TECHNOLOGY FORESIGHT IN A RAPIDLY GLOBALIZING ECONOMY

Author: Ben R. Martin, SPRU - Science and Technology Policy Research, University of Sussex,

Abstract

This paper[1] begins by examining the challenges posed for technology and research in a rapidly globalizing economy and by the transition to a 'knowledge-based economy'. It then examines the concept of technology foresight, looking at how it offers a tool for the strategic management of research and technology. It describes how technology foresight has evolved from its origins in the United States. Widely used in Japan over the last 30 years in both the public and private sectors, it spread extensively during the 1990s and is now employed in many industrial nations. The paper considers experiences in Japan, the US, the Netherlands, Germany, France and particularly the UK with their foresight respective programmes. The paper highlights the role of technology foresight in 'wiring up' the national or regional system of innovation and hence in enhancing competitiveness in a globalizing and increasingly knowledge-intensive economy.

1. Introduction

The broad aim of technology foresight is to identify emerging generic technologies likely to yield the greatest economic and social benefits. During the 1990s, technology foresight became much more widespread. Previously, Japan had been engaging in extensive foresight activities since 1970[2], and there were several foresight initiatives in France in the early 1980s. Later that decade, other countries such as Sweden, Canada and Australia also began to experiment with foresight. However, prior to 1990, there was comparatively little foresight in the United States, the United Kingdom and Germany. Around 1990, the situation began to change with the Netherlands[3], the United States[4], Australia,[5] Germany,[6] Britain,[7] France[8] and various other countries launching major foresight exercises.

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1. Earlier versions of this paper were given at National Institute of Science and Technology Policy (NISTEP), Tokyo, 18 January 1999, at the International Conference on 'Forward Thinking: Keys to the Future in Education and Research', organised by BMBF and held in Hamburg on 14-15 June 1999, at the APEC Center for Technology Foresight, Bangkok, 21 June 1999, at the International Symposium on 'Frontiers of Science and NSFC Priority Setting', Beijing, 23-25 August 1999, and at the Swedish/EU International Seminar on 'Foresight for a Competitive and Sustainable Europe', Stockholm, 20 March 2001. It draws upon various international reviews of foresight including Irvine and Martin (1984), Martin and Martin (1989), Cuhls *et al*. (1993), Martin (1993; 1995a; 1995b; 1996; 1997), Cameron *et al*. (1996), and Martin and Johnston (1999). See also the special issue of *Technological Forecasting and Social Change*, Vol. 60 (1999).

2. Although such activities were not normally described in Japan as 'foresight' but as 'forecasting' or 'long-term strategic planning' or some other similar terminology.

3. See van Dijk (1991) and van der Meulen (1996 and 1999).

4. See Mogee (1991).

5. See e.g. CSIRO (1991), ASTEC (1994), Pitman (1994) and Martin and Johnston (1998).

6. See Cuhls *et al*. (1993), Breiner *et al*. (1994) and Cuhls *et al*. (1996).

7. See Georghiou (1996) and Martin and Johnston (1998).

8. See e.g. Quevreux (1994) and Heraud (1996).

In this paper, we first summarise the economic and political background to this increasing interest in technology foresight. We identify some of the key 'drivers' of change in an era of globalization, competition and a shift towards a more knowledge-intensive economy and society. Next, we consider what is foresight and why it is needed. We then analyse its historical evolution, focusing on developments in Japan, the United States, the Netherlands, Germany and France before examining in more detail the UK Foresight Programme. We end with some general conclusions about the role and nature of foresight, in particular its role in 'wiring up' the national or regional system of innovation, enabling it to learn and innovate more effectively.

2. Global Driving Forces and the Challenges for Technology Policy

Some of the main drivers of change in the global economy over coming decades can be summarised in terms of the 'four Cs':

- increasing **C**ompetition
- increasing **C**onstraints on public expenditure
- increasing **C**omplexity
- increasing importance of scientific and technological **C**ompetencies

As we shall see, these factors also underlie the upsurge of interest in foresight, giving rise to its emergence as a global concept and policy tool. Let us consider each of these four driving forces briefly in turn.

2.1. Increasing Competition

There is widespread recognition that we live in an increasingly competitive world. Over the last ten years or so, many more market-economy 'players' have emerged - in Asia, in Central and Eastern Europe, in Latin America and elsewhere. This has greatly increased the level of economic competition between countries as well as companies. At the same time, we are witnessing huge (and perhaps historically unprecedented) variations in labour costs (e.g. by a factor of 100 or more between Germany and China). These are occurring at a time when companies can much more easily shift resources and production between countries to benefit from lower costs or other advantageous local resources. For the richer and more industrialised countries, the key to success lies in continuous innovation to achieve ever higher productivity and thus enhanced competitiveness.

In this era of competition and increasingly rapid change, new technology is playing a growing role in relation to economic and social development. As we move towards the knowledge-based economy, industrial competitiveness is coming to depend to a greater degree on new technologies and innovation. Yet emerging technologies and the strategic research which underpins them are often too far removed from the market, too risky or too expensive for industry to take sole responsibility for their support. Governments must assume at least part of the financial responsibility. Yet (as we describe below) governments cannot afford to fund all areas of research and technology which their scientists or industrialists would like them to support. Choices have to be made, and technology foresight offers a process to help make those choices.

At the same time, there is increasing concern about the interaction between economic competitiveness and a number of social factors such as unemployment and working conditions, inequality and social cohesion, environment and sustainability, and new risks (those associated with the introduction of new technologies) and their distribution across different sectors of society compared with the distribution of benefits. There is therefore a need for new national S&T policies that **balance** competitiveness against unemployment, inequality, sustainability, risk and so on. This requires new policy tools such as technology foresight.

