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SCIENCE TECHNOLOGY INDUSTRY

Special Issue on Government Technology Foresight Exercises

Initiatives in Futures Research at the OECD

Technology Foresight: A Review of Recent Government Exercises (Summary report of the OECD meeting held on 14 September 1994)

Featuring studies on technology foresight exercises in:

- Japan
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- France
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No. 17

STI REVIEW

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
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FOREWORD

Prepared by the OECD Directorate for Science, Technology and Industry, the *STI Review,* published twice yearly, presents studies of interest to science, technology and industry policy makers and analysts, with particular emphasis on cross-country comparisons, quantitative descriptions of new trends and identification of recent and future policy problems. Because of the nature of OECD work, the *STI Review* explores structural and institutional change at global level as well as at regional, national and sub-national levels. Issues often focus on particular themes, such as surveys of firm-level innovation behaviour and technology-related employment problems.

The OECD Committee for Scientific and Technological Policy's Working Group on Innovation and Technology Policy organised an *ad hoc* meeting of experts on 14 September 1994, to discuss recent government technology foresight exercises. Issue No. 17 of the *STI Review* contains a brief report of the meeting, and an introductory article setting recent government foresight exercises in a historical perspective, together with expanded and updated versions of the presentations given by representatives from Australia, France, Germany, Japan, the Netherlands and the United Kingdom.

The views expressed in this publication do not necessarily reflect those of the Organisation or of its Member countries. The *STI Review* is published on the responsibility of the Secretary-General of the OECD.

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INTRODUCTION: INITIATIVES IN FUTURES RESEARCH AT THE OECD

Aware of its importance for outlining foreseeable options and designing potential policy approaches, the OECD's Directorate for Science, Technology and Industry (formerly the Directorate for Science) has pioneered futures research ever since its inception.

The ever-increasing number of technical choices associated with the formulation of scientific and technological policy imply a permanent reassessment of potential technological trajectories, their validation, and the evaluation of their consequences for the economy and society. Futures research, of which technology foresight is one aspect, is therefore becoming part and parcel of the decision-making process.

Already from the 1960s, under the aegis of the Committee for Science Policy (later the Committee for Scientific and Technological Policy), high-level groups of experts analysed the current state of the art and helped clarify the influence of new scientific and technological developments on the economy and society. New approaches underwent careful scrutiny and their pertinence for government policies was analysed.

Whether concerning methods, practice or incentives, futures research has experienced various tides of interest. This is reflected both in changes in the terminology used and in the nature of the attempts to institutionalise futures research as a fully recognised advisory activity.

As early as 1963, a report, published under the title *Science and Policy of Governments* had a considerable influence on the development of science policy in Member countries. Its main points were, firstly, the need to manage the scientific and technological resources of a country as a whole and, secondly, to understand more clearly the influence of new scientific and technological developments on other government policy areas.

The first "state of the art" study of the framework of techniques and organisational aspects of technological forecasting was published in 1967 under the title, *Technological Forecasting in Perspective* (OECD, 1967). In 1965 and 1966, Erich Jantsch, the author, visited twelve Member countries, drew on the knowledge and experience of a wide range of experts, and presented a comprehensive survey of the techniques and trends of technological forecasting.

According to Jantsch's definition, "technological forecasting is a probabilistic assessment, on a relatively high confidence level, of future technology transfer. Exploratory technological forecasting starts from today's assured basis of knowledge and is oriented towards the future, while normative technological forecasting first assesses future goals, needs, desires, missions, etc., and works backward to the present. The subject of both types is a dynamic picture of a technology transfer process. Technological forecasting may be aided by anticipation and may 'harden' to prediction". (OECD, 1967.)

The full potential of technological forecasting, therefore, would be realised only where exploratory and normative components are joined in an iterative mode or, ultimately, in a feedback cycle.

Continuing rapid and massive change in science and technology led the OECD to set up a second *ad hoc* group on science policy at the end of 1969 in order to identify the new trends and problems. The report of this group was published in 1971 under the title *Science, Growth and Society* (OECD, 1971). The prevailing theme was the importance of mastering the impacts of technological change on society so as to avoid undesirable side effects on society, environment and quality of life. The key policy requirement was a wider range of options in the early stages of the innovation process combined with a more rigorous process of choice. This implied a more careful exploration of technological alternatives.

"The forecasting aspect of technology assessment is complex in itself. The difficulties lie not only in forecasting technological development in the narrow sense, but also in assessing the ways in which social changes will influence the evolution of technology. The problem is that neither social change nor technological change are independent variables. They react on each other in surprisingly devious and indirect ways, and one of the consequences of this is that assessment is an art rather than a science – an art to which science has much to contribute, but for which it cannot substitute." (OECD, 1971.)

In the late 1960s and early 1970s both policy makers and the public at large were increasingly concerned with the unwanted and often unforeseen side effects of technology. The management of technology in the broad social interest was the underlying theme of the OECD Seminar on Technology Assessment in January 1972.

Starting from the proceedings of the Seminar, François Hetman assembled and analysed the main features of technological society, the concepts of technology assessment, development of methodological approaches, areas of application, and political and institutional problems in *Society and the Assessment of Technology* (OECD, 1973).

The technology assessment movement represented a basic change in public attitudes toward science and technology and was to be understood as a normative component of policy, implying a political commitment to better application of technology for the benefit of society as a whole.

"The concept of technological assessment is defined as a process for mapping out technological options. As a way of charting the range of possible or alternative futures, it may be carried out to influence the direction and pace of technological development. It may be problem-oriented or technology-oriented. In the former case, the process begins with the widespread effects of technology, in the latter it is concerned with identifying the future consequences of a new technology." (OECD, 1973.)

Scientific discoveries and technological developments have always involved social adjustments and accommodation to new ideas and the emergence of new values, but the speed at which the impact of new knowledge and its implications are felt is an unprecedented feature of society in most OECD countries.

Science and technology affect all aspects of contemporary life, so their effects tend to attract public controversy. This was the starting point of the study *Technology on Trial* (OECD, 1979*a*).

"Public preoccupation with the impacts of technological developments, fears about their possible dangers and risks, ethical considerations over the potential misuse and side-effects of scientific research techniques or results are major public concerns behind many contemporary scientific and technological controversies. There is also another central factor: concern about social values. It is this preoccupation with current values – those that some people want to preserve, those that others wish to modify – that lies at the heart of many so-called scientific or technological debates."

The report of the "Interfutures" project, *Facing the Future,* OECD (1979*b*), was also published in 1979. This three-year project was a wide-ranging and thorough investigation of the likely scenarios for future development of advanced industrial countries as well as of developing countries. The report, based on the research of an international team specially set up for this purpose under the leadership of Professor Jacques Lesourne, analysed prospects, constraints and issues in the longer-term perspective of the developed countries. The report presented, rather than forecasts nor predictions, a well-documented exploration of a range of scenarios, with the objective of contributing to government thinking and decision making – as said in the sub-title "in the area of mastering the probable and managing the unpredictable".

"Interfutures was conceived as an attempt at prospective analysis, not as a forecasting exercise. Prospective analysis recognises that an attempt must be made to imagine the different futures that could result from the behaviour of the actors involved within the limits of the systems through which they act. It attempts, therefore, to distinguish trends whose dynamics are almost invariant from those which can be affected by the decisions of the actors concerned and by uncertain events. It endeavours to grasp the projects which these actors will seek to implement and which will shape their future behaviour. These actors will create and invent new solutions."

One of the main outcomes of the choice of "prospective analysis" was the construction of global or partial scenarios worked out at different levels. "These scenarios offer pictures of the future at certain time horizons and describe the paths that lead there. Their interest lies in the light they throw on the possible policies of certain actors, particularly governments." (OECD, 1979*b*.)

The report *Technical Change and Economic Policy,* published in 1980, was prepared by a group of 15 internationally known experts chaired by B. Delapalme under the aegis of the Committee for Scientific and Technological Policy. The group was asked to review the complex issue of the reassessment of the interactions between scientific and technological trends and economic performance. The report concluded that many of the then current economic problems had structural long-term roots and, as a consequence, would not be resolved by attempted solutions in which economic and scientific and technological policies stood apart from each other as they had done all too often in the past.

The report examined trends in research and development and innovation and the impacts of technological change on productivity growth, employment, capital investment and inflation. Though it did not touch directly on methodological approaches, it implied an ongoing analysis of technological trends. The report states that "there are important differences amongst sectors in the rate and direction of technical change, however measured. Many of today's policy problems arise because of these differences. They also arise because there have been significant shifts in the rate and direction of technical change, which again differ from sector to sector as a result of developments within science and technology and of the pressures and opportunities arising from the economic and social system."

Furthermore, "Each country must find its own way to structure such policies. However, we can offer two general guidelines. First, funding agencies should not presume it is possible to predict what technologies will be best ten or 20 years from now. Second, public support of basic technology should aim at a technological pluralism.

By 'technological pluralism' we mean a concern to keep the door open to alternative technological solutions. OECD countries must sponsor intelligent and creative diversity in time so that they are not taken short by political or technological surprises for lack of alternative solutions." (OECD, 1980.)

Following the concern expressed by Member countries as to the need for better understanding of the interactions between technological development, the economy and society, the OECD commissioned an "integrated and comprehensive approach" towards these issues in 1988, the Technology/Economy Programme (TEP). A wide range of studies and documents were assembled resulting both from the work carried within the Secretariat and several international seminars and conferences devoted to this subject.

The TEP report *Technology in a Changing World* (OECD, 1992) was published in 1992. The central strand is the clarification of the interactive character of the innovative process. "The process of technology creation and innovation cannot however be described only as a simple and flexible reaction to market forces. The character of the technology itself circumscribes the range within which products and processes can adapt to changing economic conditions and technological evolution. Progress in scientific knowledge obviously also plays a crucial role in opening up new possibilities for technological developments, even though it may account for only a fraction of the input in the innovative process. This is true not only of the science-based sectors – *e.g.* biotechnology or pharmaceuticals – but also of what can be termed the 'transfer sciences', *i.e.* engineering and other sciences bridging basic science and product development."

Special attention was paid to the phenomenon of "globalisation" which calls for a new concept of relationships between national government policies and internationally "global firms". One of the main aspects of globalisation is the increasing co-operation and networking among firms at the global level. This has come about largely by the surge of new technologies, especially sophisticated information and communications technologies. Strategic alliances appear as a mix between co-operation and competition. The increased world-wide co-operation between firms may lead to oligopolistic or even monopolistic situations. The technology trajectory of new technologies is therefore influenced more and more by global firms.

Another major problem for technology policy is the social acceptance of new technologies. As has been underlined in former reports, technological progress is not only a matter of innovation and diffusion, but also of social acceptance.

"Insufficient understanding of positive and negative impacts and of the ramifications of new technologies, coupled with a failure effectively to involve and inform the public, not only can delay technological change but also may lead to social dissension. If technological progress is to be continued with adequate social acceptance greater efforts must therefore be made to assess carefully and objectively the risks and benefits of new technologies and to promote public discussion and participation in the decision-making process." (OECD, 1992.)

All these succeeding OECD efforts and publications can be considered as cumulative contributions to a deeper understanding of technological innovation and its impacts on economy and society. They make it quite clear that the interactions are extremely numerous, since technology permeates all aspects of economy and society, thus implying a continuous search for new and complementary methods of investigation and the need for new approaches in view of a more effective integrated policy making.

Following up one of the recommendations made at the conclusion of the TEP programme, the Committee for Scientific and Technological Policy created its Working Group on Innovation and Technology Policy in 1993, with one of its major objectives being the identification of "best policy practices" among Member countries. It was with this objective in mind that the Group held an international Meeting of Experts on Government Technology Foresight Exercises in September 1994. The studies first presented in this Meeting, subsequently assembled, updated and revised for this issue of the *STI Review,* constitute another important contribution in this area.

François Hetman
Hiroko Kamata

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TECHNOLOGY FORESIGHT: A REVIEW OF RECENT GOVERNMENT EXERCISES

Summary Report of the OECD Meeting Held on 14 September 1994

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This report was prepared by Benjamin Martin, Director of Graduate Studies, Science Policy Research Unit of Sussex University, United Kingdom.

SUMMARY

Under the aegis of the OECD Committee for Scientific and Technological Policy (CSTP), the Working Group on Innovation and Technology Policy organised an *ad hoc* meeting of experts to discuss recent government technology foresight exercises on 14 September 1994. Presentations were given by representatives from Australia, France, Germany, Japan, the Netherlands and the United Kingdom. In addition, the OECD prepared a list of questions on key issues in technology foresight to help structure the discussion.

This report of the OECD meeting first sets out a definition of "technology foresight" and briefly reviews the history and the lessons which emerge from previous international reviews of foresight. The six national presentations made at the OECD meeting are then summarised. These national experiences are analysed to address certain key questions on foresight. For example, why do governments engage in technology foresight? What lessons emerge from the history of foresight? What are the different methodologies used? What are the strengths and weaknesses of Delphi surveys? How reliable are the results? How should industry be involved? Is there scope for international collaboration in technology foresight. And what effect will foresight have in international co-operation or competition?

A number of conclusions emerged from the meeting. The first is that there is wide-spread and growing recognition that technology foresight represents a useful tool to aid decision-making in relation to technology policy, whether at the national level or at a more micro-level. Secondly, no individual foresight approach is perfect. Each has its own strengths and weaknesses. A third and closely related conclusion is that individual countries may adopt quite different approaches, depending, for example, on the size and nature of their economies. Fourthly, most participants at the meeting were doubtful as to whether a multi-country foresight exercise was desirable, at least at this stage. This is partly because no single, universal foresight approach is possible, and partly because different countries have widely varying objectives and needs in relation to technology foresight. Finally, with the number of countries experimenting with technology foresight now quite large, some mechanism is required to promote the regular interchange of ideas, experiences, problems and lessons.

The report concludes with some recommendations as to what the OECD and the Working Group might consider doing next. The first is that OECD could organise another meeting on technology foresight in 12-18 months. Secondly, participants at the *ad hoc* meeting and OECD officials should convey to CSTP members the consensus view that the meeting was very valuable. Thirdly, OECD could act as a central clearing house for information on technology foresight. Fourthly, OECD might also assume a "marriage broker" role, where a country seeks to collaborate with others. Finally, OECD might create an electronic bulletin board on technology foresight, overseeing its operation and publicising its existence.

I. INTRODUCTION

The last five years have witnessed a dramatic upsurge of interest in technology foresight. Prior to that, Japan had been engaging in extensive foresight activities since 1970, and there had been several technology 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 technology foresight in the United States (apart from periodic field surveys – see Section II.2 below), the United Kingdom and Germany (at least in the public sector).

Around 1990, the situation began to change. In the Netherlands, two ministries embarked on foresight exercises (see Section III.5 below). In the United States, a number of critical technology exercises were carried out (Section II.2). In 1992, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia conducted a large foresight study. Also in 1992, the first foresight initiatives were taken in Germany, including a collaboration with Japan which was then in the process of carrying out its fifth 30-year Delphi survey (Section III.1). A year later, a major technology foresight programme was launched in Britain (Section III.6). More recently, France has begun a large Delphi exercise using the same survey topics as in the Japanese and German survey (Section III.3).

There have been various international reviews of foresight in science and technology in the past. In 1983, the UK Government commissioned the Science Policy Research Unit (SPRU) to review foresight exercises in France, Germany, Japan and the United States (subsequently published as Irvine and Martin, 1984). Between 1987 and 1989, the Dutch Government commissioned a more extensive review of foresight in those four countries along with Australia, Canada, Norway and Sweden (Irvine and Martin, 1989). In 1992, the Fraunhofer Institute for Systems and Innovation Research (ISI), Karlsruhe, Germany, reviewed the US critical technology exercises and recent foresight studies in Japan (Cuhls *et al.,* 1993). However, given the large number of developments in technology foresight in the last three years, it is timely to review these recent initiatives and to share the lessons learned.

Following a proposal from Japan, under the aegis of the OECD's Committee for Science and Technology Policy, the Working Group on Innovation and Technology Policy organised an *ad hoc* meeting of experts to discuss recent government technology foresight exercises on 14 September 1994. Presentations were given by representatives from Japan, Germany, France, Australia, the Netherlands and the United Kingdom. In addition, the OECD prepared a list of questions on key issues in technology foresight to help structure the discussion, particularly in the final session of the meeting. (These are reproduced in a slightly modified form in Section IV.)

This report of the OECD meeting first sets out a definition of "technology foresight" and briefly reviews the history and the lessons which emerge from previous international reviews of foresight. The six national presentations made at the OECD meeting are then summarised. These national experiences are analysed to address the questions on foresight prepared by the OECD. The final section attempts to draw the main conclusions from the meeting and puts forward some preliminary recommendations as to what the OECD and the Working Group might consider doing next.

