. In those days, it was nuclear technology which attracted far more public attention and far more government funds than ICT. It had been by far the most spectacular and the most effective and devastating technology of the war and it had been the direct result of a massive government programme for the development of technology – the so-called “Manhattan” Project. Enthusiasm for ICT was confined to those few people in the academic world who had pioneered small-scale computer projects, sometimes in collaboration with the military, for aircraft design, artillery computations, or decoding enemy communications. In those early days even firms, such as IBM who already had some experience of government projects were not at all optimistic about the future applications of computers in industry.

These perceptions changed radically in the 1950s, 1960s and 1970s. Many new firms entered the industry and a wide range of new applications was rapidly developed, such as payroll and stock control. Costs fell by an order of magnitude and the speed of executing simple instructions increased by several orders of magnitude (Table 1). As the technology was improved still further, and new software programmes multiplied, large numbers of people became familiar with them and social scientists, such as David Bell and Manuel Castells began to speak and write about the “Information Society” or the “Knowledge Economy”. These terms passed into general use reflecting the almost-universal social acceptance of the new technology. Every human society of the past has of course been in some sense an information society but the use of electronic computers to record, store and disseminate information revolutionised the concept.

Probably, therefore, the development and diffusion of ICT has been the most widely supported technology policy of all time. At various times, and for short periods, the concentration of technological efforts and the proportion of government funds directed to another particular technology may have been somewhat greater. This may have been the case, for example, with aircraft technology and with radar in a few countries early in the Second World War. It was certainly the case with nuclear technology at the end of the Second World War and during the first decades of the ‘Cold

War'. But for sustained activity over a very long period and with an enormous range of applications in the civil economy, ICT is without parallel. Moreover, it was and is also without parallel in the range of countries which have followed deliberate policies to improve and diffuse the technology and to extend the scope of applications.

In this perspective it is perhaps not surprising that both policy-makers and visionary scientists are sometimes engaged in trying to identify the next great "General Purpose Technology" which should be promoted in good time in order to keep pace with world development or even gain an early lead in world competition. The second section of this article therefore examines the characteristics of successful pervasive technologies and compares these with some which have not been quite so successful. In the light of this discussion, Section 3 looks at the claims of biotechnology to offer such a wide range of investment opportunities and potential applications that it might follow ICT as a general purpose technology capable of giving a new impetus to the entire world economy and usher in a new period of high economic growth.

However, great expectations are not always fulfilled and every major new technology has its own unique characteristics. In the case of biotechnology, these are not so favourable to high growth as was the case with ICT. Moreover, each new technology has to be developed and applied in new historical circumstances, which may not be so favourable as was the case with ICT. Section 4 of the article briefly considers the events which are now unfolding in the world economy and concludes that they may be less favourable for a period of high growth unless rather different technologies are promoted combining ICT with biotechnology and also with renewable energy technologies.

2. Successive Industrial Revolutions

The hugely successful world-wide diffusion of ICT has done much to restore the concept of “successive industrial revolutions” first enunciated by the Austrian economist and one-time Finance Minister, Joseph Schumpeter. Whilst Professor of Economics at Harvard from the early 1930s until his death in 1950, he became very well-known for his insistence that it was innovation which was at the heart of competition, economic development and growth in capitalist societies. More than any other economist he popularised the ideas of the Russian economist, Nikolai Kondratieff, in the economics profession. In particular, in his work on Business Cycles, he designated the longer cycles of 40 to 60 years’ duration as “Kondratieff Cycles”. Schumpeter explained these long-term transformations in terms of periodic revolutionary changes in technology.

According to his interpretation, innovations could not be regarded as isolated, discrete, individual events, but as “clusters” of events, which were both technically and economically inter-related. Consequently, the appearance of new technologies and their entry into the social system was not a smooth, continuous process, but one of alternating periods of explosive change, followed by periods of relative stability.