2.2. Constraints on Public Expenditure

At the same time, governments in many countries have been experiencing significant public expenditure constraints because of the need to balance their budgets (for example, to meet the Maastricht criteria for European monetary union). Those constraints are likely to grow over time for a number of reasons including demography and the ageing population, and the increasing costs of - and rising expectations concerning - healthcare, education and social welfare. Another possible factor here is that we may have reached the politically acceptable limits to tax-raising; if a government attempts to extract taxes above a certain level, companies or more affluent individuals may take their business 'off-shore' to a country where the tax system is not so burdensome, something which has been made much easier by new technology and the growing use of electronic transactions.

These constraints on public spending will result in increasing demands for greater accountability and for better 'value for money' from all areas of government spending. In the case of research and technology, this requires new policy tools, along with a better justification for government funding of research and technology. We also need policies to develop technologies to deliver healthcare, education and social welfare more effectively.

Because of these trends and the escalating cost of research and technological development, no government can afford to do everything in research and technology, not even the richest. Governments now realise that they must be more selective - they must have explicit policies and clearer priorities for research and technology. Choices have to be made. In the past, those choices tended to be made tacitly - they just 'emerged' from the policy process. The question now is whether we should continue with this approach, or whether we should attempt to devise a more systematic procedure for priority-setting in relation to technology and research. Foresight offers a tool (but not a panacea) for helping to identify those priorities.

2.3. Increasing Complexity

Another factor is a trend towards growing complexity. This is driven by greater coupling and closer interactions of systems of a variety of forms, including interactions between:

- local, national, regional and global systems - for example, between national systems and the European Union, and between each of these and world bodies such as WTO;
- research and technology, on the one hand, and the economy, politics, culture, environment, on the other (as described in Section 2.1 above);
- public and private sectors - for example, in such areas as healthcare and transport;

- different technologies - here Kodama's notion of technology 'fusion'[9] is particularly important; often the most important radical innovations arise when two or more previously separate streams of technology come together and 'fuse';

- different producers of knowledge - according to the thesis of Gibbons et al.,[10] in the 'Mode 2' form of knowledge production, a far wider range of knowledge producers is involved and there is considerable 'blurring' of the institutional boundaries between them (e.g. between the industrial and university sectors).

As a result of these growing interactions between systems of different forms, there is a need for the following:

- a better understanding of complex systems;

- **flexible** policies, responses and systems;

- policy tools linking different partners and their needs, values and so on;

- increased and more effective networks, partnerships and collaboration;

- a clear division of responsibility between national, regional and global bodies and their respective policies.

As we shall see below, technology foresight provides a process for addressing several of these issues in a systematic, open and collaborative manner.

2.4. Increasing Importance of Scientific and Technological Competencies

The final key driver is the increasing importance of scientific and technological competencies. Here, one can distinguish between knowledge and skills. As argued above, scientific and technological knowledge is becoming a strategic resource for companies and countries. It is also increasingly vital to improving the quality of life. As many science policy studies have demonstrated,[11] at least as important as codified knowledge (encapsulated in textbooks, scientific papers, patents and so on) is tacit knowledge. Such tacit knowledge is not easily transferred; generally it requires people or organisations to be brought together, ideally with individuals working together at the same location for a period of time. Again, technology foresight can forge the connections that help bring this about.

Scientific and technological skills or expertise are also becoming ever more important in relation to wealth creation and improvements in the quality of life. Here, matters are complicated by the fact that new technologies not only demand new skills; they also make old skills obsolete (arguably, at an increasing rate). This points to the need for continuous learning, both at the level of the individual (with a shift away from the notion that the individual is educated only in the first 20 years or so of life to one of 'lifetime learning', a shift in which new technologies can make a major contribution), and at the organisational level (with the creation of the 'learning organisation'). In addition, because of the growing complexity and interaction of systems described above, we need new generic or system-wide skills - skills such as interdisciplinary approaches, team-working, networking and

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9. Kodama (1992).

10. Gibbons et al. (1994).

11. E.g. Faulkner and Senker (1995).

collaborating, all of which can be fostered or exchanged through the technology foresight process.

2.5. The Changing Social Contract Between S&T and Society

As has been argued elsewhere,[12] what the above factors may be producing is a shift in the 'social contract' between science and technology, on the one hand, and the state or government, on the other. In the forty or so years after the end of the Second World War, the 'science-push' model exerted a dominant influence on funding policy for research. According to this model, advances in basic research give rise to opportunities in applied research which, in turn, make possible the development of new technologies and innovations. Society therefore supported basic research in the expectation that it would ultimately generate benefits in the form of wealth, health and national security, but governments were fairly relaxed about exactly what form those benefits might take and when they might occur. Now, faced with increasing industrial competition, tighter financial constraints and demands for accountability, governments are expecting more specific benefits in return for continued investments in research. Foresight represents one way of linking the interests of the scientific community in pursuing the most promising research opportunities with the needs of industry and society in relation to new technology and innovation.

This leads us to another reason why governments have become involved in foresight - namely, that the successful use and exploitation of science and technology depends increasingly on the creation of effective networks between industry, universities and government research laboratories. Foresight can help to establish and strengthen those links. As is argued in Section 6 below, this might be seen as part of the process of 'wiring up' the national or regional innovation system so that it can learn and innovate more effectively.