II. DEFINITION AND HISTORICAL BACKGROUND

1. Definition and rationale

In what follows, the following working definition of "technology foresight" is used:

> systematic attempts to look into the longer-term future of science, technology, economy and society with a view to identifying emerging generic technologies likely to yield the greatest economic and/or social benefits.

There are five important aspects to this definition. First, the attempts to look into the future must be *systematic* to come under the heading of "foresight". Secondly, those attempts must be concerned with the *longer term* – by which we mean a typical horizon of ten years (and generally in the range between five and 30 years). Thirdly, successful foresight involves balancing "science/technology push" with "market pull" – in other words, identifying likely demands relating to the *economy and society* as well as scientific and technological opportunities. Fourthly, the focus is on the prompt identification of "*emerging generic technolo-*

gies"[1] – that is, technologies which are still at a pre-competitive stage in their development and where there is consequently a legitimate case for government support. Lastly, attention must be given to the likely *social benefits* (including the impact on the environment) of new technologies and not just their impact on industry and the economy.

What are the reasons for carrying out technology foresight? The primary rationale is the 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 technology foresight is to identify potentially important emerging technologies at as early a stage as possible, and to facilitate their development and exploitation.

2. Historical background

Technology forecasting first came to prominence in the late 1950s and early 1960s in the United States and, more specifically, in the US defence sector. The latter was responsible for developing some of the principal tools of technology forecasting, such as the Delphi survey and scenario analysis. Technology forecasting was also taken up by certain private companies (*e.g.* in the energy sector).

Towards the end of the 1960s, Japan decided that technology forecasting represented a potentially useful tool for assisting policy-makers. A team was sent to the United States to consult with experts about the advantages and disadvantages of different approaches to forecasting. In 1970, the Science and Technology Agency (STA) of Japan undertook its first 30-year forecasts of the future of science and technology. The aim was to construct an overview 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 (rather than specific priority-identification). Several thousand experts (mostly active researchers as opposed to senior managers) drawn from industry, universities and government organisations, together with a few maverick thinkers (*e.g.* journalists and science fiction writers) were surveyed 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 were then given an opportunity to confirm or modify their former views.[2] These

30-year forecasts have been repeated approximately every five years, the most recent (the fifth) being in 1991 (see Section III.1 below).

It is important to stress two points in relation to Japan. First, the STA surveys constitute just one of a wide range of technology foresight activities in Japan. Secondly, most of those other foresight exercises use techniques other than Delphi surveys, such as panels, brain-storming, scenarios, commissioned studies 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. Several other Japanese ministries also conduct foresight for areas of technology relevant to them (*e.g.* transport). At the next level down, industrial associations and informal *ad hoc* groupings of companies perform or commission foresight for specific industrial or technological sectors. More micro-level foresight is carried out within individual firms, with the major science-based companies devoting considerable effort to forecasts which are specific to particular product ranges or processes. Lastly, in Japan there are numerous think-tanks which conduct commissioned foresight studies for the public and private sector (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 over the last 20 years. 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 or more of these field reviews were carried out on such areas as physics and astronomy. After a gap, several more reviews were conducted during the 1980s by the National Research Council. In each case, the methodology was similar. A large committee of eminent scientists and perhaps a few industrialists was set up. They in turn appointed a number of sub-committees to focus on sub-fields. Meetings were held and a certain amount of information was compiled. The resulting reports set out the array of exciting opportunities available in that particular 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 invariably ended up by asking the federal government to double the budget for that field over the next four or five years. As a result, although they stimulated some discussion, they generally had little direct impact on the federal government or on Congress. These and various other foresight initiatives such as the Five-year Outlooks and the Research Briefing are described elsewhere (*ibid.*).

From 1945 to the latter part of the 1980s, there was an argument in the United States that the federal government did not need an explicit technology policy. This, together with the pluralist approach to the support of science and technology (with half a dozen federal agencies funding R&D on a large scale), meant that the demand for technology foresight in the public sector was less than in other countries. However, towards the end of the 1980s, there appears to have been a sea-change in attitude as a result of increasing concern about US industrial and technological competitiveness, particularly in relation to Japan. The emerging recognition that the United States needs to have a coherent technology policy largely explains the upsurge in interest in technology foresight over recent years (Martin, 1993).

The favoured approach to foresight in the United States over the last five years has been through the construction of lists of critical technologies (*i.e.* technologies critical to the future of the US economy or to national security). The Department of Defense has carried out two or three such exercises, while others have been conducted by the Department of Commerce and a panel set up by the Office of Science and Technology Policy. In addition, various industrial consortia (*e.g.* aerospace, computer systems) have drawn up more specific lists of critical technologies for their sectors. The methodology in all these has involved starting with an initial long list of emerging or new technologies, identifying explicit selection criteria, and then using those criteria to produce a short list (typically of around 20) of the most important technologies for the United States. These exercises have provoked a lot of discussion but they have been criticised on a number of grounds, including making only limited use of data, involving relatively few people, and identifying technologies that are rather too broad for policy decisions (*ibid.*).

In France, there were several interesting foresight initiatives in the first half of the 1980s. For example, in 1982, a National Colloquium on Research and Technology was held which, together with various regional meetings which preceded it, involved 3 000 people. It identified half a dozen key technologies and the government subsequently launched National "Mobilising" Programmes[3] 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 (Martin and Irvine, 1989). However, after the change of government in 1986, interest in foresight somewhat declined.

Later in the decade, foresight began to spread to other countries, such as Sweden, Canada, Australia and Norway (their experiences are described elsewhere – see *ibid.*). The Dutch Government also embarked on foresight around 1989 (see Section III.5 below). However, at that stage there was still little foresight in Germany, at least in the public sector. One reason for this lay in the constitutional stipulation that "science ... shall be free" – in other words, free from too direct intervention on the part of the government. Likewise in the United Kingdom, although a review of foresight in 1983 had recommended the adoption of a small-scale experimental approach to foresight, this had not been taken up. The government, in line with its policy of reducing the role of government, was not therefore inclined to initiate a foresight exercise. Although it recognised the need for a process to identify national priorities for research in order to stimulate the effective exploitation of new technology, the belief was that one could largely leave such matters to the private sector and the market.

3. Lessons from previous international reviews of foresight[4]

Several conclusions emerge from the international reviews of foresight described in Section I. The first is a widespread recognition of the growing importance of new technology for economic competitiveness and social progress. With research costs rising and the number of scientific opportunities expanding, no organisation or country can afford to do everything. Choices have to be made – and research priorities selected. In the past, those choices tended to be made tacitly (they just "emerged" from the policy process) or in an unsystematic manner. The question now is whether countries should continue with this approach or attempt to devise a more systematic procedure for research priority-setting.

Secondly, technological forecasting, after enjoying some popularity in the 1960s and early 1970s, fell into disrepute following the general failure to foresee the 1973 oil crisis. During the second half of the 1980s, interest shifted to foresight or *la prospective*.[5] 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, foresight and la prospective assume that there are numerous 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 have the power to shape the future through the decisions they take today.

Thirdly, research foresight needs to be carried out at several levels, ranging from bodies responsible for the co-ordination of overall national S&T policy down to individual companies or research organisations.

Thus, some foresight exercises need to be "holistic" in scope, others more micro-level. Furthermore, the foresight activities at different levels should be fully integrated, the results from higher and/or lower levels of foresight being fed into the process, and the results in turn feeding into subsequent foresight efforts at higher or lower levels.

Fourthly, successful foresight involves counter-balancing several "intrinsic tensions". The first requirement is to balance technology-push and demand-pull factors. At least for strategic research,[6] these need to be given approximately equal weight. A second tension concerns striking a balance between top-down and bottom-up approaches. The third relates to the extent to which responsibility for foresight is allocated to an interested party (involved in funding or performing research or in exploiting the results) or to a more neutral "third party". The former approach helps when it comes to implementing the foresight results but brings with it the accompanying risk of falling prey to vested interests (for instance, from established scientific disciplines or from sectors of industry).

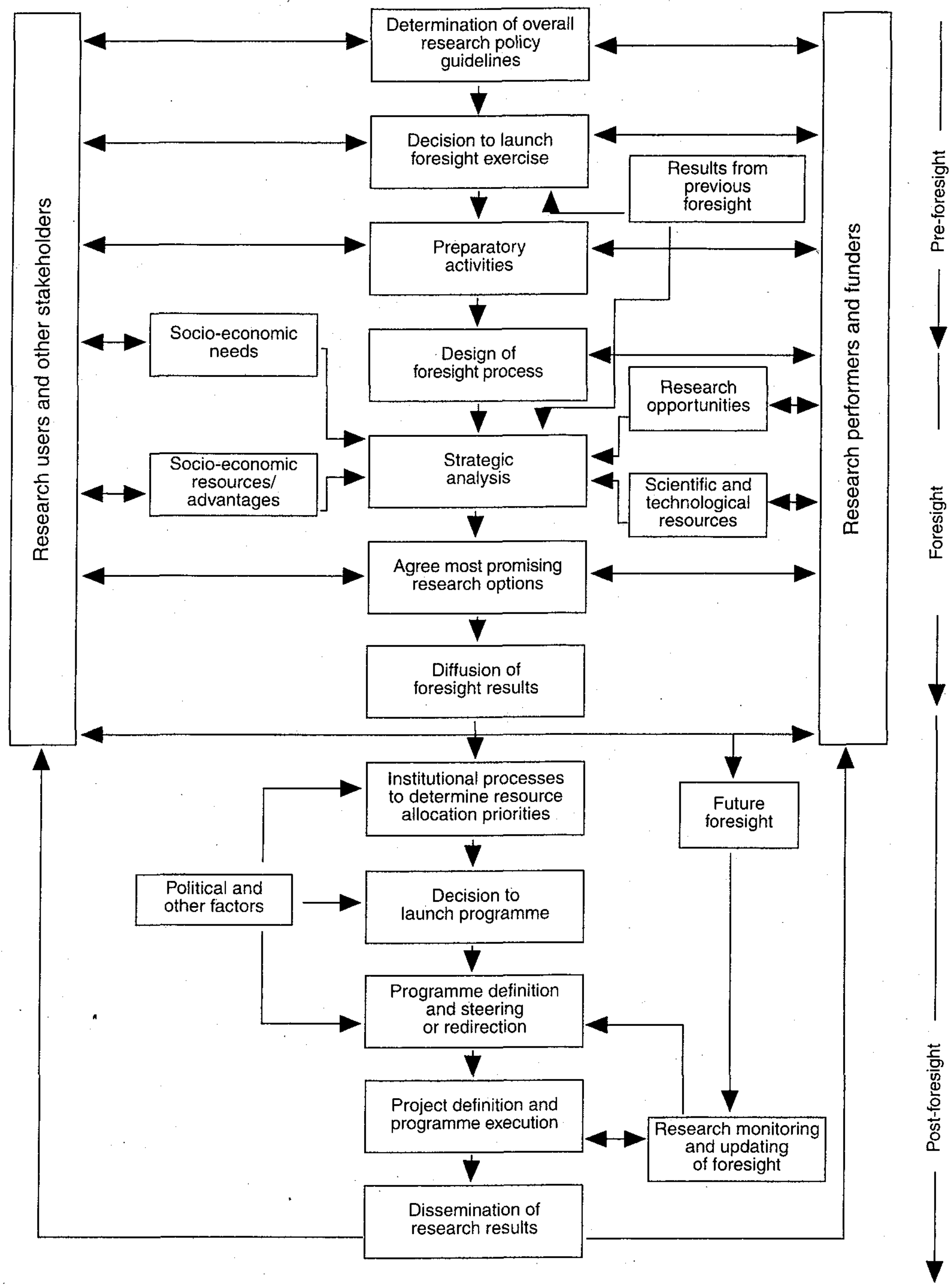
Fifthly, although the aim of research foresight is often to help set research priorities, it can be used for several other functions. These include national direction-setting or creating a shared vision of the future, anticipatory intelligence, generating consensus, advocacy (*e.g.* defending an existing R&D programme), and communication and education (*e.g.* about research opportunities or potential industrial benefits).

A sixth and closely related point is that research foresight depends for its success on involving a wide variety of people – scientists, industrial researchers and R&D managers, policy makers in government and funding agencies, in some cases even the general public. The lesson here is that the process involved in research foresight is generally more important than the immediate outputs (forecasts, priorities or whatever). Those aspects of the research foresight process which are most important can be summarised as "the five Cs" (Irvine and Martin, 1984, p. 144):

- *communication* – bringing together disparate groups of people and providing a structure within which they can communicate;
- *concentration on the longer term* – forcing individuals to concentrate seriously and systematically on the longer-term;
- *co-ordination* – enabling different groups to co-ordinate their future R&D activities;
- *consensus* – creating a measure of consensus on future directions and research priorities;
- *commitment* – generating a sense of commitment to the results among those who will be responsible for translating them into research advances, technological developments and innovations for the benefit of society.

Another contribution from previous work of Susse University's Science Policy Rearch Unit (SPRU) on research foresight has been the construction of a conceptual model for the process. This is summarised in Figure 1 (taken from Martin and Irvine, 1989, p. 30). The model distinguishes three main phases – pre-foresight, foresight and post-foresight. One conclusion from the empirical work is that many foresight efforts failed because insufficient attention was given to the pre-foresight or post-foresight phase. Details of the main factors to be taken into account during these two phases can be found elsewhere (*ibid.,* pp. 29-39). Instead, it is worth

Figure 1. **Elements and stages in foresight for priority setting (including implementation)**



Source: Martin and Irvine (1989).

focusing here on the heart of the foresight process – the box labelled "strategic analysis" in Figure 1.

As mentioned above, foresight for strategic research involves balancing science-push and demand-pull considerations. At the same time, one needs to take account of emerging opportunities and threats, on the one hand, and internal strengths and weaknesses, on the other.[7] This two-by-two combination means that there are four main inputs to be assessed in the strategic analysis:

- evolving economic and social (*e.g.* health, environment) needs and threats;
- emerging scientific opportunities;
- factors affecting a country's capability to exploit the potential economic or social benefits of the new technology including its comparative industrial strengths and weaknesses;
- relative scientific strengths and technological capabilities and other factors influencing the ability to take advantage of the scientific opportunities – for example, the research skills available, the financial resources likely to be forthcoming and the strength of the scientific infrastructure.

This section has examined the historical development of technology foresight and the relevant lessons. Section III will summarise some of the recent developments in six OECD Member countries, based on presentations made at the September 1994 meeting.

III. NATIONAL PRESENTATIONS

1. Japan

In his presentation, Terutaka Kuwahara from the National Institute for Science and Technology Policy (NISTEP) described the fifth Delphi survey of the Japanese Science and Technology Agency (STA), which focused on the period 1991-2020 (Kuwahara, see this issue). A Steering Group was established and the whole of science and technology was divided into 16 areas. Panels were established in each of the 16 fields, involving a total of 130 leading experts from industry, universities and government. The experts started by examining the 1 070 topics used in the fourth Delphi survey. They decided to re-use approximately 300 of them, to modify a further 300 and to create over 500 new ones. The topics can be classified into four categories corresponding to different phases of the innovation cycle:

- elucidation, *i.e.* developing a scientific understanding – 87 topics;
- development of the technology – 344 topics;

– first practical use of the technology – 476 topics;
– widespread use of the technology – 239 topics.

A majority of the topics fall in the last two categories and relate to meeting economic or social needs rather than making scientific or technological advances. Hence, any criticism that the exercise is dominated by "technology push" considerations is misplaced.

As in previous Delphi surveys, over 2 000 experts drawn from industry, academia and government provided their views on the degree of importance of each topic, when it was likely to be realised, whether there is a need for international joint development, where Japan stands in terms of R&D level compared with other countries, and the likely constraints to be encountered in realising that goal.

The results from the survey are seen as having two main uses:

– compiling background data for R&D planning, in particular: *i)* providing a synthesis or overview of longer-term technological trends; and *ii)* identifying important emerging technologies;
– monitoring current science and technology, including: *i)* the level of current Japanese R&D activities; *ii)* areas where there is an emerging need for international collaboration; and *iii)* factors constraining technological development.

The results form 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 such as the Ministry of International Trade and Industry (MITI) and for industry. NISTEP recently carried out a survey of private companies to assess how much use they made of the results from the fourth Delphi exercise. Out of nearly 250 respondents, 59 per cent considered the results "very important" and a further 36 per cent judged them "worthwhile". However, only 12 per cent found them "very useful", although another 61 per cent regarded them as "useful to a certain degree". This partly reflects the fact that companies draw upon a wide range of other foresight information, and partly the fact that, even with over 1 000 topics, the STA results are often rather broad for company purposes. The main uses of the STA results include "planning for R&D and business projects" (72 per cent), "analysing medium-term technological trends" (61 per cent) and "analysis of the specific content of the topics surveyed" (60 per cent).