Schumpeter himself was not specially interested in developing technology policies in the sense of active efforts to promote or prevent the creation and diffusion of technologies, believing, as he did, that only the efforts of outstanding innovative entrepreneurs could drive such changes. His major work on “Business Cycles” appeared only in 1939 and was overtaken by the events of the Second World War, which however showed conclusively that the appearance and application of new technologies could indeed be accelerated for the needs of the military forces. This was shown not only for weapons systems but also for drugs, such as penicillin. Earlier wars and the preparations for them had already demonstrated that such innovations could be introduced and applied as a result of determined policies, even with a fairly low level of funding. The significance of the Second World War technologies was the spectacular scale of development, the close collaboration of industry, universities and government and the links between science and technology. Policies for the development of science and technology which had hitherto been spasmodic and relatively small-scale, now became recognised as a regular requirement of government, at first in the military field but soon for civil industry as well. The military example proved contagious.

The area in which this was most quickly recognised and most energetically pursued was of course nuclear technology – by far the most spectacular and the most expensive of all the technologies developed during the war but by no means the only one.

Military objectives continued as the main incentive for the vast expenditures of the super-powers, as well as some smaller countries such as France, the United Kingdom, and Yugoslavia. But in all these countries too, civil nuclear technology was also energetically pursued. Thus, although it could not perhaps be described as a "general purpose" technology, it was certainly a multi-purpose technology, since cheap and abundant energy was thought to offer the possibility of lower costs and greater efficiency in almost any industry. Although he did not speak of "general purpose" technologies, Kondratieff himself did emphasise the importance of waves of new investment in the infrastructure in stimulating economic growth.

However, this early enthusiasm for civil nuclear technology was followed by a long period of disillusion and in the last few decades of the twentieth century very few new nuclear power stations were ordered or constructed. Thus, in the same period that

ICT was advancing by leaps and bounds all over the world, nuclear power stagnated. The explanation of this contrast is fundamental to the purpose of identifying the future prospects for other candidates as general purpose technologies. Table 2 lists the key requirements for success and demonstrates that while ICT possessed them all, nuclear technology did not prove to do so over the long haul and in fact, lost some of its comparative advantages during the last quarter of the twentieth century. The key to this relative failure was in the persistently high capital costs of nuclear power stations which meant that other sources of energy remained highly competitive, even when oil and coal became more expensive. This was quite contrary to the early expectations in the 1950s of universal availability of cheap nuclear power.

The cost experience of ICT was completely different. Costs fell by orders of magnitude in numerous applications and a series of major breakthroughs in technology promoted universal expectations of continued cost reduction (semi-conductors, integrated circuits, optical fibres, etc. etc.) which proved well-founded and generated a virtuous circle of cost reduction and expanding sales.

The nuclear industry itself is hoping for a renewed spurt of growth following the depletion of fossil fuels to a point where they become much more expensive. There are still powerful lobbies for nuclear energy in several industrialised countries. However, the prospects for more genuinely renewable energy sources, such as wind power, tidal power and solar power must now be taken much more seriously, as well as the potential of hydrogen for automobiles. The world-wide political and social environmental movements are now a major factor in the business environment as well as in the political system itself. Consequently, the long-term future of nuclear power must still be considered as rather uncertain and certainly in no way so bright as ICT.

3. The Future of Biotechnology

The discussion in Section 2 is helpful when it comes to considering the future of biotechnology. Every technology is unique but the discussion points to some features of their diffusion and assimilation which are essential for the success of any technology. As was the case with nuclear technology, the scientific predictions of its potential were so favourable that its success seemed assured and it was widely regarded as a probable successor to ICT. Almost as much excitement and hype attended the launch of some new biotech firms on the stock market as with some internet firms a few years later. Biology, which had for a long time been the Cinderella of the natural sciences, now became the most favoured recipient of grants and contracts from industry and government.

Yet a brief consideration of the points in Table 2 must give cause for some reservations about the long-term future of biotechnology. The discussion here of course refers to the “new” biotechnology (or “molecular biology” as it is sometimes known) and not to the “old” technologies, such as fermentation which have been used in the food and drink industries for hundreds, even thousands, of years. It was the new biotechnology based on the revolutionary technologies which followed the discovery of the double helix, which gave rise to such high hopes both for medicine and for the economy as a whole.