3. Foresight - Definition and Rationale

In what follows, the following definition of 'foresight' is used:

> foresight is the process involved in systematically attempting to look into the longer-term future of science, technology, the economy, the environment and society with the aim of identifying the emerging generic technologies and the underpinning areas of strategic research likely to yield the greatest economic and social benefits.

There are six important aspects to this definition. First, foresight is not a technique (or even a set of techniques) but a **process** that, if well designed, brings together key participants from different stakeholder groups (the scientific community, government, industry, NGOs and other public interest or consumer groups) to discuss what sort of world they would like to create in coming decades. Secondly, the attempts to look into the future must be **systematic** to come under the heading of 'foresight'. Thirdly, those attempts must be concerned with **the longer-term** - by which we mean a typical horizon of ten or more years (and generally in the range between five and 30 years). Fourthly, successful foresight involves balancing science or technology 'push' with market 'pull' - in other words, identifying likely demands relating to the **economy and society** as well as potential scientific and technological opportunities. Fifthly, the focus is on the prompt identification of **emerging**

12. E.g. Guston and Keniston (1994), de la Mothe and Halliwell (1997) and Martin and Etzkowitz (2001).

generic technologies[13] - in other words, technologies that are still at a pre-competitive stage in their development and where there is consequently a legitimate case for government funding. Lastly, attention must be given to the likely **social benefits** (or adverse consequences) of new technologies (including the impact on the environment) and not just their impact on industry and the economy.

It is important to stress that foresight is not the same as technology forecasting. Technology forecasting, after enjoying some popularity in the 1960s and early '70s, fell somewhat into disrepute following the general failure to foresee the 1973 oil crisis and its effects. During the second half of the 1980s, interest shifted to foresight or *la prospective*.[14] This has a different philosophical starting-point from that of traditional predictive or extrapolative forecasting. The latter assumes that there is one, unique future. It is then the task of the forecaster to predict, as accurately as possible, what this will be. By contrast, with foresight and *la prospective* one assumes that there are numerous (or infinite) possible futures. Exactly which one we will arrive at depends upon the choices made today. In other words, foresight involves a more 'active' attitude towards the future; countries, organisations and indeed individuals have the power to shape the future through the decisions they take today.

As has been argued above, there is a widespread recognition that emerging generic technologies are likely to have a revolutionary impact on industry, the economy, society and the environment over coming decades. These technologies are heavily dependent for their development on advances in science. If one can identify emerging technologies at an early stage, governments and others can target resources on the strategic research areas needed to ensure rapid and effective development. The aim of foresight is to identify potentially important emerging technologies at as early a stage as possible, and to facilitate their subsequent development and exploitation.

4. Historical Evolution of Foresight

Technology forecasting first came to prominence in the late 1950s in the United States defence sector and in work by consultants such as the Rand Corporation. The latter were responsible for developing some of the principal tools of technology forecasting, such as the Delphi questionnaire survey[15] and scenario analysis. Large forecasting exercises were carried out during the 1960s by the US Navy and by the US Air Force. Technology forecasting was also taken up by private companies (e.g. in the energy sector).[16] However, the next developments, and the emergence of what we now term 'foresight', took place in Japan.

4.1. Japan

Towards the end of the 1960s, Japan decided that technology forecasting represented a potentially useful policy tool and a team was sent to the United States to consult with experts. In 1970, the Science and Technology Agency (STA) undertook its first 30-year forecast of the future of science and technology. The aim was to construct a holistic overview

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[13]. A 'generic technology' may be defined as "a technology the exploitation of which will yield benefits for several sectors of the economy or society" (Martin, 1993, p.51).

[14]. The approach of *la prospective* has been pioneered by Godet (e.g. 1986 and 2001) and others in France.

[15]. The essential feature of a Delphi survey is that respondents have a second chance to give their views in the light of opinions expressed by everyone else.

[16]. For further details, see Irvine and Martin (1984).

encompassing **all** science and technology, thus providing decision-makers in both public and private sectors with the background intelligence on long-term trends needed for broad direction-setting. Several thousand experts from industry, universities and government organisations were surveyed (using a Delphi questionnaire) about possible innovations or technological developments, when they were likely to occur, their importance and the probable constraints on their realisation. The results from the first round of the survey were synthesised and fed back to the same experts who in the second round of the Delphi exercise were given an opportunity to confirm or modify their views. These 30-year forecasts have since been repeated approximately every five years up to the present.

The results from these surveys are seen as having two main uses: (a) compiling background data for R&D planning, in particular providing an overview of longer-term technological trends and identifying important emerging technologies; and (b) monitoring current science and technology, including the level of current Japanese R&D activities in relation to those in other countries, highlighting areas where there is an emerging need for international collaboration, and identifying factors constraining technological development. The results have formed one of the inputs to decisions by the Council for Science and Technology of Japan on future government science and technology policy. They also represent background intelligence for other government ministries and for industry.