NISTEP has also assessed the accuracy of the results from the first Delphi survey. They found that only 28 per cent of topics had been fully realised in the intervening 20 years but, if one includes those topics which have been partially realised, the figure rises to a very respectable 64 per cent. There are, however, some variations with field; in information technology (IT) and health, the figure for full or partial realisation is 80 per cent, while in industry and resources (including energy) it is only 50 per cent. Given that this was the first Delphi survey and therefore rather experimental, and given also the long time-horizon, these rates of realisation are quite encouraging and certainly appreciably higher than those one might expect on the basis of chance. Where the forecasts proved inaccurate, this was often not so much in relation to technological developments but as a result of subsequent political or social changes.

A comparison of the results from this survey of Japanese experts with those from the German survey (using identical topics – see Section III.2 below) reveals good agreement in general. This suggests that technology foresight, and more specifically the Delphi approach, can be used consistently across countries and is not too susceptible to national specificities.

NISTEP and the Fraunhofer Institute for Systems Innovation Research (ISI) in Germany are currently collaborating in a "mini-Delphi" study focusing on just four fields. This has two objectives: *i)* to explore the effect of jointly selecting the topics (previously, the German experts were sent the list of topics identified in Japan); and *ii)* to improve the Delphi methodology (for example, distinguishing the potential economic importance of a topic from its likely social importance and its impact on science and technology). In 1995, NISTEP will begin preparing for the sixth Delphi survey. It is willing to exchange information with other countries on this and perhaps to collaborate in some way.

2. Germany

Hariolf Grupp (ISI) described how the upsurge of German interest in foresight had been triggered by the country's re-unification and the resulting question of how to integrate two very different national research systems. Other contributing factors were the economic recession and the issue of the conversion of military technology following the end of the "cold war". One of the first foresight exercises was carried out by a committee set up by the Federal Ministry for Research and Technology (BMFT) in 1992 to review the future of basic science. Using a fairly conventional approach of discussions with experts and brain-storming, and by applying explicit selection criteria (*e.g.* "In which areas are the best scientists in Germany working?"), they produced a list of 14 priority research areas, prominent among which were various topics in environmental and life sciences.

In a rather more ambitious foresight exercise on "Technology at the Threshold of the 21st Century", BMFT commissioned ISI to work with experts from BMFT programme managing agencies (*Projektträger*). The first step was to review recent US critical technology exercises and other foreign foresight initiatives. Next, a long list was drawn up of 86 science-based technologies with potential economic or social utility. Using a "relevance tree" approach, the experts then evaluated each technology in terms of a set of criteria to identify the most important ones along the various dimensions, although no single list of top priorities was produced (Grupp, see this issue).

The other major German foresight exercise involved a collaboration between ISI and NISTEP (also described in the previous section). The first step was to take the 1 150 topics prepared in Japan for the fifth Delphi survey and to translate them into German. This proved to be a non-trivial task, and, after a preliminary translation by professional translators, German experts had to check each topic to ensure that its meaning had been accurately reproduced. The topics were sent to a large sample of experts drawn from industry, universities and government. The response rate was lower than in Japan (30 per cent), partly because of the novelty of such an exercise in Germany but also probably reflecting certain doubts on the part of German experts as regards the appropriateness of foresight in general and of some of the Delphi topics chosen in Japan in particular.

A comparison of the responses by German and Japanese experts shows quite close agreement on the likely time-scale for realising the various goals described in the 1 150 topics (Grupp, this issue). However, there are significant differences between the two countries as regards the relative importance of individual topics and the likely constraints to their realisation. Yet since both these aspects are linked to the national research system, such inter-country differences are not unexpected. Another interesting finding to emerge from both the German and Japanese results is that the experts in a particular sub-field sometimes disagree with experts from neighbouring sub-fields. In some cases, experts in a sub-field are perhaps inclined to act as proponents for a particular technology, understandably if their careers depend on its successful development and exploitation.[8] However, one strength of the Delphi approach is that such a bias on the part of experts can be detected and taken into account.

There are several examples which demonstrate the utilisation of results from these foresight exercises in different sectors (Grupp, this issue). In the federal government, the findings have been an important input to "strategic talks" with industry and large research organisations. They have also had an influence on budget priorities, for instance, within IT. At the level of state governments, there have been investigations of the regional implications of the foresight results in the case of two *Länder* and various policy recommendations have been made. In industry, the participation by companies in the Delphi exercise undoubtedly led to a general improvement in knowledge. (In some firms, in-house experts found, in the second round of the Delphi survey, that their first set of predictions were out of line with the majority view, which sometimes led to some awkward explanations to senior managers!) In a number of cases, the results have formed an input to the company's technological strategy (in some instances, ISI has been commissioned to help). Industrial associations have also drawn upon the results in sector-specific foresight exercises. Lastly, there has been a wider impact on society. The foresight reports have been extensively circulated and discussed in the media. Significantly, there seems to have been some modification in the previously anti-technology stance of certain critical commentators, who have now come to see that the development of at least *some* technologies is desirable.

3. France

Alain Quévreux (Ministry of Higher Education and Research) and Jean-Alain Heraud [*Bureau d'Économie Théorique et Appliquée* (BETA), University of Strasbourg] described the manner in which the current Delphi exercise in France arose from a recognition of the need to improve the technological vision of the government and to provide a more systematic approach to priority-setting. Faced with a large array of foresight tools, there is some uncertainty as to which ones are the most effective. In the past, there has been much work in France on *la prospective* and scenarios. However, there was previously little experience of the Delphi method. An experiment has therefore been launched. This is currently at its mid-stages, so it is too early to judge its success or the utility of the results for public policy.

The topics from the fifth Japanese Delphi survey have again been used, although they were translated from the German rather than the original Japanese versions (Quévreux, see this issue). In certain cases, topics were felt to be inappropriate for France. The entire "lifestyle and culture" section of the survey was omitted for this reason. Even so, receiving the Delphi questionnaire apparently came as a cultural shock to some French experts, who telephoned to find out why these questions were being asked. Indeed, a number of them raised the more fundamental issue of whether it is appropriate to search for consensus in a country like France, as opposed to identifying divergent clusters of opinion. Nevertheless, despite these reservations, the response rate (30 per cent) is similar to that obtained in Germany.

Thus far, only views of experts from the first round of the Delphi survey are available. Nevertheless, there are some intriguing preliminary findings. For example, in line with the German experts, the French disagree with the Japanese over the importance of certain topics and the likely constraints to their realisation, but they also differ with both the Japanese and the Germans over the timing of various developments. For example, in the environment area, German experts generally foresee innovations happening sooner (except for the very long-term developments, more than 20 years in the future, where the situation is reversed). The Germans also attach greater importance to technological developments in the environmental area. Furthermore, the Germans assess themselves to be more expert on environmental topics, although the French experts on this area claim to have given more precise forecasts! It is not yet possible to say whether such differences reflect differing national perspectives or are merely an artefact of the sampling procedure.

Although the French Delphi survey is still at a comparatively early stage, it has already raised several important methodological issues. First, how should one interpret a topic which is given high importance but on which there is low consensus? Secondly, there is some ambiguity over how experts answer questions on a particular topic – do they respond solely with respect to their own country or from a global perspective? Thirdly, there is no satisfactory statistical method available for analysing data based on opinions. For example, how should we weight the views of one "true" expert compared with those of ten moderately expert people (especially given the potential bias problem with experts referred to in Section III.2 above)? Lastly, how does one deal with different *types* of experts – for example, academic compared with industrial experts? Ideally, one needs to construct profiles of the views of different types of experts. It would then be possible to mix the information about both the experts and their answers using appropriate statistical tools in order to derive distinct scenarios or visions of the future. In short, much more methodological and conceptual work is needed on the Delphi approach.

4. Australia

The presentation by Michael Pitman (Chief Scientist, Australia) focused on a current study by the Australian Science and Technology Council (ASTEC) on "Matching Science and Technology to Future Needs" (Pitman, see this issue).[9] Among the issues that need to be taken into account in any technology foresight exercise in Australia are: *i)* sustainable development (soil degradation and water quality are major challenges); *ii)* an ageing population; *iii)* a high degree of urbanisation combined with many isolated communities; *iv)* an evolving multicultural society; *v)* the relatively small and open economy; and *vi)* an abundance of mineral resources and a large rural base. At the same time, the country currently has a lower level of manufacturing activity and devotes a smaller percentage of GDP to R&D than the OECD average, primarily because industrial spending on R&D is comparatively low although it has been increasing rapidly.

The ASTEC study is an experiment to determine whether foresight can assist government and industry in making better informed decisions on the development and application of science and technology, and whether the resulting benefits are specific to Australia. It is assessing the extent to which foresight techniques can help the government in identifying potential mismatches in the supply of, and demand for, science and technology in the period up to 2010. It is also analysing whether the process of consensus-building is a cost-effective way of balancing supply and demand for science and technology.

The approach adopted in the study reflects the philosophy that the *process* benefits from foresight are likely to be more important than the specific products. Efforts have therefore been made to ensure the involvement of the full range of stakeholders in the public and private sectors. With small and medium-size enterprises (SMEs) forming a comparatively large element of Australian industry, the goal of ensuring their participation has proved a central challenge. The study is consequently characterised by a high degree of pragmatism and consultation.

Primary responsibility for the study lies with an ASTEC working committee, with advice and inputs from a "reference group" consisting of eminent representatives from research, industry, government and the general community. The first stage of the study involved an analysis of supply and demand issues based on the four key inputs to foresight described earlier (see Section II.3) – namely: *i)* economic, social and environmental needs; *ii)* economic, social and environmental advantages and resources; *iii)* scientific and technological opportunities; and *iv)* scientific and technological strengths and resources. Drawing on a wide range of information, the working committee, aided by various working parties, began by producing a preliminary overview of Australia's current position in relation to these four factors. A *Background Report* was prepared in August 1994, followed by a series of *Issues Papers* for discussion. The *Issue Papers* contain three elements: *i)* they analyse findings from overseas foresight exercises; *ii)* they attempt to provide an Australian focus for information on global trends in science and technology; and *iii)* they review social developments and economic opportunities. Efforts were also made in this first phase to ensure wide publicity for the study, with extensive consultation with all interested parties. The aim here was to raise awareness and to generate a "foresight culture" in which it becomes normal to ask such questions as: "Where is technology taking us?" and "Where can technology make a contribution?"

The second stage has two main components, one of which involves developing partnerships between ASTEC and various stakeholders in the industrial, environmental and social arena. The partnerships are conducting collaborative studies and collecting information, the aim being to demonstrate that useful outcomes can be achieved through the systematic analysis of future needs. The other component consists of independently managed studies. Besides providing more detailed analysis, the studies should ensure that, with several other foresight activities under way or recently completed in Australia, information on methods and results is fully disseminated and shared, thereby enhancing the level of understanding of the issues raised and also securing the involvement of a broad range of groups. The final stage of synthesis will include holding Round Tables early in 1995 to discuss the *Issues Papers* and the preliminary conclusions, prior to the preparation of a report to the Commonwealth Government later in the year.

5. Netherlands

In the first part of the Dutch presentation, Marja Hilders described two foresight exercises by the Ministry of Economic Affairs (Van Dijk *et al.*, see this issue). The objectives have been three-fold:

- to produce an input to technology policy;
- to provide SMEs with an early warning system of opportunities and threats;
- to create networks.

There are four main steps in the foresight process:

- *consultation* during which five selection criteria (maturity of the technology, its multi-disciplinarity, the application potential, its pervasiveness and the potential for creating networks) are used to draw up a short list of technologies to be examined;
- *analysis* – a study of the selected technology is commissioned from consultants, their task being to draw international comparisons, to identify the key players, to examine potential bottlenecks, and to analyse the opportunities;
- *a strategic conference* is then held to bring together the stakeholders, to test the preliminary results, to create consensus (on how to overcome the bottlenecks and take advantage of the opportunities) and to generate commitment to implementing the results;
- *follow-up* – examples here include launching a pilot project for transferring technology (matrix composites) from universities to SMEs, and creating a new institute (in adhesives).

Three fields were selected and analysed in the first exercise in 1990 (*e.g.* chip-cards) and another three in 1992 (*e.g.* signal processing).

In order to evaluate the effectiveness of the first exercise, a questionnaire was sent two years later to all those who had participated. This revealed that 75 per cent had found the information generated "very valuable", and a similar number had made new contacts as a result of participating in the process. In addition, 60 per cent had taken follow-up action – for example, in the form of new product development (45 per cent), providing advisory services (44 per cent) or launching demonstration projects (30 per cent).

A number of lessons emerge from these two exercises. First, they require considerable effort (which is why the Ministry contracts part of the work to external consultants). Secondly, follow-up activities take a lot of time to organise, in large part because of the need to identify a "product champion" outside the Ministry to assume responsibility for implementing the results. Thirdly, because SMEs represent such an important component of Dutch industry, it is vital to gain their involvement, yet there are considerable difficulties in doing so because of the wide variation in the level of their innovation capabilities. Fourthly, 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. Overall, the evidence suggests that these two exercises have largely succeeded in meeting the three aims (listed above), although in the case of the second objective (providing an early warning system for SMEs) a lot more progress still needs to be made.

Barend van der Meulen (Ministry of Education and Sciences, see this issue) described the work of the Foresight Steering Committee which was created in 1992. It has two aims: *i)* to initiate, support and co-ordinate foresight exercises (as opposed to running foresight studies on its own); and *ii)* to advise the Ministry on options for science and technology policy. The committee consists of a dozen senior scientists and industrial research managers, but it works closely with other institutions in the research system. It has been involved in over half a dozen foresight exercises on such subjects as micro-electronics, agriculture and energy.

The methodology has several elements. Initially, the committee holds discussions and takes account of any external requests for foresight studies, producing an overview and selecting certain topics for further analysis. The next step is to gain the co-operation of key decision-makers in research councils or other research bodies. Possible and necessary contributions of science and technology to society are then examined (*e.g.* using scenario analysis) and discussed (*e.g.* at workshops). Particular emphasis is given in the Netherlands to the contributions of science and technology to society (in addition to industry and the economy), reflecting the wider political climate. The contributions of research to society through higher education and the creation of expertise is also stressed.

The Foresight Steering Committee has devoted significant attention to ensuring that the design of the foresight process is such that it leads to results that can be effectively implemented. Five questions are central here:

- On what type of field is the foresight focusing (including the institutional as well as the cognitive dimension)?
- What factors have previously constrained the identification of priorities in this field?
- Who should be responsible for implementing the results?
- Who is most competent to articulate the needs of society and industry in relation to this field?
- What information is required and how will it be obtained?

Three main conclusions can be drawn from the efforts of the Foresight Steering Committee. First, one must tailor the foresight process to the specific field. This ensures flexibility and enhances the prospects of implementation. Secondly, the Committee faces several specific problems in the Netherlands, including: *i)* determining priorities and "posteriorities" (*i.e.* negative priorities) at a national level; *ii)* establishing how best to articulate research needs; and *iii)* overcoming a distrust of foresight in certain quarters engendered by previous budget cuts. Thirdly, the scenario approach has proved especially effective at wresting participants away from their immediate problems and encouraging them to focus on the longer term.

6. United Kingdom

In 1992, SPRU reviewed foresight activities in the United Kingdom and (more briefly) in Germany, the United States and Australia, and recommended certain options for the United Kingdom (Martin, 1993). The following year, the Government White Paper on Science and Technology adopted one of those options and launched a large-scale Technology Foresight Programme. As Richard King of the Department of Trade and Industry described, the overall objective is to enhance wealth creation and the quality of life in the United Kingdom. More specific aims include the following:

- to identify areas of research and technology likely to meet future market requirements over the next 10-20 years and thus increase UK competitiveness;
- to create partnerships and long-term networks linking industry, the science base (universities, research council laboratories, etc.) and government;
- to focus attention on market opportunities;
- to ensure more effective use of the science base (especially university expertise).

The Office of Science and Technology (within the UK Cabinet Office) has overall responsibility for the programme but it is aided by other ministries (*e.g.* the Department of Trade and Industry) and the Research Councils. The programme is directed by a Steering Group of leading figures from the industrial and scientific communities and from government. Under the authority of the Steering Group, 15 panels are responsible for different sectors and they, in turn, have drawn upon the advice of large pools of experts. Work has also been commissioned from consultants (Walshe, see this issue).

The programme has three principal phases. In the first "pre-foresight" stage, a number of "Focus on Foresight" seminars were held in different regions to generate interest in the programme and ideas on how best to approach it. co-nomination approach (a "snow-ball" technique for getting experts to identify other experts) was used to draw up a list of several thousand experts. The Steering Group also selected the 15 sectors and panel members.