Numerous new applications were being forecast during the 1970s and early 1980s, but many of these hopes have not been fulfilled. In particular, biotechnology has not transformed the chemical industry, although it has begun to transform the pharmaceutical industry. In basic chemicals and animal feeding stuffs, new routes for production based on molecular biology have generally not proved cost-competitive with the established process routes. “Bio-reactor” facilities have hitherto shown high capital costs and even the present enthusiasm for using farm animals as live bio-reactors rather than special plant and equipment has not yet reduced costs decisively. R&D costs for new products and processes also continue at a rather high level but the combination of scientific advances in biology with huge increases in the capability of computers does still hold out the promise of big cost reductions in the future.

By 1988, an OECD group of experts concluded that while biotechnology would have major social consequences in terms of healthcare and in agriculture, it would not become a dominant technology in industry. They rated ICT as two or three times more economically significant in terms of the range of new products or services offered and three times more effective in terms of cost reduction for existing products and services (OECD, 1988: 36).

Since then, the one area where molecular biology has made very impressive progress is of course agriculture. Huge improvements in crop yields have been demonstrated by the use of GM techniques (i.e. by the use of genetic manipulation in the production of seeds). But this example also demonstrates one of the major problems with the diffusion of biotechnology: social acceptability. Whereas GM techniques have been quite widely diffused in United States agriculture and in a few other countries, there has been considerable hesitation and even resistance in most European countries and parts of Asia and Latin America. Fears of monopolistic control of seed production and distribution have interacted with environmentalist fears of long-term effects on other plants and animals in the eco-system.

Many of these fears and doubts are based on a poor understanding of the science of genetics and the techniques of producing GM foodstuffs, or even on complete ignorance of these topics. Nevertheless, even those fears which are irrational cannot be completely ignored and some of the reservations are actually quite well-founded, creating an area of fruitful debate within the scientific community. As the previous case of nuclear technology already demonstrated, problems of social and political acceptance can seriously increase the costs of diffusion and delay the process considerably. Finally, as with nuclear technology, there are problems of the high skills required. One of the main reasons for the slow adoption, or even the non-adoption of biotechnology in chemical firms was the lack of appropriate skills in biology and biochemistry. In some large firms, the management and even the R&D were almost a monopoly of chemists and chemical engineers who were often unsympathetic to the claims and the potential of the new rival technology.

As was the case with nuclear technology, the adverse influences on diffusion interact with each other. The failure to achieve major cost breakthroughs in industry, the public fears and opposition, and the still relatively narrow range of applications all interact to make biotechnology an unlikely candidate for the role of a general purpose technology capable of lifting the entire world economy onto a new plane of high growth. This certainly does not mean, however, that it will be an unimportant technology in the twenty-first century. On the contrary, it is likely to be extremely important, although in a different way from the early expectations. Paradoxically, it will be important not as a successor to ICT but in combination with ICT. In the form of bio-informatics it will be a major source of transformation of the quality of life while the diffusion of ICT itself will probably continue to be one of the main engines of growth in the world economy.

According to one estimate (*The Economist*, 2002), the world bio-informatics market is expected to grow from $12 billion in 2001 to $38 billion in 2006. This source attributes the extraordinary growth of this market not only to the IBM Life Sciences Division, Sun Micro-Systems, Hewlett Packard and other large ICT firms, but also to a new swarm of start-up small firms. This new band wagon for the computerisation of genetics resulted from the sequencing of the human genome combined with the invention of DNA micro-arrays and the continuing massive increase in computing power with Pentium micro-processors.

The past history of public support for technology policies has demonstrated that the greatest attractors have been in the areas of defence and of medicine and it is probable that many countries will continue to invest public funds in both. This is particularly true in the case of the United States, already committed to huge expenditures in the Budget forecasts. But these public outlays, although certainly very significant would not in themselves be sufficient to drive the entire economy upwards, unless they are complemented by even greater private investment expenditures. The new investments of the drug companies, desperate to bring new drugs to the market are one indication of the possibilities in the growth of bio-informatics. However, the range of this activity is still far too narrow to generate the kind of world-wide upturn in economic activity which is needed. The final section of this article turns to consider the state of the world economy and the nature of such a stimulus.