A few years ago, NISTEP carried out a survey of companies to assess how much use they made of the results from the fourth Delphi exercise. Out of nearly 250 respondents, 59% considered the results were “very important” and a further 36% judged them “worthwhile”. The main uses of the STA results include “planning for R&D and business projects” (72%), “analysing medium-term technological trends” (61%) and “analysis of the specific content of the topics surveyed” (60%). NISTEP also assessed the accuracy of the results from the first Delphi survey in 1970. They found that 64% of topics had been fully or partially realised in the intervening 20 years. Given the long time-horizon and the fact that this was the first Delphi survey in Japan, these figures are particularly encouraging. Where the forecasts had proved inaccurate, this was often not so much in relation to technological developments but as a result of subsequent political or social changes.[17]

Three points should be stressed regarding Japan. First, the Japanese recognise that the main value from foresight is often not so much the direct outputs (forecasts, and subsequent policies based upon them) but the **process benefits** of foresight. These process benefits can be summarised as the ‘five Cs’ **- C**ommunication, **C**oncentration on the longer term, **C**o-ordination, **C**onsensus, and **C**ommitment. Secondly, the STA surveys constitute just one of a wide range of foresight activities in Japan. Thirdly, most of those other foresight exercises use techniques other than Delphi surveys, such as expert panels, brain-storming, scenarios, commissioned studies from consultants and so on. For example, the Ministry of International Trade and Industry (MITI) periodically produces ‘10-year visions’ as well as organising numerous other foresight efforts. At the next level down (‘meso-level’ foresight), industrial associations and informal *ad hoc* groupings of companies perform or commission a variety of foresight exercises for specific industrial or technological sectors. Lastly, a lot of micro-level foresight is carried out within individual firms, with the major science-based companies devoting considerable effort to forecasts specific to particular product ranges or processes.[18]

4.2. United States

17. Kuwahara (1994).

18. See Irvine and Martin (1984) and Martin and Irvine (1989) for further details.

In the United States, the Department of Defense has continued to be an enthusiastic user of technology foresight. For example, the US Air Force has carried out some of the largest and most systematic foresight exercises. In the civil sector, one of the main approaches to foresight has been a series of reviews of individual scientific fields. In the 1960s and early 1970s, a dozen of these field surveys were carried out. After a gap, several more were conducted during the 1980s and 1990s by the National Research Council. In all of these, the approach was similar with most of the work being done by a large committee of eminent scientists and a few industrialists. The resulting reports each set out the exciting scientific opportunities available in that field. However, with one or two exceptions, the reports shied away from identifying priorities. They also gave relatively little attention to 'demand-pull' considerations, and they almost invariably ended up by asking the federal government to double the budget for that field over the next few years. As a result, they generally had little direct impact on the federal government.[19]

Prior to 1990, the prevailing belief in the US was that the Federal Government did not need an explicit technology policy; the country, it was argued, was rich enough to aspire to leadership in **all** areas of science and technology. This meant that the demand for foresight in the public sector was generally less than elsewhere. However, at the end of the 1980s, there appears to have been a sea-change in attitudes as a result of increasing concern about US competitiveness, particularly in relation to Japan. The emerging recognition that the US needed to have a coherent technology policy largely explains the upsurge in interest in foresight during the early 1990s.

The favoured approach to foresight in the US during this period was to draw up lists of critical technologies (i.e. those critical to the future of the US economy or to national security). The Department of Defense carried out several such exercises, while others were conducted by the Department of Commerce, the Council on Competitiveness, and the Office of Science and Technology Policy. In addition, various industrial consortia (e.g. aerospace, computer systems) drew up more specific lists of critical technologies for their sectors and often produced 'road maps' setting out how each of these was to be developed. The methodology in all these exercises involved starting with an initial long list of emerging technologies, identifying explicit selection criteria, and then using those criteria to produce a short list (typically of around 10-20) of the most important technologies. These exercises provoked much discussion but were criticised for making only limited use of data, for involving relatively few people in the scientific and industrial communities, and for identifying technologies that are too broad for specific policy decisions.[20]

4.3. Netherlands

Technology foresight in the Netherlands has taken a different form from that in other European countries. Among its characteristics are a high degree of decentralisation, the use of a range of methods (although not Delphi surveys), close integration with existing policy processes and structures, and a focus on specific fields (as opposed to the holistic foresight exercises of the three large European countries). Technology foresight also has a longer history in the Netherlands than in Britain or Germany. It had its origins in attempts during the 1970s to examine and strengthen the relationship between science and society. Since 1980, the sector councils (for agriculture, environment and health) have carried out various foresight activities. In the 1990s, the Foresight Steering Committee (described below) assumed responsibility for co-ordinating these activities.

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[19]. These and various other US foresight initiatives such as the 5-Year Outlooks and the Research Briefing are described elsewhere (*ibid*.).

[20]. See e.g. Mogee (1991) and Martin (1993).

The Ministry of Economic Affairs began to carry out technology foresight in 1990.[21] Rather than looking at the whole of technology, these exercises were based on a few critical technologies. Three fields were analysed in 1990 (e.g. chip cards) and another three in 1992 (e.g. signal processing). The objectives were to produce an input to technology policy, to provide SMEs with an early warning of opportunities and threats, and to create networks. There are four main steps in the foresight process: (a) **consultation** to draw up a short list of technologies to be examined; (b) **analysis** to identify the key players, potential bottlenecks and opportunities; (c) a **strategic conference** to bring together the stakeholders, to test the preliminary results, to create consensus and to generate commitment to implementing the results; and (d) **follow up** (e.g. launching a pilot project or creating a new institute).