The main foresight phase in turn can be divided into three sub-components:

- *initial analysis* – this has involved: *i)* panel discussions, "scene-setting" exercises, and analyses of UK strengths and weaknesses; *ii)* consulting the expert pools; and *iii)* preparing preliminary reports;
- *wider consultation* – the three elements currently under way here are: *i)* conducting an extensive Delphi survey (of up to 7 000 experts); *ii)* holding regional workshops; and *iii)* organising wider discussion of the panels' initial findings;
- *assessing priorities* – *i)* panels will produce reports setting out the main factors influencing future markets and identifying priorities within their sector; *ii)* the Steering Group will consider the panel reports, attempt to identify priorities across the sectors and prepare a report to the Government early in 1995.

The third and final stage of "post foresight" (*i.e.* implementation of the results) will include several tasks:

- helping to shape decisions on government R&D priorities in ministries, Research Councils and the Higher Education Funding Councils;
- providing inputs to company R&D strategies;
- improving industry/science base partnerships;
- influencing wider government policy (*e.g.* on regulation, standards, or fiscal policy);
- drawing lessons for the next Technology Foresight Programme (the aim is to repeat them at approximately five-year intervals).

IV. CROSS-CUTTING ISSUES IN TECHNOLOGY FORESIGHT

The list of questions drawn up by the OECD Secretariat provides a good starting point for addressing certain key issues in relation to technology foresight on the basis of the experiences of the six countries described above. Some of the OECD questions were slightly modified, however, to reflect the content of the national presentations and in particular the focus of the discussion which followed those presentations.[10]

1. Why do governments engage in technology foresight?

We live in a world of increasingly rapid change in which new technology is playing a growing role. The world is also becoming more competitive, with national competitiveness depending ever more on technology 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. At the same time, governments in many OECD countries are experiencing public expenditure constraints and demands for better "value for money". Partly for this reason and partly because of the escalating cost of much research and technological development, no government can afford to do everything in science and technology, not even the richest. One consequence of this is that governments now realise that they must be more selective in relation to technology – they must have clearer priorities. Technology foresight represents a systematic tool (but not, it should be emphasized a solution or a panacea) for helping to select those priorities.

In addition, there are various other reasons why governments have become involved in technology foresight. One is 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. Technology foresight can help to establish and strengthen those networks. Other reasons for government interest in technology foresight include the desire to stimulate small and medium-size enterprises (SMEs) to take advantage of new technological opportunities, and concerns about the effect of technology on society and the environment. The latter two factors are particularly strong in the Netherlands.

2. Can technology foresight make technology policy more efficient?

At this stage, although the notion that technology foresight can make technology policy more efficient is more an article of faith than a conclusion based on sound empirical evidence, the implicit assumption here (and indeed in policy research more generally) is that more information, especially systematic information, will result in better policy decisions. At present, however, there is little direct "hard" evidence that foresight results in more effective technology policies. Nevertheless, we do have accumulating indirect evidence of the beneficial effects of technology foresight, most clearly in the case of Japan with its 25 years of experience, but also now from Germany, the Netherlands, Australia, Norway, Sweden, Canada and the United States. However, in the case of the

United Kingdom and of the recent French Delphi exercise, it is too soon to tell whether the outcome of these foresight processes will be beneficial.

3. Is there a need for technology foresight?

Section IV.1 above sets out some of the main reasons why technology foresight is needed. Evidence that this need is becoming widely recognised comes from the upsurge of interest in foresight over the recent years, most notably in countries like Britain and Germany, which were previously rather sceptical about the utility of technology foresight. The large attendance at the OECD meeting (over 60) re-enforces this impression.

A subsidiary question which is relevant here is the following: "If Japan and other major countries are doing foresight and making the results public, can we 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 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 the Netherlands. Secondly, as the presenters from several countries emphasised, the benefits associated with the process of carrying out foresight are at least as important as the direct outputs (priorities, policies or whatever).

4. What lessons emerge from the history of foresight and how have methodologies evolved?

In four of the six presentations at this meeting, Delphi surveys featured prominently. Like scenario analysis, the Delphi technique was developed for analysing technological trends in the US defence sector during the late 1950s and early 1960s. It was then adopted by Japan, which carried it forward over the next 20 years, making it more systematic and comprehensive. Now, with the collaboration between Japan and Germany, there is perhaps emerging the next generation of Delphi surveys, for example, with a more differentiated approach to assessing the likely impact of a technology or innovation on the economy, on society and on science. In the United Kingdom, there is presently an innovative attempt to blend Delphi with panel-based approaches to foresight.

However, there are many other approaches to technology foresight. The presentations by Australia and the Netherlands illustrated that quite different approaches have been developed, that are better suited to nations with smaller populations and with economies dominated by SMEs.

5. How does technology foresight differ from technology assessment?

Although this question was not specifically addressed at the *ad hoc* meeting, certain observations can be made. There is clearly a considerable overlap between technology assessment and foresight in terms of the questions addressed, the techniques employed and the information compiled. However, they have different starting points and objectives. In the case of technology assessment, one begins with a particular technology (or set of technologies) and asks what the impact (both positive and negative) is likely to be. In foresight, by contrast, one is trying to establish which technologies one should choose in order to derive the greatest economic and social benefits. In order to answer this, one again needs to consider all the various forms of impact that different technologies may have, but the overall goal is different from that of technology assessment.

6. What are the different methodologies used in technology foresight?

Although Delphi surveys featured prominently in four of the national presentations, there are many other approaches to technology foresight. In Japan, for example, in addition to the "holistic" foresight exercises organised by STA, there are several other distinct levels of foresight activity below this, in particular by: *i)* MITI and other ministries; *ii)* industrial associations or informal groupings of firms; and *iii)* individual companies. Only the STA surveys involve large-scale Delphi surveys.

Similarly in Germany, several different approaches to foresight have been adopted. The BMFT Committee on Basic Science adopted a fairly traditional panel-based approach. The project on "Technology at the Threshold of the 21st Century" involved a combination of "critical technology lists" (as used in several US exercises) and "relevance tree" analysis. The collaborative foresight exercise with Japan relies on a Delphi survey. At lower levels, industrial associations and individual companies are also engaged in foresight exercises using a variety of approaches.

In the Netherlands and Australia, the approach combines widespread consultation, compiling systematic information, panel discussions, establishing and tapping networks, commissioned studies, and explicit selection criteria. The UK foresight programme was initially conceived as primarily a Delphi survey, but over time the panel component (brain-storming, scenarios, etc.) has grown in importance.

7. What factors govern the choice of methodologies?

The choice of methodology must reflect several different aspects of the technology foresight exercise:

- the objectives of the exercise (*e.g.* priority-setting, creating consensus, establishing networks);
- the intended audience and/or implementer of the results;
- the level (*e.g.* holistic versus micro-level);
- the time-horizon;
- the field or sector;
- the wider economic circumstances (*e.g.* a high proportion of SMEs);
- the broader political and social climate (*e.g.* emphasis on the environment).

However, the results from foresight should not be overly sensitive to the choice of one particular methodology over another – in other words, the results should be reasonably robust.

8. What are the strengths and weaknesses of Delphi surveys?

The Delphi technique has a number of advantages. First, it permits a synthesis of the views of large numbers of experts. Secondly, it is suitable for looking at the longer term (*e.g.* 10 to 30 years into the future). Thirdly, it is good at generating the process benefits (the "5 Cs") described earlier – in other words, encouraging communication, fostering concentration on the longer term, providing a means of co-ordination, creating consensus, and generating commitment to the foresight results. Lastly, it can be applied in different countries, and one can then compare the results – for example, to identify the effect of any national influences.

Among the disadvantages are the fact that large-scale Delphi surveys can be expensive, and they are certainly time-consuming. Furthermore, they need the participation of at least a thousand experts or so if the results are to be statistically significant. Consequently, they are perhaps less suited to smaller countries. However, one possible way round this difficulty might lie with bilateral or multilateral collaboration between smaller nations. If so, there may be a role for international organisations like OECD in fostering such international partnerships and keeping other countries informed.

9. What are the key questions in foresight? How should the methodology be designed?

As described in Section II.3, the four key questions to be addressed in technology foresight are:

- evolving economic and social (*e.g.* health, environment) needs and threats;
- emerging scientific opportunities;
- factors affecting a country's capability to exploit the potential economic or social benefits;
- relative scientific and technological strengths.

These factors feature prominently, for example, in the Australian and British exercises. Each of the items above can in turn be broken down into a number of sub-questions (see Martin and Irvine, 1989, pp. 33-36). Other important questions to be addressed are the costs (and risks) of developing each technology or innovation and the likely time-scale.

As regards the design of an appropriate foresight methodology, some of the central issues are discussed in Section IV.7 above and in the second Dutch presentation (see Section III.5).[11] A number of other points mentioned in discussion at the meeting also need to be taken into account. For example, one should recognise that foresight is an iterative process, so the design must be such that it can be regularly updated and revised. Secondly, the identification of likely obstacles or constraints may be at least as important as the identification of important new technologies. Thirdly, as we note in the following section, one can never completely remove the biases of experts, but the foresight methodology should be designed to make those biases as visible as possible. Lastly, the foresight approach must be such that one can give full attention to non-technological factors (*e.g.* the effects of regulation) since these, rather than technological factors, may often be more likely to give rise to bottlenecks.

10. What are the biases?

Given that technology foresight depends to a greater or lesser extent on the inevitably rather subjective views of individual experts, bias is almost inevitable. Indeed, the more closely the foresight is linked to identifying priorities for funding, the greater the risk that the process may be distorted by those biases. However, in a well designed foresight process, one should be able to detect more pronounced examples of bias and then allow for the effects.

In the national presentations, two examples of bias were cited. In the first, certain differences between the views of Japanese and German experts were noted, for example, over the relative importance of different technologies or innovations, and the factors likely to constrain their development. However, this may more accurately be seen as a reflection of different national research and innovation systems than as an example of true "bias". The French experts, in contrast, differed more substantially in their views, including over the timing of advances. This finding is rather harder to account for in terms of different national innovation systems. However, the French results are still very preliminary (the second round of the Delphi survey had yet to be completed at the time of the meeting) so they must first be confirmed before an explanation is sought.

The second and perhaps more interesting example of bias emerging from the Japanese and German Delphi results is the tendency for experts in a given subfield to put forward rather more optimistic views about the future for their area than the slightly less expert respondents from neighbouring fields.[12] One possible explanation is that those experts may also be *proponents* for a particular technology. An example of this is the prediction of nuclear fusion experts in the 1950s that commercial fusion power lay about fifty years in the future. Forty years later, that prospect is still seen as lying some 50 years hence!

11. How reliable are the results of technology foresight?

At first sight, the analysis of the forecasts made in the first STA Delphi survey in 1970 suggests that the reliability of foresight is not very high. Only 25 per cent of the forecasts were fully realised over the next 20 years. However, if those topics which have been partially realised are included, the figure rises to 61 per cent. Given the long-time scale of the forecasts, this figure is quite respectable and far better than one would expect on the basis of chance. In other words, using foresight to obtain imperfect results is better than not doing it at all.

To some extent, however, the issue of "reliability" is perhaps not the right question. A "good" forecast may foresee a major problem and result in action being taken to avoid it happening. A forecast may therefore be inaccurate or "unreliable" but nevertheless very useful in relation to policy-making, as well as in yielding some of the process benefits discussed above.

12. What factors govern the choice of time-horizon?

The choice of time-horizon is governed by a variety of factors, including the objectives of the technology foresight study, the level (whether it is holistic or more micro-level), the chosen methodology, the nature of the technological field or sector, institutional budget-cycles, and even the periodicity of government elections (see also Section IV.7 above). To take the case of Japan, foresight is carried out there with a variety of time-scales. At the holistic level, the STA surveys focus on the next 30 years (although most of the topics considered are clustered within the range of 10-20 years). The foresight activities of MITI and other ministries typically have a horizon of approximately ten years. For industrial associations and informal groupings of companies, the horizon might be five to ten years. Lastly, for individual companies, a horizon of three to five years is more common (although some Japanese corporations do have very long-term views of the future). In short, one needs an entire national system of technology foresight carried out at different levels and with complementary time-horizons.[13]

13. How unstable are the predictions? What is the statistical distribution of responses? How can foresight analysis make better use of the data?

The discussion at the meeting suggested that there is much work to be done before clear answers to such questions will emerge. Technology foresight is a comparatively young field. More research is needed on these and other related questions. (It is significant that the French, although still in the early stages of their Delphi exercise, have already begun to consider these issues.) The element that is most needed, therefore, is regular, effective communication between countries engaged in technology foresight, so that they can learn from one another. OECD might have a role in organising periodic workshops for this purpose.

14. Can one interlink or combine different methodologies? Is this useful?

Again, exploration of the potential for the combined use of several methodologies is still at a relatively early stage, but some interesting examples were cited at the *ad hoc* meeting. In the German project on "Technology at the Threshold of the 21st Century", the "critical technology lists" approach was combined with "relevance tree" analysis. In the Dutch and Australian exercises, a combination of several methodologies is involved. In the UK technology foresight programme, a Delphi survey is being fused with panel-based approaches. Given the limited state of knowledge, regular interaction (perhaps under the auspices of OECD) between countries engaging in foresight would be useful in order to enhance mutual understanding.

15. Should there be links with industry? What are the most appropriate links, in particular with SMEs?

Links with industry are essential. One of the main factors influencing success in foresight is achieving a good balance between "technology push" and "market pull". Those who are best placed to assess emerging or future market needs which may be addressed with new technology are mostly to be found in industry. Their participation in foresight is therefore vital.

As regards the participation of SMEs, the extent to which they are involved depends on their importance in the national economy. In countries like Australia and the Netherlands, where their relative importance is greater than in Britain or Japan, attention must be given to designing a foresight methodology which ensures that they play a full role. An important lesson to emerge here is that, almost certainly, *different kinds* of links are needed for SMEs as compared with multinational companies. SMEs are more interested in niche markets than global ones, and they also possess very different levels of technological expertise. In the UK Technology Foresight Programme, the panel-based approach and the Delphi survey is resulting in good interaction with large firms. However, a different approach based around regional workshops is to be used to gain the involvement of SMEs. In Australia and the Netherlands, the approach to technology foresight has been more heavily oriented to achieving close links with SMEs right from the outset.

16. What is the role of international comparisons in relation to foresight exercises?

Comparisons of the results from foresight exercises in different countries are essential. As noted above, technology foresight is still a relatively young field, and many benefits may arise from sharing information. (For example, there might be some scope for secondary analysis of Delphi questionnaires from different countries in order to draw detailed comparisons.) However, given the recent proliferation of foresight in different countries, there is almost certainly a need for some international co-ordination, a role which perhaps OECD could usefully perform.

17. Is there scope for international collaboration in technology foresight?

From the presentations and the subsequent discussion at the meeting, it is clear that there is considerable scope for international collaboration in foresight to share both methodological experiences and results as well as experiences in how best to embed foresight in wider discussions of science and technology policy. The German-Japanese collaboration shows how fruitful such collaborations may be. The general consensus, though, was that *bilateral* arrangements are more appropriate at this stage in the development of technology foresight than multinational foresight exercises. The main reason is that different countries may have very different objectives and needs in relation to foresight; the approaches they adopt may therefore differ, as will the conclusions (not least because of their differing strengths and weaknesses in relation to industry and to science and technology). Moreover, in a multinational foresight exercise, there is the risk of weakening the contacts at the national level which are essential for ensuring the foresight results are properly implemented. There were therefore doubts at the *ad hoc* meeting about the need for a wide-scale EU (or pan-European) foresight exercise, although specific foresight exercises linked to EU programmes or "big science" facilities might be productive.

18. What effect will technology foresight have on international co-operation or competition?

Technology foresight may have a mixture of beneficial and adverse consequences. As many years of experience at OECD have demonstrated, the effect of countries working together and learning from each other generally leads to substantial mutual benefits. On the other hand, if technology foresight were to result in countries choosing similar priorities in technology and R&D, this may create problems of conservatism and, more seriously, of increased international competition. In Japan, for example, some concern has been voiced that the prominent role of foresight may have led companies (*e.g.* in the IT sector) to concentrate their R&D efforts on an overly narrow range of technologies, with the result that they may have missed out on some of the more exotic technological developments while at the same time aggravating the already very fierce competition between firms. Nevertheless, there are few in Japan who would argue that the disadvantages of foresight outweigh the benefits.

While foresight in other countries is still at a much earlier stage, the experiences of the Netherlands and Australia suggest that foresight is more likely to result in the pursuit of diverging government policies than converging ones. In this respect, technology foresight might contribute to a clearer international division of labour, lessening competitive pressures and friction rather than aggravating them. There are therefore grounds for optimism in believing that the same balance between the benefits and disadvantages of technology foresight holds more generally outside of Japan.

V. CONCLUSIONS AND RECOMMENDATIONS

The first conclusion from the meeting is that there is wide-spread and growing recognition that technology foresight represents a useful tool to aid decision-making in relation to technology policy, whether at the national level or at a more micro-level. Japan, after nearly 25 years of experience with technology foresight, is still an enthusiastic devotee. In other countries, technology foresight has begun to take root. There has been marked progress in the Netherlands and Germany and in both these countries foresight is now quite firmly established. Australia and the United Kingdom are currently in the midst of ambitious foresight exercises; although not yet complete, they are already starting to bring 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, another approach may be more appropriate.