4. *The Growth of the World Economy and the Development of New Technologies*

Drawing together the arguments of the first three sections of this article, it seems highly improbable that biotechnology has the necessary combination of characteristics to give the scale of impetus to the world economy which is likely to be needed to usher in a new period of really high growth. It does not have the huge range of applications of ICT or even of some earlier general purpose technologies such as electrification or steam powered mechanisation. Nor does it yet show the huge cost reductions which have been such a remarkable feature of the progress of ICT. Finally, like nuclear power, it has been dogged by widespread public opposition in many different countries arising from anxieties about the long-term environmental and social consequences of some major applications. These anxieties are unlikely to be diminished by the present international concerns with terrorism and biological weapons, although of course in some narrow specialised areas large R&D and diffusion programmes will be pursued to counteract these threats.

Even if the further development of biotechnology proves more favourable than this assessment suggests, it is unlikely that it would prove strong enough to overcome the weaknesses in the world economy single-handed. It simply does not have the scale of investment and sales which would be needed to achieve this. Whereas it is some-times asserted that the "fundamentals are sound" in the United States economy, this is far from true, as is evident from numerous indications. The deep decline in the stock market between 2000 and 2003 is only one of these. This decline cannot all be attributed to anxiety and uncertainty about a forthcoming war, although this has certainly been a major cause for concern. The United States administration has attempted to counter this decline by a combination of monetary and fiscal policies but, as Alan Greenspan himself made clear in his testimony to the Senate Banking Committee on February 11th, 2003, there are serious doubts about the proposed increases in Federal expenditures, which he himself shares.

It was not only in Congress that very serious doubts have been expressed about the combination of heavy increases in expenditure and big tax reductions for several years ahead. Aggregate debt of households, corporations and government in the United

States already increased from $4 trillion in 1980 to $31 trillion towards the end of 2002. These levels of debt were only surpassed as a percentage of GDP in the Great Depression of the early 1930s. The decline in the dollar and the likelihood of further international currency adjustjments is an additional cause for concern. Some of these worries found expression in the statement of a large group of American economists, including four Nobel prize winners.

The long-term decline in the savings rate and the demographic trends with the so-called “baby-boomers” reaching retirement age will place further increased strains on the public finances as well as on private households. Finally, internal security expenditures and the war on terrorism seem likely to prolong a general climate of uncertainty and fear which is unfavourable to new productive investment and economic growth, both in the United States and elsewhere.

In the second half of the twentieth century, despite some serious fluctuations, the world economy experienced its fastest economic growth rate ever achieved over a long period. In analysing this relatively rather successful period economists often used the expression “engines of growth” to describe the source of the major stimuli to the sustained growth of the world economy. It was often pointed out that if the growth rate faltered in one or other region of the world, this could be compensated by higher growth elsewhere in the global system. For example, when growth in the United States or Western Europe slackened in the 1960s or 1970s, this was to some degree compensated by higher growth in Japan and other Asian countries. When growth in Japan slowed in the 1990s this was compensated by a renewed surge of growth in the United States and so forth. The fear was always there that all the “engines” might slow down together, thus inducing a deep world-wide depression as in the 1930s. These fears were especially intense in periods when the world price of oil rose rapidly and many countries simultaneously took measures to counteract inflationary pressures. However, although the growth of the world economy did indeed slow down in the fourth quarter of the century in comparison with the third, there was enough steam (or oil) in the various engines of growth to avoid a deep world-wide depression of this kind.