For each field, consultants produced reports on how the technology might be exploited, in particular by SMEs. A range of mechanisms were used to implement the results including the creation of networks, improvements to the knowledge infrastructure, new training courses and publications. SMEs were the main target group, but the problem here is that the most innovative SMEs are generally already aware of the new technology, while less innovative ones tend not to be involved in the foresight process nor to be very influenced by the results. In order to evaluate the effectiveness of the first exercise, a questionnaire was sent two years later to participants. Of these, 75% had found the information generated "very valuable", and a similar number had made new contacts as a result of participating. In addition, 60% had taken follow-up action (e.g. developing a new product).[22]

A number of lessons emerge from these exercises. First, they require much effort and the follow-up activities take a lot of time to organise, largely because of the need to identify a 'product champion' responsible for implementing the results. Secondly, because SMEs are such an important component of Dutch industry, it is vital to involve them, yet there are considerable difficulties in doing so because of the wide range in their technological and innovative capabilities. Thirdly, the choice of foresight methodology depends on the objectives - an approach appropriate for identifying resource allocation priorities may be ineffective at stimulating companies to take advantage of the economic opportunities.[23]

The Ministry of Education and Science also became involved in foresight, setting up a Foresight Steering Committee in 1992.[24] It had two tasks: (i) to initiate, support and co-ordinate foresight exercises; and (ii) to provide advice to the Ministry on options for science and technology policy. Among the areas in which foresight exercises were initiated were chemistry, transport and infrastructure, agriculture, energy, nanotechnology, informatics, educational research, legal research, economic research, social sciences, and health. The methodology normally involved a preliminary selection of topics based on an overview of the committee members and requests from outside organisations. The foresight process was designed to ensure both close cooperation with key policy-makers, and that priorities were based on an assessment of potential contributions of science and technology to society. The design of the foresight process also took account of the characteristics of the research field - for example, whether it is concentrated in a few laboratories or highly fragmented.

The main conclusions to emerge from these foresight activities are three-fold. First, designing a foresight process geared to a specific field has two advantages: (a) it makes implementation far easier; and (b) it provides greater flexibility in dealing with specific issues and problems. Secondly, the main problems encountered involve: (a) setting priorities and

21. van Dijk (1991).

22. Ministry of Economic Affairs (1994).

23. Martin (1996a).

24. This section draws on van der Meulen (1996 and 1999). Later in the 1990s, the Ministry of Agriculture also became involved in foresight.

‘posteriorities’ (i.e. negative priorities), especially at the national level; and (b) the fact that budgetary cuts tend to induce distrust in foresight. Thirdly, the scenario methodology forces participants to think beyond their usual framework and ad hoc problems.[25]

4.4. Germany

The attitude towards foresight in Germany changed appreciably after 1990.[26] Up till then, there was comparatively little research or technology foresight. The reasons included the stipulation in the federal constitution that science should be autonomous, the political climate under the Christian Democrat Government, and the country’s federal structure with the division of responsibility for research between the *Länder* and the Federal Government. However, around 1990 there was a major policy change that brought about the launching of various foresight activities by the Government. The reasons for that change include problems associated with unification, recession and the structural crisis, and the renewed emphasis on technology foresight in other countries.[27]

Since 1990, several foresight exercises have been completed. One was on ‘Technology at the Threshold of the 21st Century’. The first step in this was a review by the Fraunhofer Institute for Systems and Innovation Research (ISI) of the lists of ‘critical technologies’ drawn up in the US and the results of other foreign foresight initiatives. Next, a long list was prepared of 86 technologies with potential economic or social utility over the next 10-15 years. Using a ‘relevance tree’ approach, experts from BMFT agencies (*Projekttraeger*) evaluated each technology in terms of such criteria as timing, economic importance and non-economic benefits, identifying the most important ones for Germany in terms of each criterion.[28]

In another initiative, ISI collaborated with NISTEP in Japan which was conducting the fifth STA 30-year forecast. The first step was to translate the Japanese Delphi topics into German.[29] The topics were sent to a large sample of experts from industry, universities and government. Comparison of the German and Japanese responses showed close agreement on the likely timing of advances, suggesting that the Delphi approach can be used reasonably consistently across countries. Where there were differences between the two sets of results was over the relative importance of individual topics and likely constraints. Since both these are closely linked to the respective national research systems, such differences are not unexpected. Another result to emerge was confirmation of the earlier Japanese finding that experts in a particular sub-field sometimes put forward unduly optimistic views. One strength of the Delphi approach is that such a bias can be identified and taken into account.[30]

Although the exercise was reasonably successful, in particular, enabling the views of German and Japanese experts to be compared, the approach had some weaknesses. The two countries therefore carried out a ‘mini-Delphi’ exercise to develop an improved methodology. Among the changes were for the two countries to select the topics jointly, the distinguishing of different categories of ‘importance’ (to science and technology, on the one

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25. Ibid.

26. This section draws on Grupp (1996).

27. Cuhls *et al*. (1996).

28. However, they were unable to arrive at a single list of priorities (see Grupp, 1994a; 1994b).

29. This proved a non-trivial task; after a preliminary translation by professional translators, German experts had to check each topic to ensure that its meaning had been accurately reproduced.

30. Grupp (1994a; 1994c; 1996).

hand, and to the economy, the environment and society on the other), and the inclusion of questions on the conditions to foster innovation. The findings from this exercise included the following:

1. the mini-Delphi is an important methodological tool;

2. international selection of the Delphi topics is recommended for such joint exercises;

3. questions relating to market demand should be included in discussions of S&T policy;

4. Delphi surveys should seek qualitative as well as quantitative information - for example, views on alternative solutions to particular problems.[31]

Foresight in Germany has had an impact at several levels. First, at the Federal level, it has influenced budget priorities within the Federal Ministry of Education and Research (BMBF), although technology foresight is just one of many inputs. It has also played a role in 'strategic talks' with industry and large research organisations. Secondly, a number of state governments have carried out investigations of the regional implications of the national foresight results. Thirdly, in industry, there have been more specific foresight exercises carried out by industrial associations. A pharmaceutical company has also conducted a Delphi survey of several thousand doctors, and a number of other companies are known to have performed in-house foresight activities. Lastly, foresight has had a wider impact on German society. The results have been published and widely discussed in the media. This has helped generate a more positive debate on future technologies, with distinctions being made between individual technologies and whether each of them is desirable or not.