A third and closely related conclusion is that individual countries may adopt quite different approaches. Japan, Germany, Britain and France are making use of a large-scale Delphi survey. In the Netherlands and Australia, the Delphi method is not being employed; instead, the emphasis is on other approaches, such as panel discussions and brain-storming, commissioned studies, and creating or tapping networks.

Fourthly, most participants at the meeting were doubtful as to whether a multi-country foresight exercise was desirable, at least at this stage. This is partly because no single, universal foresight approach is possible, and partly because, as we have seen, different countries have widely varying objectives and needs in relation to technology foresight. Instead, bilateral (or perhaps trilateral) collaborations are likely to prove the more fruitful route to explore. However, there may be a role for multinational foresight exercises linked to *specific* sectors (*e.g.* EU programmes) or to areas of "mega-science".

Finally, with the number of countries experimenting with technology foresight now quite large, there is a need for a mechanism to promote the regular interchange of ideas, experiences, problems and lessons. The OECD meeting was found very useful in this respect by participants, but similar meetings will be required in the future.

Participants in the meeting made recommendations as to what OECD might consider doing next in relation to technology foresight. In arriving at their recommendations, participants in the *ad hoc* meeting took into account the fact that the OECD Committee for Scientific and Technological Policy (CSTP) previously judged technology foresight to be a relatively low priority, and that the OECD Secretariat is already stretched. In the light of these considerations and of the doubts over the wisdom of conducting a multi-country foresight exercise, the meeting did not recommend any major technology foresight initiative by OECD. However, it did identify several possibilities where OECD might develop a role as a broker.

Recommendation 1

OECD could organise another meeting on technology foresight in 12-18 months (when the Australian, British and French exercises will have been completed).

Recommendation 2

Participants at the *ad hoc* meeting and OECD officials should convey to CSTP members the consensus view that the meeting was very valuable.

Recommendation 3

OECD could act as a central clearing house for information on technology foresight. Member countries would then submit reports or any other written material on foresight in their country, along with the names of contacts (including telephone and fax numbers) in ministries, agencies and elsewhere.

Recommendation 4

OECD might also assume a "marriage broker" role; where a country seeks to collaborate with others (perhaps because of its small size or a lack of experience with foresight), it would notify OECD of its needs. OECD could then offer advice on which country (or countries) and, within that, which organisation(s) it might approach to explore the possibilities for collaboration.

Recommendation 5

OECD might take the lead in creating an electronic bulletin board on technology foresight, overseeing its operation and publicising its existence.

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NOTES

1. 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, 1992, p. 51).
2. 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.
3. The term "mobilising" indicates the emphasis given to mobilising the industrial and scientific communities to work together in pursuit of noational goals.
4. This section is based on Martin (1993, pp. 13-15).
5. The approach of *la prospective* has been pioneered by Godet (*e.g.* 1986) and others in France.
6. "Strategic research" is defined here as "basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised current or future practical problems" (Irvine and Martin, 1984, p. 4).
7. Strategic planning based on an examination of Strengths, Weaknesses, Opportunities and Threats is sometimes termed "SWOT" analysis.
8. The finding in Japan that predictions made in 1970 in the energy sector had been less accurate than those in other sectors may be partly accounted for by the tendency of certain groups in this area (*e.g.* researchers on nuclear energy) to act as *advocates* for their area and to come up with unduly optimistic forecasts of the future prospects.
9. A description of earlier foresight exercises in Australia can be found in Martin and Irvine (1989) and Martin (1993).
10. It should be stressed that what follows represents a personal assessment of the main conclusions to emerge from the discussion.
11. The design of the foresight process is also discussed extensively in Martin and Irvine (1989, Chapter 11).
12. This effect had been noted in earlier STA results (see Martin and Irvine, 1989, p. 154).
13. See also the discussion in Martin and Irvine (1989, p. 27).

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TECHNOLOGY FORESIGHT IN JAPAN: A NEW APPROACH IN METHODOLOGY AND ANALYSIS

CONTENTS

This article was written by Terutaka Kuwahara, Director, National Institute of Science and Technology Policy (NISTEP), Tokyo.

I. OUTLINE OF JAPANESE FORESIGHT ACTIVITIES

Foresight of government

The Science and Technology Agency (STA) has conducted a technology forecast survey using the Delphi method every five years since the first survey in 1971. In the five surveys carried out to date, the number of topics has increased with each survey. The forecasted time of 30 years has been the same for all surveys (Table 1). The surveys are large-scale and very extensive, covering all technological areas. These surveys, carried out on a regular basis and for such an extended period, are without parallel anywhere else in the world.

Technology forecasting activities in Japan are conducted not only by the STA but by other organisations at various levels. Many ministries and agencies carry out their own foresight surveys or support surveys conducted by semi-public foundations and societies. The results of these surveys are usually made public.

Typically, this type of survey is aimed at providing guidelines for government activity and to induce R&D activity of enterprises. These foresight activities can be classified by methodology (Delphi method or other) and by coverage of technological area (specific area or all areas).

Most surveys are of the "non-Delphi/specific area" type. One recent example was that of a survey carried out by the Telecommunication Technology Council of

Table 1. **Changes in the coverage of STA's technology forecast surveys**

	Survey period	No. of areas	No. of topics	Forecasted period	No. of effective responses
First survey	1970-71	5	644	30 years to 2000	2 482
Second survey	1976	7	656	30 years to 2005	1 316
Third survey	1981-82	13	800	30 years to 2010	1 727
Fourth survey	1986	17	1 071	30 years to 2015	2 007
Fifth survey	1991	16	1 149	30 years to 2020	2 385

Source: Author.

the Ministry of Posts and Telecommunications (1995). 293 critical telecommunication technologies were chosen, and the survey evaluated current R&D in Japan and other countries, the degree of technological importance and the degree of technological difficulty. The timetable for realisation, necessary funding and human resources were also reviewed.

Surveys using the Delphi method are not so common. One example is a survey done by the National Institute of Environment to forecast future environmental trends. Another is a survey conducted by the Japan Foundation for Ageing and Health (1995). This survey is supported by the Ministry of Health and Welfare and the objective is to obtain an overview of the technologies needed to prepare for an ageing society at the beginning of the 21st century. The survey methodology including survey parameters is very similar to that of the STA Delphi. Another example is that of a study done by the Japan Electronic Industry Development Association (1995). In this study, the long-term demand for, and trend in, electronic technologies was studied using the Delphi method, focusing in particular on multi-media.

An example of a forecast survey that covers all technology areas is one carried out by the Economic Planning Agency (1991). The objective of this survey is to evaluate the degree of impacts of future technologies on industry and the economy. 101 technologies are evaluated concerning the state of Japanese R&D, institutional constraints, the time to practical use, the expected market size, possible positive/negative impacts. The data source for these evaluations is the 12 panelists' views.

Technology foresight of enterprises

Some non-government organisations conduct technology foresights with the support of Ministries for instance the survey conducted by the Japan Foundation for Ageing and Health which has already been mentioned. In addition many large enterprises undertake their own foresight activities, the results of which are generally not made public. However, there are some cases in which the outlines of the survey are known. One example is a survey conducted by a utility company which is used to identify critical technologies and to develop a long-term R&D plan. The company surveyed socio-economical and technological trends that could affect its business. The long-term technologies were selected through this analysis, and forecasts made.

Another example is that of a survey done by a housing material and equipment company. This company analysed the results of STA's fourth and fifth survey. It is also analysed patent trends and trends in the government's R&D projects. They merged these results with information on other trends in business, economy, society, life style, etc., to create a future business plan.

II. THE FIFTH TECHNOLOGY FORECAST

The outline of the survey

In contrast to other technology forecasts, this survey applying the Delphi method is done for the purpose of gaining an overview of important innovation trends in science and technology. This is done in order to provide information to the planning processes of the state in science and technology policy and to provide industry with this information.

Table 2. **Survey areas and number of topics in the fifth Delphi survey**

1.	Materials and processing	108
2.	Information and electronics	106
3.	Life science	98
4.	Outer space	46
5.	Particles	40
6.	Marine science and Earth science	82
7.	Mineral and water resources	39
8.	Energy	51
9.	Environment	50
10.	Agriculture, forestry and fishery	74
11.	Production	72
12.	Urbanisation and construction	65
13.	Communications	65
14.	Transportation	62
15.	Health and medical care	109
16.	Lifestyles and culture	82

Source: Author.

From the fifth survey the National Institute of Science and Technology Policy (NISTEP) assumed responsibility for conducting the survey and compiling the results. NISTEP conducted the fifth survey over three years from 1990, and published the results in November 1992 (NISTEP, 1992). The fifth technology forecast survey covered 1 149 topics classified into 16 technological areas. In the first round, responses were received from 2 781 experts in various technological fields, and the second questionnaire was answered by 2 385 experts. The forecast period was thirty years starting from 1991 (the survey year) to 2020.

Surveyed technological topics and parameters

An absolutely vital part of the technology forecast survey using the Delphi method is preparing effective technological topics. For the Fifth Technology Forecast Survey, NISTEP formed a steering committee comprising 30 experts from various fields to promote and control the project. After the 16 areas had been set by the committee, 13 sub-committees, each comprising 5-10 experts, were established under the steering committee to decide upon the framework to prepare suitable topics that could explore the essence of technological progress in each of the areas. The individual topics were then prepared within this framework. Each of the sub-committees re-evaluated the topics of the fourth survey. As a result, around 300 topics were surveyed again, around 300 topics were modified to take account of technological developments in the previous five years, and around 500 were newly created by the members of sub-committees.

Covering all 16 areas, questionnaires were structured in exactly the same way, and included such variables as the degree of expertise of the respondents, the degree of importance, the forecasted realisation time, the degree of certainty, the necessity of international joint development, constraints on realisation and, in the second round, a comparison of the current R&D level of Japan and other countries. The committees then selected experts in each of the 16 technological areas to answer the questionnaire. Sub-committees gave special consideration in the selection process to ensure that there was no imbalance among industry, academia and government. Respondents were asked to assess their own degree of expertise.

Table 3. **Survey parameters of the fifth Delphi survey**

1. Degree of expertise (high/medium/low/none)
2. Degree of importance (high/medium/low/none)
3. Forecasted realisation time (91-95/96-00/01-05/06-10/11-15/16-20/21 – or never) degree of certainty (high/medium/low)
4. Necessity for international joint development (high/medium/low/none)
5. Comparison of current R&D level between Japan and other countries (Japan is superior/ equivalent/other countries are superior)
6. Constraints on realisation (multiple choice at most two: technical/institutional/cultural/cost/ funding/human resources/R&D system/other)

Source: Author.

Table 4. **Survey on the use of technology forecasts**

Percentages

1. What is your interest in Science and Technology Agency technology forecast surveys?	
1) Technologies	
a) To gain a wide-ranging understanding about future trends of technology in various areas	49.4
b) To grasp future trends of specific technological areas or technologies of interest	48.6
c) Others	1.2
d) No response	0.8
2) Forecast time	
a) To grasp long-term technological trends (at least ten years ahead)	24.7
b) To grasp medium-term technological trends (5-10 years ahead)	60.7
c) To grasp short-term technological trends (up to five years ahead)	11.7
d) Others	0.8
2. What Science and Technology Agency technology forecast information have you used? (multiple answer)	
a) Subject matter of the forecast topics itself	59.9
b) Importance assessment	51.0
c) Realisation time	76.1
d) Limitations on realisation (technological, economic and social)	37
e) Methods of promoting R&D (independent R&D, introduction of technology, international joint development)	16.2
f) Main R&D promoter (government, private sector, both government and private sector)	12.6
g) Government measures (funding, human resources, systems, etc.)	13.8
h) Comments (minority opinions)	18.2
i) Others	0.4
3. How useful has the information been?	
a) Very useful	11.7
b) Useful to certain degree	61.1
c) Cannot say either way	19.0
d) Not very useful	4.9
e) Not useful	2.0
f) Others	0.4
g) No response	0.8
3. How significant is the information?	
a) Information is extremely important and necessary	58.7
b) Information is worthwhile having	36.4
c) Information is not very important (not particularly necessary)	2.0
d) Do not know	0.4
e) Others	0.8
f) No response	1.6

Source: Author.

Utilisation of STA Delphi

The STA Delphi is conducted under the remit of the Council for Science and Technology (CST) – which is chaired by the Prime-Minister – and the report is submitted to it. CST has responsibility for developing national master plans and for recommending necessary measures to the cabinet. The Delphi results are utilised in the discussion of sub-committees of CST when developing plans to promote science and technology activities. In addition, the Delphi results are available to all government organisations, and are often utilised as a database for their own foresight activities.

The Delphi process itself has an important influence on Japanese R&D activities. More than 100 senior researchers are involved in the design of the survey and in the analysis of the results. They have responsible and effective positions in their institutes, universities and enterprises. Furthermore, around 3 000 researchers participate in the survey as respondents.

To ascertain the extent to which the results of the technology forecast surveys are used, in 1990, NISTEP conducted a user questionnaire survey of people and organisations that had purchased the Fourth Technology Forecast Survey Report which had been published as a book. 247 responses were received (Table 4). About 70 per cent of the respondents indicated that they had bought the report for using it in R&D and technology development or for the formulation of business plans, and of these, about 73 per cent indicated that the information contained in the report had been very useful or useful to a certain degree in achieving these aims.

It is always difficult to evaluate the impacts of a survey like this, but with the results of the questionnaire shown above, concrete influences on Japan's research and development as well as technology developments in general, can be discerned.

Most of the respondents were interested in the short-term future technologies which were forecasted to be realised within ten years. We can observe that around half of respondents were concerned with the results in a specialised field, and the same population with those in various other fields. This reflects today's interdisciplinarity of technologies and the fact that enterprises have to watch the possibility that alternative and competitive technologies may be developed in other fields.

In their evaluation of the STA Delphi, 12 per cent of respondents think it is very useful and 61 per cent useful to certain degree. Enterprises need precise information to support their own project planning and the 1 000 topics covered by the STA Delphi are not enough in this aspect. Effective development of business plans require the acquisition and analysis of additional information from both within and outside the organisation.

We asked what methodologies (*i.e.* the kind of survey methods employed) were popular in the forecasting activities of Japanese enterprises: forecasted results by trend analysis, Delphi method, scenario writing, relevance tree method.

The respondents pointed out some difficulties for enterprises in conducting forecasting. Difficulties in securing enough staff and in collecting reliable information were emphasised. Other problems were the cost and time involved. Because of these difficulties, 15 per cent of the respondents carried out forecasting surveys by themselves, while 36 per cent contracted them out to other organisations such as think-tanks.

III. AN ASSESSMENT OF THE RELIABILITY OF DELPHI FORECASTING

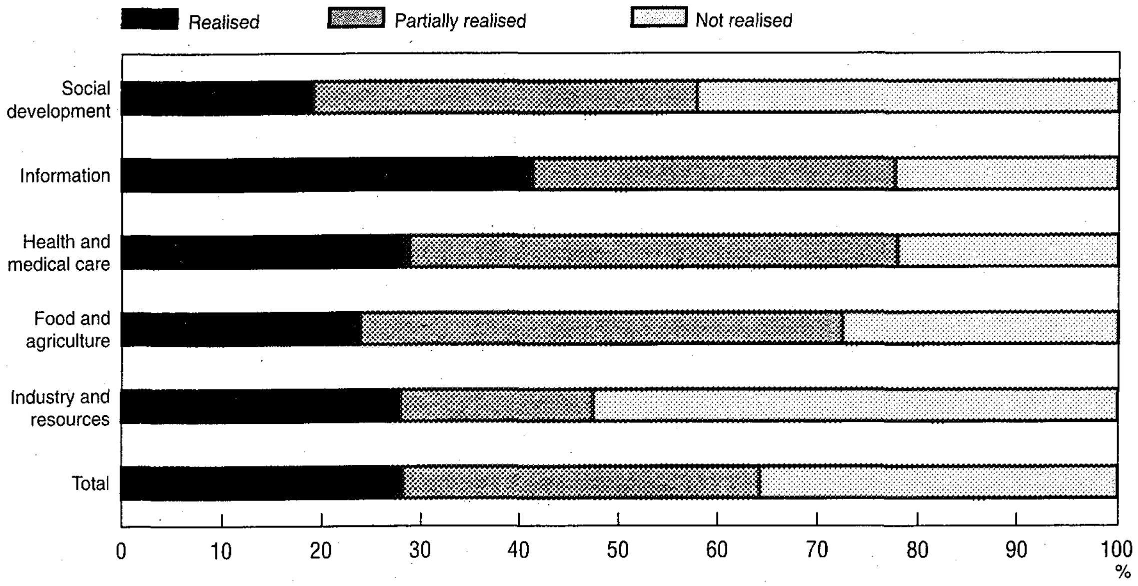
The first survey was carried out in 1971 with the scope of 30 years by 2000. NISTEP has conducted an assessment of the results of this survey with the assistance of the experts who were the members of the fifth survey's subcommittees. 530 topics of the survey (644 in total) were selected. These topics include those which had been forecasted to be realised before 1991, as well as those which had already been realised by 1991 even though the forecasted time of realisation was after that date.