During the fourth quarter a subtle shift took place in the use of the expression "engines of growth": whereas in the third quarter it simply referred to fast or slow-growing *countries* or *regions* of the world, in the fourth quarter, it was increasingly used with reference to *technologies*. Among professional economists the work of Bresnahan and Trajtenberg (1995) was influential in spreading the concept of engines of growth linked to general purpose technologies. Among investment analysts the book by Alasdair Nairn (2002) on "*Engines that Move Markets*" was typical of this new genre, which sought to demonstrate, after the manner of Schumpeter, that from the time of canals and railways to the time of the Personal Computer and the Internet, the growth of world markets had been driven by successive technological revolutions. Alan Greenspan himself took up this theme when he attributed the spurt of growth in the United States in the 1990s to the so-called "New Economy" based on ICT.

One reason for some of the increased pessimism about the prospects for world economic growth in the twenty-first century is that neither the "country" engines nor the "technological" engines appear to be in good enough shape to lead a major revival. Scepticism about the "New Economy" boom was already quite widespread before the bursting of the Internet Bubble.

However, although at first glance the outlook appears bleak, a deeper analysis shows that there are actually some more hopeful possibilities both for the "country engines" and the "technological engines" and even more for a combination of the two. In the first place, analysis of technological revolutions and their diffusion shows that the initial spectacular upsurge and the bursting of the early bubbles is usually followed by a longer period of absorption during which the enormous potential of the technology is fully exploited after learning the hard lessons of some unprofitable ventures and blind alleys. Schumpeter himself already pointed to this type of sequence and a number of economists have recently presented convincing arguments that there is still a huge as-yet-unrealised potential in ICT, especially in combination with other new technologies and in the less developed regions in the world. One example of this more optimistic analysis is the work of Brian Arthur (2002) of the Santa Fe Institute. He points out that the bursting of the early railway bubbles in the 1840s was followed by a long period of growth based on railways. Another example is the work of Carlota Perez (2002) in her book on "*Technological Revolutions and Financial Capital*" which is particularly notable for its analysis of the changing roles of financial capital and production capital during successive phases of a technological revolution. Her argument leads to the conclusion that a prolonged period of more prosperous growth is quite possible as ICT is absorbed into the international economy on a vast scale through a wave of new production investment.

Justification for her view is to be found in the relative performance of the Chinese economy in recent years and to some degree also in that of the Indian economy. These countries, the two largest of the less developed economies, have both enjoyed high growth rates of their ICT industries, together with growth of their economies more generally, yet there is still obviously far more scope for raising living standards both there and throughout Asia and even more in Latin America and Africa. To adapt the new technologies to meet the needs of the poorest people is surely one way to develop new engines of growth in the world market. It was this possibility which inspired the leading development economist in the United States, Jeffrey Sachs, to speak of "Weapons of Mass Salvation" (WMS) and to argue that the US Administration should be spending more on WMS than on WMD (Weapons of Mass Destruction). He argued the case largely on humanitarian grounds – combatting AIDS, malaria, TB and so forth – but a very strong case can also be made on narrower economic grounds. The future prosperity of the whole world economy (and the defeat of terrorism) will probably depend in this century on developing new engines of growth by combinations of new and old technologies in the poorer countries of the world.

With ICT firmly established as the dominant world technology, the greatest possibilities for further growth lie not in an attempt to replace it with another general purpose technology but in such new combinations of ICT with other technologies. One such combination – bio-informatics – has already been discussed and there are others, especially in the area of energy technology. The need for a vast expansion of renewable energy technologies and for a simultaneous programme of energy conservation is universally acknowledged. Progress has certainly been made with the technologies of wind power, solar energy, tidal energy and wave power. Yet in none of them has there been the kind of cost breakthrough which would justify a general concentration of development resources on that one technology. It seems more probable that what is needed is to advance a large number of possible combinations of these new technologies with ICT to take full advantage of local resources and skills. This form of growth has been characteristic of prolonged periods of prosperity in the past, as with the combination of electrical and mechanical technologies during the period of electrification.

This type of development of technology can be encouraged and promoted by well-conceived national and international programmes but they will only be fruitful in an economic climate which favours high growth in the developing countries to compensate for the rather weaker prospects in the United States and other leading OECD countries, such as Japan and Germany. The developing country engines of growth could compensate for these weaknesses.

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