4.5. France

In France, there were several interesting foresight initiatives in the early 1980s under a Socialist Government which gave high priority to technology as a means to achieving economic and social progress. For example, in 1981 there was a major Technology Consultation exercise in which 1,200 experts were involved and which yielded reports on five priority fields together with an overview report.[32] A year later, a National Colloquium on Research and Technology was held which, together with various regional meetings, involved 3,000 people. It identified half a dozen key technologies and the government subsequently launched National 'Mobilising' Programmes[33] to promote these. Regular foresight was then used to 'steer' or redirect these national programmes during the 1980s. Other examples of foresight include an exercise by the *Centre National de la Recherche Scientifique* (CNRS) in 1984 to identify 20 strategic themes and the 'Prospective 2005' conference organised by CNRS and the Planning Commissariat in 1985.[34]

However, after the change of government in 1986, interest in foresight declined until 1994 when a Delphi survey on future technologies was launched by the Ministry for Higher Education and Research.[35] This was carried out in parallel with another foresight experiment by the Ministry of Industry to identify 'key technologies',[36] an exercise which gave more

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31. Subsequently, Germany collaborated with Japan in the latter's sixth Delphi exercise in the late 1990s.

32. Irvine and Martin (1984).

33. The term 'mobilising' indicates the emphasis given to mobilising the industrial and scientific communities to work together in pursuit of national goals.

34. Martin and Irvine (1989).

35. This section draws on Heraud (1996b).

36. This 'key technologies' exercise was repeated five years later.

emphasis to the needs of industry and society and rather less to science and technology 'push'. The Delphi survey used many of the same questions as the earlier Japanese and German surveys so that the views of French experts could be compared with those of Germans and Japanese.[37] Among the aims were to see if a Delphi survey would work in France, to establish whether experts would participate, and to find out whether decision makers would be influenced by the results.

Questionnaires were sent to over 3,000 experts drawn fairly equally from industry, universities and public research organisations, and covering 15 sectors. Among the questions considered in analysing the results were the level of consensus among experts and, conversely, whether there were groups of experts with distinctly different views, and whether experts held different views from those slightly less knowledgeable on that topic. A comparison of the results with those from the Japanese and German surveys revealed that French experts held very similar views on the timing of technological developments or innovations to their German and Japanese counterparts.

In some sectors, there was also consensus on the relative importance of individual topics. For example, in life sciences, the list of ten developments judged most important by French experts was very similar to that for the Germans, and likewise for the materials sector. However, for all the sectors combined, there was very little overlap between the top ten most important topics for each country (with only one topic common to all three lists). Topics on which there was most difference between Japan and the two European countries include domestic robots, exploitation of the oceans and the development of supersonic passenger planes, differences which would seem to reflect economic and other national specificities.

In the question on which nation is currently the technological world leader, there were interesting differences, with French experts having a surprising tendency to regard the US as pre-eminent, while the Germans were more predisposed to see the Japanese as leaders. The question dealing with likely technological constraints also revealed national differences; for the French, the sector with the least constraints was agriculture, for the Germans transport, and for the Japanese architecture and construction. Lastly, the question on which topics most required international collaboration again revealed a lack of agreement between France and Germany, a finding with potential implications for EU RTD policy.[38]

One weakness often cited in relation to Delphi surveys is that they artificially create consensus and can, as a result, give rise to misguided policies. However, the French exercise showed that one can use the Delphi results to identify groups of experts with systematically different views. For example, experts employed in large firms tend, on average, to be less optimistic on the timing of particular developments than those working in SMEs. Finally, as in other countries, the national exercise has encouraged lower-level foresight activities. For example, a regional foresight exercise was conducted in the Bordeaux region, exploring the implications of the national results for that area.

4.6. Other countries

In the latter part of the 1980s, foresight began to spread to other countries, such as Sweden, Canada, Australia and Norway. In Sweden, for example, there were foresight initiatives by the Council for Planning and Co-ordination of Research (FRN), the National Board for Technical Development (STU), the Royal Academy of Engineering Sciences (IVA), the Defence Research Institute (FOA) and in industry. Their experiences and those of

37. Quevreux (1994).

38. Heraud (1996a)

organisations in Canada, Australia and Norway are described elsewhere.[39] More recently, foresight has spread further afield - for example, to Hungary.

5. The UK Foresight Programme

In 1983, the UK Cabinet Office and the Advisory Council on Applied Research and Development (ACARD) commissioned the Science Policy Research Unit[40] (SPRU) to carry out a study on the approaches adopted to identifying exploitable areas of science in France, Germany, the US and Japan in both government and industry. The resulting SPRU report[41] advocated that Britain should learn from overseas experiences with foresight, and in particular from Japan, and should try foresight on an experimental basis. Unfortunately, 1983 was not a propitious time to suggest that the UK Government should assume a new responsibility - Mrs Thatcher being keen to reduce the role of government rather than to add to it! Although some of the ideas were subsequently taken up in an ACARD report,[42] the SPRU study had little immediate impact on policy in the UK.

By 1992 however, the philosophy of the UK Government towards technology policy had changed following the replacement of Margaret Thatcher by John Major, and the Cabinet Office commissioned a new study from SPRU. This reviewed technology foresight activities in the UK, and provided a brief update of developments in Germany and the US (building upon an extensive review of foresight conducted by SPRU for the Dutch Government in 1987-89[43]). It also identified a number of foresight options for Britain.[44] Now the timing was right; the UK had a new minister for science and technology, the first of cabinet rank for thirty years, who was trying to produce a Government White Paper on Science, Engineering and Technology, the first such policy document for 20 years. He was looking for a big new idea and was persuaded that foresight should be that big new idea!