In this assessment, we simply evaluated whether some topics were realised before 1991 or not. The real time of realisation can not be exactly determined in many cases even if a topic was certainly realised before this date, therefore the forecasted year itself is not evaluated. Many topics did not have a single technological goal and we found many cases in which parts of the topics had been realised but other parts had not. These topics were evaluated as "Partially realised".

28 per cent of topics were fully realised, while 36 per cent of topics were partially realised. In other words, forecasted future trends were realised with two-thirds of technologies. This result shows that Delphi-type technology forecasting has sufficient reliability to form the basis for long-term R&D strategies.

Realisation rate is particularly high in the "Information" category. This area is composed of three sub-areas. The realisation rate (combined realisation and partial realisation rate in brackets) is 52.4 per cent (85.7 per cent) in "information technology", 30.6 per cent (77.8 per cent) in "development for the demand of society and economy" and 38.9 per cent (61.1 per cent) in "basic technology". On the other hand, typical sub-areas where the realisation rate is low are found in the "Industry and resources" area. Realisation rate in "resource development" is 12.5 per cent (33.3 per cent) and in "energy development" is 14.3 per cent

Figure 1. **Assessment and analysis of the results of the first technology forecast survey**



Source: Author.

(33.3 per cent). The oil crisis occurred after this survey had been carried out, and one reason for the low realisation rate is the drastic change in the social and economic environment.

IV. COMPARISON BETWEEN THE JAPANESE AND GERMAN SURVEYS

The German government conducted the same technology forecast survey as that of Japan. The report was published in Summer 1993 (BMFT, 1993). NISTEP and the Fraunhofer Institute for Systems and Innovation Research (ISI) subsequently carried out a joint study to analyse the two countries' results. The joint report was published in Spring 1994 (NISTEP and ISI, 1994). France has also conducted a similar survey to that of the STA Fifth Delphi, and a comparison between Japan and France is in preparation.

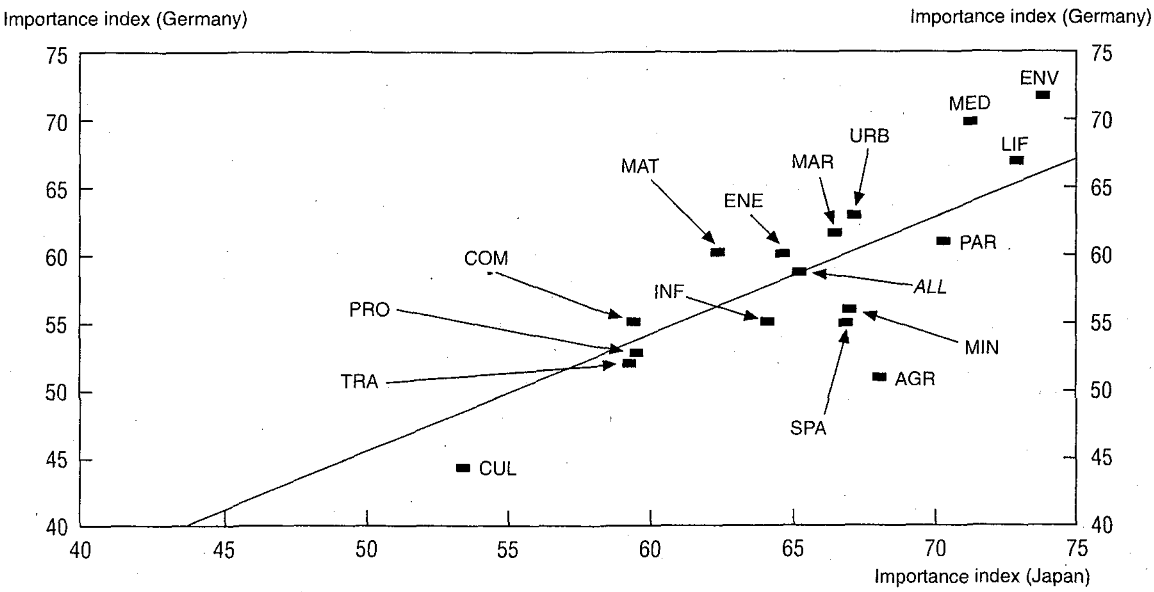
Many of the results of the German survey are more or less the same as those for Japan. Summing across all technology fields, there was very little difference between the Japanese and German estimates. From this, there is evidence that the Delphi procedure is not greatly distorted by national influences and peculiarities. Progress in technology seems to be of a really international nature in many fields with practically no information deficits in Japan or Germany. This leads to conclusions on the openness of world-wide scientific and technological information.

When evaluating the importance of topics, the average index is 65 in Japan and 59 in Germany (this index is 100 if all the respondents think the topic is "very important" and 0 if all think it "not necessary"). Japanese experts tended to rate the importance as slightly higher than their German counterparts, but the difference between the two is not particularly large.

Considering that the topics used in the German survey were prepared by Japanese experts premised on Japanese science and technology and socio-economic conditions, the difference is indeed slight. This is a good indication that today's science and technology has an international universality, and that in industrialised countries, such as Japan and Germany, science and technology and socio-economic conditions are, in general, closely linked.

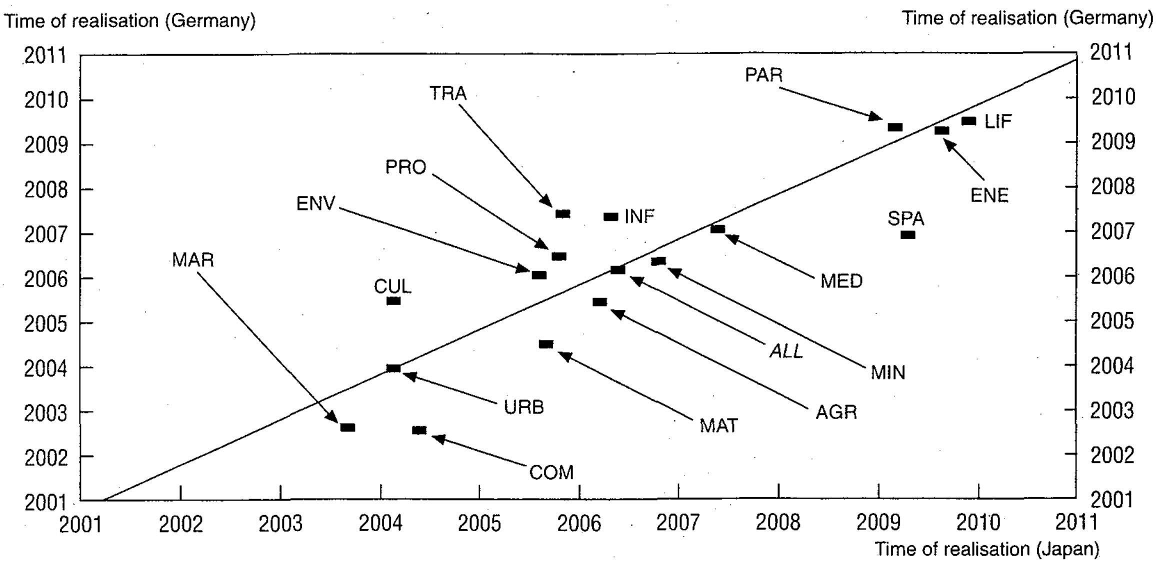
There was conformity between the Japanese and German surveys in ratings for importance for Environment (Env), Life Sciences (Lif) and Medical Care and Health (Med). These three areas were evaluated as the three most important

Figure 2. **Comparison of Japanese and German importance ratings per area**



ALL: overall average value.
Source: Author.

Figure 3. **Comparison of Japanese and German forecasted year of realisation per technological area**
The drawn line connects the origin (1990) with the overall average value



ALL: overall average value.
Source: Author.

technological areas, while Culture and Lifestyles was rated of low importance in both surveys.

Another important survey parameter is time of realisation. The average realisation time for all 1 146 topics was the same for both the Japanese and German surveys with both recording 2006. There were few topics in which there was a large difference in the forecasted realisation time between Japan and Germany; 278 topics (24.3 per cent) had a difference in forecasted realisation time of less than one year, 506 topics (44.2 per cent) had a difference of less than two years, and 709 topics (61.9 per cent) had a difference of less than three years. Thus, it can be observed that in about two-thirds of all topics, the difference is less than three years between Japanese and German forecasts.

The technological areas with a later forecasted realisation time (average value later than 2009) in the Japanese survey are Life Sciences (Lif), Energy (Ene), Space (Spa), and Particles (Par) while the same areas apart from Space (Spa) are also forecasted to be realised after 2009 in the German survey. Therefore again, there is some conformity between the two surveys. Areas with an earliest forecasted realisation time (average value earlier than 2005) are Marine Science and Earth Science (Mar), Communications (Com), and Urbanisation and Construction (Urb) in both surveys.

Japanese and German trends generally conform in each technological area, and are almost all distributed in the vicinity of the straight line that connects the origin and the average for all topics. Areas with a considerable difference in which Japan's forecasted realisation time is later than Germany's are Space (Spa) and Communications (Com), while those in which Germany's forecasted realisation time is later are Transportation (Tra) and Culture and Lifestyles (Cul).

However, by looking closer at the details of responses in individual areas and single topics, several topics show strong discrepancies between the surveys, and the dominance of national communities and systems of innovation becomes obvious. The main conclusion in these cases would be that Delphi inquiries on technology should always be undertaken with an international panel including people from more than one country or continent.

The international scope of technology forecasting is important because sufficient specialist experts may not be available in one country. In addition, research has shown that there is a positive relationship between involvement in a research area and assessment of it, and that this relationship derives from the tendency of scientists to select problems in areas where there is high pay-off for successful solutions and career. The tendency to overrate fields in which a person works may be termed "bias". In the respective literature, not only a tendency toward positive bias for fields in which researchers have been active is documented, but also this bias seems to be stronger in less innovative sub-fields (defensive point of view). As market signals fail to be useful for business strategy in the long run and expert assessment is not always objective, Delphi surveys may play a part as a more objective information base in innovation management.

V. MINI-DELPHI: AN APPROACH TO INTERNATIONAL FORESIGHT

Outline of mini-Delphi

We found that international comparison of technology forecasts can provide us with valuable information for science and technology policy and for technology development strategies in the private sector. NISTEP and ISI have conducted a small Delphi project (the so-called "mini-Delphi") to promote this bilateral cooperation in foresight studies. In this project, Japanese and German specialists worked jointly on the creation and selection of technological topics and the same survey was conducted in parallel in the two countries. The surveyed areas are as follows.

Table 5. **Survey areas and sub-areas of mini-Delphi**

Materials and processing	Solar cell Superconductivity
Information and electronics	Artificial intelligence and cognitive system Nano-technology and micro-system technology
Life science and medical care	Cancer research and treatment Brain research
Environment	Waste processing and recycling Climate research and climate technology

Source: Author.

We note five characteristics of this mini-Delphi. First, the survey areas are limited and more than 15 technological topics were surveyed for each of the sub-areas. It was therefore possible to determine detailed future scenarios for each of the sub-areas. Second, Japanese and German expert panelists worked jointly to set the topics. Third, we asked the respondents to propose additional topics for this survey during the first round questionnaire. Japanese and German panels selected some of these additional topics and added them to the second round questionnaire. The number of topics in the second questionnaire was 132 including 12 additional ones.

The fourth point concerns survey parameters. In the former survey, we asked respondents to evaluate the degree of importance in general, whereas in the mini-Delphi, we asked them to estimate the importance for S&T, economy, environment, etc.

The fifth point concerns feedback from respondents. We asked the respondents during the first round to write down their comments on the topics. Typical comments were selected and shown in the second round questionnaire. Respondents sometimes supported other experts' comments and sometimes put forward counterarguments. For example, in the solar cell sub-area, respondents' comments shows that many experts think that reducing cost with an efficiency of 15 per cent is a higher priority, than developing a more efficient solar cell. This is evidence that such comments are useful, because evaluation of importance was almost the same among the topic at "20 per cent efficiency", "30 per cent efficiency" and "40 per cent efficiency".

The first round survey was carried out in the Autumn 1994, and the second round at the beginning of 1995. NISTEP and ISI held an international conference on technology foresight in June 1995 in Tokyo. The results of mini-Delphi were discussed and examined by Japanese and German experts. In this conference, experts from France, the United Kingdom, Australia and the Republic of Korea

Table 6. **Survey parameters of mini-Delphi**

Expertise
Importance
For progress in science and technology
For the economy
For the environment
For developing countries
For society
Time of realisation
Assessment of conditions for successful realisation
Solubility of scientific and technical problems
Size of future market demand
Price competitiveness on the future market
Evaluation of the framework conditions
The engagement of business
The extent of public regulations
Public support
International co-operation
Public understanding of technology
R&D infrastructure
Availability and education of trained personnel
Start-up conditions for innovations (risk capital, etc.)
The national R&D level

Source: Author.

also participated and exchanged their experiences of foresight activities in their countries and discussed the future development of the approach.

Some results of mini-Delphi

In the Japanese and German evaluation of the importance of the four areas in terms of the five criteria listed in Table 6, importance for science and technology was highest and that for developing countries was low. The importance for the economy, for society and for the environment are medium in both countries. Respondents evaluated by choosing high/ medium/ low or none, and here the importance index is calculated to be 100 when all the respondents think "high", and to be 0 when "low or none".

German experts predict higher importance for science and technology in all sub-areas. Brain research is given the highest evaluation of importance in both countries. Both experts' views show good correspondence with importance for the environment and for developing countries. The Japanese evaluation is slightly higher than the German one regarding importance for society.

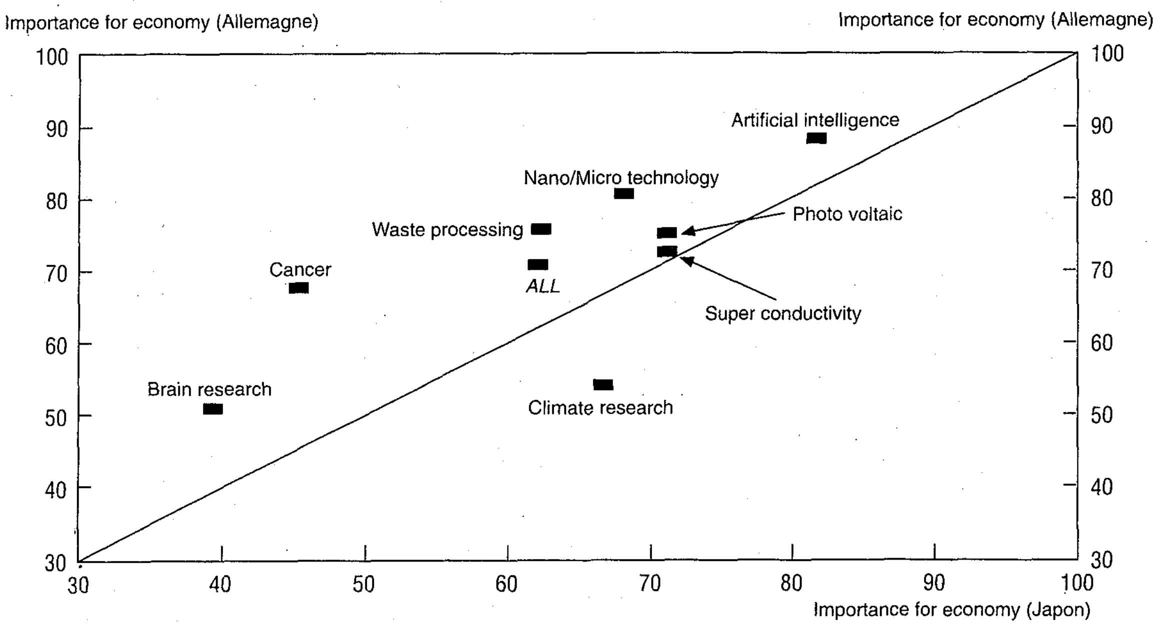
Table 7. **Importance of five criteria**

Criteria	Japan	Germany
For progress in science and technology	81	87
For the economy	63	71
For the environment	61	58
For developing countries	37	37
For society	67	62

Source: Author.

Figure 4 shows importance for the economy. Here, artificial intelligence is highest among the sub-areas in both countries, and brain research is lowest. Climate research is the only sub-area where the Japanese evaluation is higher. This reflects the fact that Japan has a large fishing industry, the activity of which is strongly influenced by world-wide climate phenomena. Superconductivity is evaluated almost the same as the solar cell which has already been applied in our society. We see that experts in both countries expect a large economic impact from superconductivity even though it is still at the development stage.