The following year, the White Paper was published,[45] setting out the need to link the UK science base more effectively to wealth creation and improvements in the quality of life. It argued that researchers who receive funds from the public purse have a duty to identify potential users or beneficiaries of their research, and to explore with them their longer-term needs in relation to science and technology. To achieve these aims, the White Paper proposed a large-scale Technology Foresight Programme.

The UK Technology Foresight Programme (TFP) was launched later in 1993 with a budget of approximately £1 million. The aims were (i) to increase UK competitiveness, (ii) to create partnerships between industry, the science base and government, (iii) to identify exploitable technologies over the next 10-20 years, and (iv) to focus the attention of researchers on market opportunities and hence to make better use of the science base. The Programme was organised by the Office of Science and Technology (OST) in co-operation with other government departments, and involved extensive use of consultants.[46] It was overseen by a Steering Group made up of leading figures from industry, universities and

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39. E.g. Martin and Irvine (1989).

40. The organisation's name was changed in 1998 to 'SPRU - Science and Technology Policy Research'.

41. The report to ACARD was subsequently published as a book - see Irvine and Martin (1984).

42. ACARD (1986).

43. Martin and Irvine (1989); also published as Irvine and Martin (1989).

44. Martin (1993). (The report was written in 1992 but was published in 1993.)

45. Office of Science and Technology (1993).

46. See Georghiou (1996) for further details.

government. In addition, 15 panels (again consisting of experts from industry, academia and government) directed the foresight efforts in different sectors.

The Programme had three main phases. In the first ‘pre-foresight’ stage, a number of ‘Focus on Foresight’ seminars were held to explain to the industrial and scientific communities what foresight is, why it is important and why they should take part, and to seek their views on how best to carry it out. As a result of their feedback, a substantial change was made to the methodological approach, with less reliance on the Delphi survey than originally envisaged. This sent a ‘signal’ to the wider community that the Foresight Programme was not just being imposed on them from above but that they were being invited to play a role in shaping it from the outset, a signal that helped generate enthusiasm for taking part. A ‘co-nomination’ exercise was also conducted in which experts were asked to identify other experts in their area. The resulting database was used in helping to determine the membership of the 15 sector panels, and in constructing a pool of experts on whom each panel could draw for information and advice.

The second stage was the main foresight phase. In this, panels began by holding discussions to set the scene in their sector and to identify strengths and weaknesses. They also consulted with their pool of 60-100 experts, as well as engaging in wider consultation through regional and topical workshops. In addition, a major Delphi survey was carried out with questionnaires being sent to some 7000 experts. All these information sources were drawn upon by panels in identifying technological priorities for their sector. Each panel produced a preliminary report which was circulated for comment and then revised. The structure of each panel report was broadly similar. They began by analysing the sector in terms of its scope, characteristics, contribution to GDP and so on, before benchmarking UK strengths and weaknesses. They identified the main trends, driving forces, barriers and challenges, and analysed a range of scenarios. Next, they examined a range of technological opportunities for making contributions to wealth creation or improved quality of life. Each report then narrowed these down to a list of priorities together with a set of key recommendations for their implementation and for future technology foresight in the sector.

The Steering Group synthesised the findings of the 15 panels, identifying a total of 27 generic technological priorities (i.e. priorities emerging from two or more panels) which they grouped into six categories:

- harnessing future communications and computing (example priorities include information management, and the modelling, simulation and prediction of complex systems);
- from genes to new organisms, processes and products (e.g. bio-informatics, and health and lifestyle);
- new materials, synthesis and processing (e.g. catalysis, and chemical and biological synthesis);
- getting it right: precision and control in management (e.g. management and business process engineering, and security and privacy technology);
- a cleaner world (e.g. environmentally sustainable technology, and product and manufacturing life-cycle analysis);
- social trends and the impact of new technology (e.g. demographic change, and social impact in the workplace and the home).

They also analysed the main bottlenecks likely to impede the exploitation of those new technologies, arriving at 18 generic infrastructural priorities grouped under five headings:

- the skills base (e.g. communication skills, and business awareness);
- the science base (e.g. incentives for multidisciplinary research, and for industrial involvement);
- the communications infrastructure (e.g. promoting the information superhighway, and gathering overseas scientific and technological intelligence);
- the financial infrastructure (e.g. long-term funding for innovative R&D, and special incentives for SMEs);
- the wider policy and regulatory environment (e.g. intellectual property rights, and scientifically based standards).

The Steering Group's report concluded with over 60 recommendations for 'Taking foresight forward'. Some of these focused on the three main types of stakeholders - government departments, the science and engineering base, and the private sector. Others related to five types of key activities: (i) maintaining the networks and panels, (ii) infrastructural issues, (iii) focusing on Europe and the global dimension, (iv) focusing on partnership, and (v) monitoring the outputs.

The third phase of the Programme - that of 'post-foresight' or implementation - had a number of components including (i) shaping new government R&D priorities (in ministries, Research Councils and the Higher Education Founding Councils), (ii) influencing company R&D strategies, (iii) improving partnerships between industry and the science base, (iv) influencing wider government policy (e.g. towards regulation), and (v) drawing lessons for the second Foresight Programme (which took place in 1999-2001). The process benefits of the Foresight Programme (in particular, the 'five Cs' discussed in relation to Japan in Section 4.1 above) were particularly important, corresponding as they each did to areas of previous British weakness. In addition, the Government established a Foresight Challenge Fund of some £30 million which, with matching funds (in fact, rather greater amounts) from the private sector funded two dozen foresight projects based on partnerships between public-sector research organisations and firms. The spending patterns of the Research Councils was appreciably altered in the light of the priorities emerging from the Foresight Programme, and the same is true (although to a lesser extent in certain cases) of the government departments which fund R&D. There was also an impact on industry, with some companies drawing upon information and particularly the contacts that they had made during the Foresight Programme and with others engaging in their own foresight exercises.[47]

In 1997, the new Labour Government, after a positive review of foresight, decided to continue and indeed to strengthen foresight. In the second Foresight Programme, which began in 1999 and for which the main phase will shortly be completed, efforts were made to learn from the first exercise. The new Programme has also aimed for harder targets - getting foresight into company boardrooms, financial institutions and SMEs. In addition, more emphasis has been given to social considerations such as the ageing population and crime prevention. Although the Delphi component was dropped, one innovation has been the construction of a digital 'knowledge pool' - a managed database of foresight material collected from all round the world as well as produced during the UK programme. Lastly, to help give the programme wider visibility, there has been a change in title. It is now called 'foresight' rather than 'technology foresight' on the grounds that it is as much to do with foreseeing changing markets and social and environmental needs as with new technologies.

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47. For example, the author recently worked with a major financial institution in the City of London to carry out a Delphi-based foresight exercise.

With these improvements, it is hoped that foresight will become more widely accepted, embedded and successful in the UK.

6. Foresight for 'Wiring Up' the National System of Innovation

One reason for the adoption of foresight by a growing number of countries over the last decade or so is linked to a central concept to emerge from science policy research over the last decade or so – the notion of the national (or regional) system of innovation.[48] Such a system is seen as being made up of a number of actors – firms, government laboratories, universities and so on. However, the most important element is not so much the individual actors as the links between them. A national innovation system made up of actors which are not necessarily particularly strong but where the links between them are well developed may operate more effectively (in terms of learning and in generating innovations) than another system in which the actors are stronger but the links between them are weak. If the concept of the national (or regional) innovation system is a valid one, then the question for policy makers is how to create and strengthen the links between the various components of the system. Foresight, as we have seen above, offers a tool for achieving this – for getting the individual components of the national innovation system to communicate with each other, to discuss issues of longer-term common interest, to co-ordinate their respective strategies, in some cases to collaborate. In short, foresight provides a means for 'wiring up' the national or regional system of innovation.[49]

There is an intriguing analogy here with the development of the infant brain.[50] This needs stimuli to develop links between the neurons and thus to 'wire up' the brain, enabling it subsequently to learn faster and more efficiently. Likewise, for the national system of innovation, there need to be processes and incentives to develop links between the various actors. The more the wiring up takes place between the component parts, the more effective the national innovation system as a whole becomes in terms of learning and innovating. Foresight provides a means to achieve this.

7. Conclusions

What general conclusions can be drawn from the above analysis? First, there is wide-spread and growing recognition that technology foresight represents a useful tool to aid decision-making in relation to research and technology policy, whether at the national or regional level or at a more micro-level. Japan, after 30 years of experience, still makes extensive use of foresight. In other countries, foresight has begun to take root since the start of the 1990s. There has been marked progress in Germany where foresight is now quite firmly established. The Netherlands, France and the United Kingdom have also undertaken foresight exercises and are starting to gain some of the process benefits discussed earlier, such as better communication between all the relevant stakeholders, the creation of networks, and the stretching of time-horizons in relation to decision-making.

Secondly, no individual foresight approach is perfect. Each has its own strengths and weaknesses. If the aim is to achieve a long-term holistic overview of technology in a country with a large number of experts on technology and innovation, then a Delphi survey is well suited to the task. However, in other circumstances such as technology foresight at the company level or for an industrial sector, another approach may be more appropriate.

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48. See e.g. Freeman (1987), Lundvall (1992) and Nelson (1993).

49. Martin and Johnston (1999).

50. Martin (2001).

A third and closely related conclusion is that individual countries or organisations may adopt quite different approaches. Japan, Germany, Britain (initially at least) and France have made use of large-scale Delphi surveys in their holistic foresight exercises. In the Netherlands and Australia, the Delphi method has not being employed; instead, the emphasis has been on other approaches, such as panel discussions and brain-storming, commissioned studies, and creating or tapping networks. Such approaches are also often favoured in meso and micro-level foresight by companies.

One question that is sometimes asked in countries contemplating whether to become involved in foresight for the first time (given that the costs are far from negligible) is the following: 'If Japan and other major countries are engaging in foresight and making the results public, can we not just purchase their results and act upon them?' The short answer is 'No'. There are two main reasons for this. First, each country has its own particular strengths and weaknesses in industry and in science and technology. This means that the choices made, for example, by Japan will not necessarily be the same as those made by a country like Australia or Hungary. Secondly, as has been stressed earlier, the benefits associated with the **process** of carrying out foresight are at least as important as the direct outputs (priorities, policies or whatever).

Finally, we have seen how the growing spread of foresight may herald the emergence of a new 'social contract' between science and society. After several decades during which governments and the public were fairly relaxed about the exact benefits they would ultimately derive from science and when they would occur, now they are coming to expect more direct and specific benefits in return for the considerable investments that they make in science. Foresight is a tool for helping to achieve this, and perhaps also for 'wiring up' the national or regional innovation system so that it can learn and innovate more effectively.

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