Figure 4. **Importance for the economy**



ALL: overall average value.
Source: Author.

Table 8. **Topics for which time of realisation differs**

Topic	Japan	Germany
A system is practically used which supports the creation of ideas in human thinking processes	2007	2018
Polluted soil is cleaned on a large scale by the application of micro organisms for the absorption and the decomposition of polluants	2010	2003
Microsystems based on microsensors and microactuators are implanted in human bodies to diagnose the health state and attend to the patient if necessary (*e.g.* artificial pancreas)	2013	2007
The whole aspect of molecular mechanism of hippocampal long-term potentiation and suppression is elucidated	2006	2012

Source: Author.

Concerning time of realisation, the results from both countries correspond well. Only four topics in Table 8 have differences of greater than five years among the topics compared. A topic concerning a system to support the creation of ideas was added in the second round in response to a proposal from respondents.

VI. NEW ATTEMPTS TO BIND EXPERTS' VIEWS WITH PUBLIC OPINION

Technology foresight can provide us with experts' views on the future. In the science and technology policy process, it is also important to pay attention to the kinds of technologies the public wish to see developed. We are developing a method, as part of the foresight process, to find the similarities and differences between these two points of view. Similarly, as an way to understand public needs, the Australian Science and Technology Council (ASTEC) is conducting a survey "Matching Science and Technology to Future Needs" (Pitman, see this issue).

Recently, NISTEP conducted a public opinion survey on science and technology and found three axes in people's evaluation of science and technology (NISTEP, 1994). The first axis is the contribution to the life. People expect a great deal from future science and technology although they believe the contribution of S&T in this area has been low in the past. The second axis is the contribution to the convenience of life. While the past contribution of S&T is considered to be high, expectation for the future is less. The third axis is contribution of S&T to mental comfort – this has been recognised only recently by people to be of importance.

As a next step, NISTEP conducted a survey to obtain information on the wishes of the public concerning future technologies (NISTEP, 1995). Of the

1 149 technologies set forth in the Fifth Technology Forecast Survey, 191 technologies connected to people/society and most related to safety, convenience and mental comfort were selected, and the following two questions were asked in regard to each one:

- Degree of anticipation of early realisation (respondents were shown expert forecasts of realisation year and then asked if they would like to see earlier realisation or if they would accept later realisation).
- Anxiety/concerns about realisation (adverse impact on people, adverse impact on environment/health, problems with information use, increased crime/accidents, reduced human interaction, cultural/ethical problems, and other).

136 of the 191 technologies were desired to be realised at or before the year forecasted by the experts. The Top 10 were as follows:

Table 9. **Topics which the public desired to see realised earlier**

1.	Earthquake prediction
2.	Cancer-preventing medicines
3.	Cure for AIDS
4.	Earthquake victim searching equipment
5.	Restoration of crude oil spill sites
6.	Volcanic eruption prediction
7.	Heavy rain damage prediction
8.	Fire fighting robots
9.	Freon substitute
10.	Fully degradable plastics

Source: Author.

Early realisation was strongly expected in technologies related to disaster prevention (such as earthquake prediction), to health care and welfare (such as a cure for AIDS) and to environmental conservation (such as restoration of crude oil spill sites). The technologies with less expectation for early realisation vary and cannot be easily classified. Examples include, “deep subterranean cities”, “super high-rise building, baby-sitter robots”. These results show that people have anxieties about technologies which change the present living framework and decrease human interaction.

More than 30 per cent of the respondents felt some anxiety with 96 of the topics and more than 50 per cent of respondents with 35 topics. Respondents were most anxious about the following topics.

Table 10. **Topics causing high anxiety**

Percentages

Baby-sitter robot	78.1
Preservation of living bodies through hibernation method	77.9
Electronic office	72.1
Deep subterranean cities	70.3
Super high-rise buildings	67.7
Conversational robots to alleviate solitude	67.3
Diagnosis/treatment using implanted instrument	64.1
Automatic driving on highways	62.8
Computer systems for instructor/instructional use	62.7

Source: Author.

VII. NEXT STEP – SIXTH DELPHI

The mini-Delphi project will conclude at the end of 1995. Following this we will start on the sixth technology forecast project. The experiences of the mini-Delphi will be applied in the project. We would like to plan our next large scale project with the co-operation of foreign countries. Japan and Germany have agreed to co-operate on this survey. At least half of the topics will be surveyed in each country. Other topics will be created in each countriy to meet the specific technological requirements of their own society and economy.

NISTEP has already formed the steering committee for the Sixth Delphi, and will complete the technologies to be surveyed and survey parameters. The first round questionnaire will be sent out in Summer 1996, the second round in Winter 1996. The report will be published in 1997.

VIII. CONCLUSION

Japan has been conducting technology foresight exercises for a long period and in a variety of organisational contexts. STA's Delphi surveys since 1971 have worked not only to provide information for national plans but also to enhance public and private organisational activities. Through long experience with large-scale Delphi, we have accumulated considerable know-how in determining consensus in the future among Japanese experts. The assessment of our First Survey shows it is reasonable to form strategies on the basis of this foresight.

We need to further develop the survey and analysis techniques in order to utilise them more effectively for establishing technology strategies as well as to make them correspond more closely to today's internationalisation of science and technology activities. The comparative study of the Japanese and German surveys showed that international comparison can provide useful information for the policy process. Both countries' results generally coincided well, even though the relationship between science and technology and the economy, society, culture, etc., differed somewhat between the two countries. From this point of view, mini-Delphi was designed and carried out in order to develop an international survey methodology. The use of public opinion surveys with Delphi topics is another approach which makes the Delphi approach a more effective policy tool.

Foresight including Delphi has a long history. However, it is necessary to develop and improve the methods to meet developing domestic and international circumstances. I believe further international co-operation in foresight activities will be helpful in this.

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FORESIGHT IN SCIENCE AND TECHNOLOGY: SELECTED METHODOLOGIES AND RECENT ACTIVITIES IN GERMANY

CONTENTS

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I. INTRODUCTION

Growing competition on world markets and increasing technological change are forcing economies and organisations to concentrate their research activities on selected areas. In order to identify those technologies which will have the greatest impact on economic competitiveness and social welfare, several new studies on critical technologies have been published in various countries.

Recent foresight studies have been carried out with the more or less express objective of identifying those technologies which have an impact on economic welfare and competitiveness (and also national defence in the case of the United States). A systematic assessment of the studies shows that they differ considerably in terms of size, disaggregation, methodology and relevance. Technology policy issues and recommendations for mastering these technologies in the respective firms are rarely spelt out or are kept brief. These issues are more likely to be discussed in other, more general, technology policy studies, which commonly lack a detailed list of critical technologies and are, therefore, too general for industrial corporations and their innovation management. No studies were found that were both detailed in terms of technologies and comprehensive in terms of assessments and recommendations for technology policy (for a list of critical technology studies, see Martin and Irvine, 1989; or Grupp, 1994, p. 381).

A further difficulty in comparing foresight methodologies lies in the fact that the definition of "critical" technologies varies considerably; recent analyses do not always define the term with precision. Reconstruction of the selection procedures is only possible in exceptional cases. With regard to the preferred type of investigation, it is obvious that few foresight approaches are the result of original scientific work. With some exceptions, no additional data on critical technologies have been collected, nor new knowledge advanced. For the most part the analyses represent the structured knowledge of committees and reflect the scientific background of the committee members and the amount of time they dedicated to the related discussions and the writing of the report. Only in very few cases is a professional staff group involved (and paid for) to support the committees. Frequently, the foresight report is not written by the government ministries or agencies themselves, but rather delegated to personal assistants of the committee members.

An exception is the Japanese Delphi exercise which includes a comprehensive survey over two rounds, covering more than 1 000 technological topics. The Delphi exercise is considered to be highly oriented towards conformity (Woudenberg, 1991), although the huge statistical database does not automatically yield evaluations and recommendations. Based on the Delphi datapool, it would appear to be possible to make holistic assessments; however, these are not automatically provided by the data.

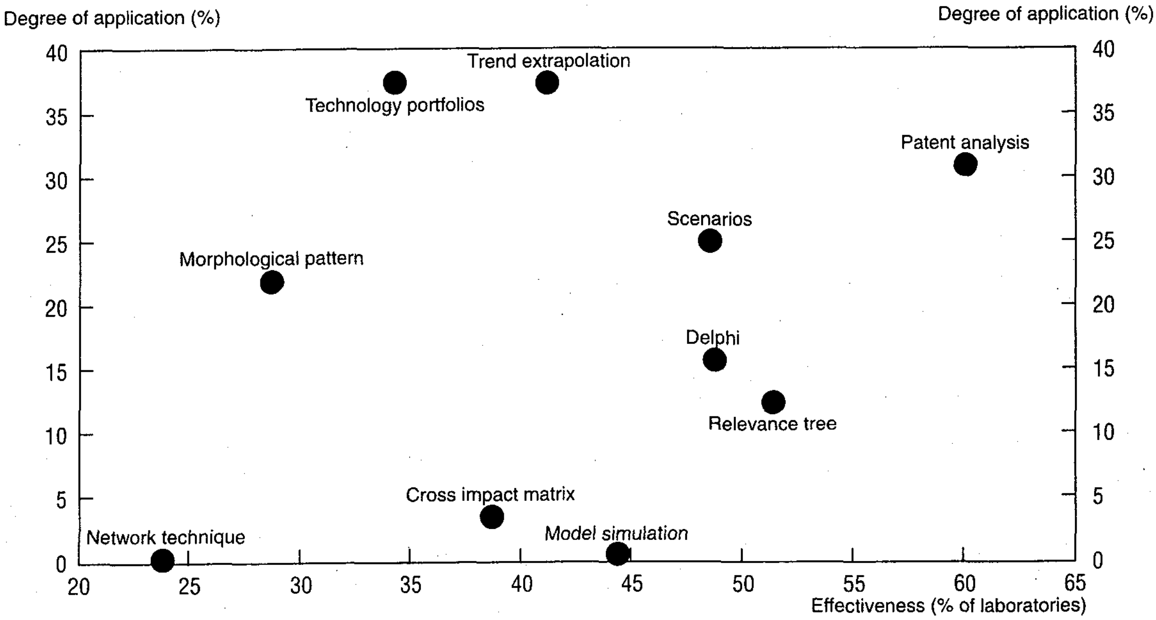
Previous government foresight activities all contained interesting aspects of great importance to countries other than those already engaged in foresight. It is recommended that published studies be consulted when undetaking further activities of this type. However, a lack of rigour in the application of methodologies as well as a lack of disaggregation is apparent in some of the studies. The formulation of specific policy issues tends to be difficult in cases where large fields of technology, such as biotechnology, are not disaggregated but are treated as a unity. This makes the exploitation of the results particularly difficult for firms.

Another point relates to the criteria used to assess the selected technologies. Such criteria as "economic growth", "technological competitiveness", "market size" and, in the United States, "national defence" are dominant. Rarely, and only in the very recent studies, are criteria other than economic or security criteria used, such as "quality of life" or "clean environment". The most advanced studies in this respect use criteria such as "growth by intelligent technologies". One key study point in this context is an analysis of the positive impact originating from future technologies (emergence of new industries and products, rejuvenation of existing ones and other favourable ripple effects), as well as the negative impact (erosion of existing industries and products by new and more competitive ones). The studies outline the most important problems for the future, such as increasing global interdependence, changing population dynamics and the ageing society, shortening of working hours (in Japan), improvement of the environment crisis, resource or energy limitations, and remedies for the increasing social maladies (drug abuse, terrorism, aids etc.). However, some reports of this type do not clearly state how these criteria are applied when sorting and evaluating the critical technologies contained in the reports.

In summarising the recent published government foresight activities, it is fair to say that some countries undertook serious and differentiated activities to determine generic critical technologies. The major problem with the studies is the comparability of the methodology used. In some cases, a clear-cut methodology was unavailable; in others, the methodological frame is missing or criteria were indicated but not strictly applied. In particular, even when the criteria used to pre-sort and assess the technologies are given, which is not always the case, it remains unclear how the criteria were applied to the critical technologies. Among the sets of criteria, growth and competitiveness issues dominate, whereas social or ecological aspects as well as future demand are largely neglected.

The assessment of the utility of foresight activities for industrial innovation management is possible if the results of a Japanese investigation into the most effective foresight methods are considered. A survey of 247 research laboratories (mostly in industry) were asked during 1989 for their views on the degree of application and the effectiveness of technology foresight methods considered or used by the laboratories (NISTEP, 1991). Figure 1 displays the results of the survey. Most widely used are technology portfolios and trend extrapolation, but these methods do not rank among the most effective ones. Patent analysis is considered as most the effective method. However, the time frame for patent forecasts is limited to about five years. Thus, patent analysis is a very good forecasting method, but is not suitable for medium- or long-term forecasting (see Section IV). It is particularly useful at firm level. Scenario writing, Delphi and relevance trees were judged by the Japanese laboratories to be the second most effective methods, but these methods are not widely used within firms because they are complex and expensive. Hence, if comprehensive investigations of science and technologies are planned, the choice of methodology for government activities should focus on the relevance tree method (see Section II) and the

Figure 1. **Degree of application and effectiveness of technology foresight methods in Japan 1989**



Source: Author.

Delphi method (see Section III). Scenarios require a predetermined framework and set-up. It is hard to imagine a comprehensive and detailed scenario covering all scientific, technological or social areas (the aim of this article). For selected areas, however, scenarios are a recommended foresight tool.

II. THE GERMAN STUDY ON "TECHNOLOGY AT THE BEGINNING OF THE 21st CENTURY"

Until recently, the German government was not very active in technology foresight activities at the federal level (see Martin and Irvine, 1989). In the early 90s, the unification of Germany and the corresponding tasks involved in restructuring a former socialist economy, as well as the budget constraints associated with the unification and the world-wide economic recession, prompted the Ministry to reconsider its position. A further argument for engaging in technology foresight activities originated from the renewed emphasis given to these activities by other countries, in particular the United States and Japan. One of the German studies (this section) is medium-term and uses a relevance tree approach, the other (Section III) is long-term and uses the Delphi approach. For short-term foresight, patent analysis is used to assess the competitive position of Germany in high-technology areas (Section IV).

The main motivation underlying one of these studies, "Technology at the Beginning of the 21st century" was to complement the neo-classical economic growth criteria by the idea of growth using intelligent, *i.e.* human-capital intensive, new technologies. Secondly, benefitting from the Japanese and US experiences, a strict and transparent methodology was applied. The approach also aimed to mobilise for foresight purposes the in-house expertise of German research administrators. In the Federal Republic, the Federal Ministry for Education, Science, Research and Technology (BMBF, formerly BMFT) is assisted by several so-called *Projektträger,* agencies mostly located in the national laboratories (*Großforschungszentren*). Representatives from these "programme operators" set up a task group and worked together on an assessment of critical technologies for the Federal Republic of Germany. The Fraunhofer Institute for Systems and Innovation Research, which had overall responsibility for this task, was asked to devise a comparatively new methodology based on relevance trees.[1]

The relevance tree method is a "normative" method. This type of method has its foundation in systems analysis: starting from future problems and needs, the technological performance required to meet those needs is identified. Relevance trees are used to analyse situations in which distinct levels of complexity or hierarchy can be identified. Each successively lower level provides finer distinction or sub-divisions (Martino, 1983). The time horizon is approximately the year 2000, whereas the horizon for the Delphi investigation is the year 2020.

The study on "Technology at the Threshold of the 21st century" concentrates on:

- the selection of critical technologies;
- the criteria to assess these technologies (relevance trees);
- the interrelation between the technologies; and
- the time scale.

Scanning all available studies from abroad and making use of the internal expertise of the "programme operators" (*Projektträger*), an initial list of about 100 technologies was established. In bilateral and panel discussions, this list was redefined and regrouped. The "list" is relatively detailed and contains items such as biochips, data network safety, genome analysis, fuzzy logic, flat displays, etc. (Table 1).

A common report form has been drawn up in order to obtain information on the technological item considered most important by the staff of the "programme operators". The form is made up of four pages, one for description and demarcation of the technological topic, including product visions to around the year 2000, the second is related to the determination of basic framework conditions, the third is dedicated to statements related to criteria assessing the technology's potential to solve economic, ecological or social problems and the fourth contains codified information on the anticipated dynamics of development through the year 2000 and on the relation to other technologies as well as the quality of the assessment.

The project team considered two separate sets of criteria to be important. One relates to basic conditions such as infrastructure and financial requirements in Germany. This set of criteria is specified in the national context. Using the notion of specialisation and division of labour, the aim is to determine what makes the development of a given technology important for Germany as distinct from other countries. The second set of relevance criteria attempts to cope with the requirements of "growth by intelligence" and seeks to provide information on the problem-solving capacity or potential of a given technology. This entails relating traditional economic criteria on competitiveness to other criteria related to health, environmental problems, etc.

Because of the fractal structure of nature (Mandelbrot, 1982), the elaboration of a hierarchical classification of technology is impossible. Broad or narrow fields of technology exist in the early or late stages of development. Some are application-oriented, some are more basic. Therefore, the interrelation of the items from the list of technologies is examined in three ways. First, the horizontal relationship of closeness is established; second, the hierarchical relationship of

Table 1. **List of critical technologies at the threshold of the 21st century**

Topics and areas	Code	Topics and areas	Code
Advanced materials	**(–)**	Telecommunications	TEL
High-performance ceramics	KER	Broad-bank communications	KOM
High-performance polymers	POL	Photonic digital technology	PHD
High-performance metals	MET	Advanced broadcasting (HDTV, DAB)	HDT
Gradient materials	GRA	Optical computing	OPR
Materials for energy conversion	ENW	**Micro systems technology**	**MST**
Organic magnetic materials	OMM	Micro-actuator technology	MAK
Organic electric materials	OME	Signal processing in micro systems	SVM
Surface and film technology	ODT	Micro-sensor technology	MSE
Surface materials	OBW	Mounting and connecting techniques	AVT
Diamond layers and films	DIA	**Software and simulation**	**(–)**
Molecular surfaces	MOO	Software	SOW
Non-classical chemistry	NCH	Modelling and simulation	SIM
Meso-scale polymers	MES	Molecular modelling	MMO
Organised supra-molecular systems	OSS	Bio-informatics	BIN
Clusters	CLU	Simulation of materials	WSI
Adaptronics	ADA	Non-linear dynamics	NDY
Multi-functional materials	MFW	Simulation in manufacturing	SIF
Lightweight construction	LBW	Cognitive systems (AI)	KIN
Composite materials	VBW	Fuzzy logics	ULO
Aerogels (solid foam)	AEG	Data network safety	DSI
Fullerenes	FUL	**Molecular electronics**	**MOE**
Material synthesis in standard shape	MSG	Bio-electronics	BEL
Implantation materials	IMP	Bio-sensor technology	BSE
Manufacturing of materials	FVW	Neuro-biology	NEB
Nano technology	**NAT**	Neuro-informatics	NEI
Nano electronics	NAE	**Cellular biotechnology**	**ZBT**
Single electron tunneling	SET	Molecular biotechnology	MBT
Nano-scale materials	NAW	Science-based medicine	MED
Manufacturing in micro and nano-scale	FMN	Catalysis and bio-catalysis	KAT
Microelectronics	**MEL**	Biological production systems	BPW
Information storage	INS	Bionics	BIK
Signal processing	SVA	Biomimetic materials	BMW
Microelectronic materials	MIW	Biological hydrogen production	BWS
High-speed electronics	HGE	Renewable resources (biomass and agents)	NWW
Plasma technology	PLA	Environmental biotechnology	UMB
Superconductivity	SUL	Plant breeding	PFZ
High-temperature electronics	HTE	**Production and management technology**	**(–)**
Photonics	**PHO**	Management techniques	MAN
Opto-electronics	OEL	Modelling in manufacturing	MPR
Photonic materials	PHW	Control station technology	LST
Laser technology	LAS	Production logistics	PRL
Flat display technology	DIS	Lean-resource production	URP
Luminous silicon		Behavioural biology	VBH
		Ethics in science and technology	ETH

Source: Author.

sub-fields to main fields is determined. The third dimension relates to preconditions and possible applications. The items on the technology list are codified according to the three dimensions contained in the report forms. They are subject to discussion within the project group and must be reciprocal; that is, if the author of one technology report establishes a relationship to another item, the author of that item must also agree with the relationship.

As a result of these interrelations, many technological overlaps are highlighted.[2] Using multi-dimensional scaling, it can be shown that the borderlines between individual technologies will become less distinct over the next decade. New disciplines are being shaped outside classical research areas. Certainly this tendency affects dramatically the necessity for technology monitoring, for technology policy implementation of R&D projects, and the appropriability of technological opportunities for firms.

Finally, the dynamics over the next ten years are examined. It is well known that progress in science and technology is not linear, but rather consists of several feedback and cyclic effects (Grupp, 1992). A standard nomenclature was agreed upon which distinguishes eight phases typically occuring in the research, development and innovation process (see Table 2 and Figure 2). The report forms specify for a given technology which phase may be assigned now and which phase is probable in the year 2000. If an estimation is not possible, the anticipated temporal development is expressed in phrases.

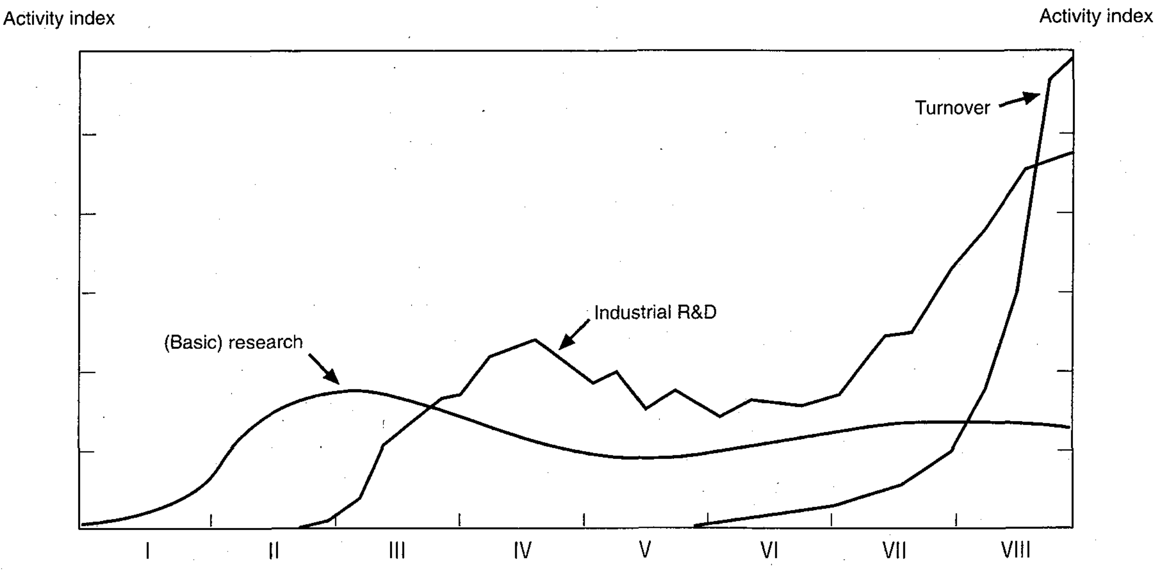
Figure 3 gives an indication that technology in general will progress over the next ten years or so in the direction of broad industrial application. However, the pace of development differs considerably and it is difficult to determine

Table 2. **Standard characterisations of typical innovation-oriented phases**

Phase	
I.	First exploratory research in scientific institutions
II.	Well established strategic research with perspectives for further extensions
III.	Fully developed research with first technical realisations and prototypes
IV.	Difficulties in transposing scientific and technical achievements into economic opportunities become apparent
V.	Temporary stagnation in science and technology and re-orientations
VI.	Industrial R&D recognises new opportunities and perspectives for further applications
VII.	First commercial applications: industrial R&D and economic development safely established
VIII.	Diffusion and penetration of many markets: industrial R&D intensity in relation to turnover loses importance

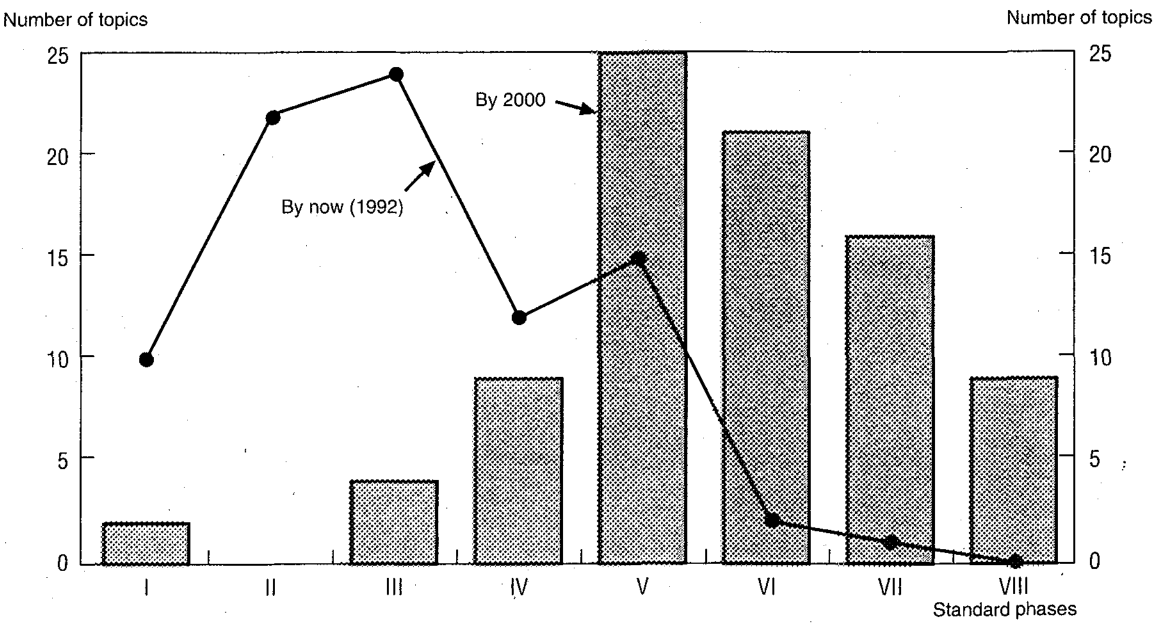
Source: Author.

Figure 2. **Sketch of standard phases in research, technological development and innovation**



Source: Author.

Figure 3. **Pace of progress of critical technologies at the beginning of the 21st century**



Source: Author.

"true" technologies at the threshold of the 21st century in terms of an "either-or" decision.

As this is a new methodology containing some traditional elements from the relevance tree approach, the results of this study are difficult to summarise briefly (for the full text, see Grupp, 1993). Whatever these may be (see Section V), a lasting impact was felt by the "programme operators" involved in the process, who can continue to use similar techniques in the future for their own purposes while carrying out their "daily business". What occured in the course of this exercise was a stimulation of the considerable knowledge of the staff of government agencies in the public R&D administration involved in foresight exercises.

This leads us to the second foresight project, the Delphi project, which contains more elements of formal foresight.

III. THE GERMAN DELPHI STUDY

The Delphi method is especially useful for long-range forecasting (20-30 years) as expert opinions are the only source of information. The Delphi method was developed during the 1950s at the RAND Corporation in order to make better use of the potential of group interaction (Rowe *et al.,* 1991). Questionnaires are sent to a group of experts over several rounds. The second-round questionnaire not only repeats the same questions, but provides information to group members on the degree of group consensus. The questionnaire is the medium for group interaction (Martino, 1983). General experience is that there is convergence of panel estimates during the sequence of rounds. The panel members will usually have widely varying estimates on each question in the first round, they do not always revise their opinion under the influence of the assessments given by the other panellists (Bardecki, 1984). Delphi panellists have just as much opportunity to keep to their original views as do members of a face-to-face group. The advantage of Delphi is that panel members can revise their position without losing face if they perceive convincing reasons for doing so (Martino, 1983).

There are two main problems associated with Delphi forecasting. The forecast questions asked in the first round must be generated elsewhere; they do not originate form the panellists. Secondly, although technology is understood to be international in nature, experts selected from one country (even if their number is large) may introduce a collective bias due to implicit natural or cultural habits or collective information deficits.

By far the best experience in government Delphi forecasting is available in Japan where, for example, since 1971 it has been used by the Science and Technology Agency (STA) for its five-yearly technology foresight exercises. It was therefore decided to draw on the Japanese experience and to perform a German

Delphi investigation following the Japanese guidelines (aims, inquiries, character and method).

The German-based survey was conducted in parallel to the fifth Japanese technology forecast survey, although it took place with a one year delay. In order to make the two investigations independent of each other ("double blind") it was arranged that, despite the lag, the German experts be unaware of the results from the Japanese sample.

In both cases about 3 000 experts were surveyed; the response rate for the first round in Japan was above 80 per cent, in Germany it was about 30 per cent. This response rate would appear to be low, but taking into account that Germany was carrying out such a survey for the first time, the rate is considered satisfactory. In both countries, more than 80 per cent of the respondents participated in the second round. There are two main reasons for the relatively low first-round response rate in Germany (as a rule of thumb, detailed and time-consuming questionnaire surveys with a response rate of some 15 or 20 per cent are considered successful). First, as has been argued in Section II, until very recently the German government was not very active in technology foresight activities. In view of the perceived "unpredictability" of events in science and technology, other public scientific bodies also had a low opinion of technology foresight activities. Therefore, the confidence of the respondents in meaningful results can be assumed to be low. (One typical German respondent argued "I hope that – in the best case – the policy impact of the Delphi will be zero. You cannot predict science. Government planners should know this. Strong priority setting enforces meaningless projects...") The second reason is that – due to the pilot nature of the German survey – it was difficult to predetermine the most pertinent sub-area of expertise of each respondent. To overcome these difficulties at least partially, some industry experts received more than one questionnaire in order to allow them to choose for themselves their specialised fields. Postal delivery of some questionnaires to the eastern part of Germany was impossible because of the enormous structural changes taking place in the region (*e.g.* addresses, names of institutes and companies).

About one-third of the experts consulted in both Germany and Japan are employed at universities or other higher education facilities, one-third come from industry and one-third from government laboratories, independent or non-profit institutions. The age peak of the respondents is between 50 and 60 years; the second most important age cohort is between 40 and 50 years in both countries. The time-consuming task of fine-tuning the German sample by age cohort and employment and matching this to the Japanese model finally paid off. These factors are not expected to influence to any great extent the answers to the survey questions.

The questionnaires were identical, with the exception of a few topics specific to Japan which were not applicable in Europe (*e.g.* hybrid rice, cosmetics designed for Japanese skin). Altogether 1 150 (Germany, 1 147) topics covering 16 broad fields were included. In the Japanese final report, only 1 149 questions were analysed because it was noticed that one technology had already been realised.

The translation of the topics from Japanese into German was extremely tedious and difficult. Specialised translators, used to translating coherent texts rather than isolated questions, experienced difficulty in grasping the general idea of the topics as the questions are not embedded in an overall context. Even the best technical translators could not provide a translation which was acceptable to technology experts in the field. The raw translations were therefore revised by German scientists who do not understand Japanese. Their version was re-checked by the translators to prevent any major divergence from the original text. There was no problem in "translating" Japanese geographic details. For example, the question on water quality in the Tokyo Bay was substituted by a question on water quality in the Rhine.

The objective of the Delphi investigation is to examine the degree of importance assigned to topics by the experts, the time of realisation between 1995 and 2020, major constraints on realisation or reasons for non-realisation, the precision of time determination, and the necessity for international co-operation in pursuing technological progress. In addition, the degree of expertise of the panellists was estimated by the panel members themselves. The German results were published in Summer 1993 (see BMFT, 1993); a systematic comparison of the Japanese and German investigations is available since Summer 1994 (see Cuhls and Kuwahara, 1994). Early in 1995, a popular version with support from scientific journalists was published by a non-scientific printing house with a broad audience (see Grupp, 1995).

An assessment of the Delphi approach in Germany is presented in Section V. Not only has the analytical part of the Delphi survey had an effect on German technology policy, but it has also had a lasting impact on the panellists themselves. Answering the questions and checking their opinions against the anonymous assessments of other experts has had a learning effect on the participants in the survey. They were provided with the estimates of the other panellists (including those from competing companies) in the course of the study, and can make free use of the information in their laboratories.

Three principal results were found in the analytical part of the study. First, many of the results of the German survey are more or less the same as for Japan. In these cases, there is evidence that the Delphi procedure is not very dependent on national influences and peculiarities. Progress in technology seems to be truly international in nature in many fields, with almost no information deficits in the major industrial countries. This could lead to conclusions on the openness of world-wide scientific and technological information (including Japan, despite the language barrier).

In the first round, the German panellists seemed to rate the time of realisation generally a few years earlier than the Japanese, and tended to minimise technical obstacles. The second round underlined that the results were similar. In the final analysis of the sum of all technology fields, there were no differences between the Japanese and German estimates. Secondly, then, it may be concluded that consensus-generating processes on uncertain events in the future are indeed at work.

Third, at the other extreme, for several topics strong discrepancies were found between the surveys, and in many details the dominance of national communities and systems of innovation was obvious. The main conclusion for these cases (Table 3 gives some examples) would be that Delphi inquiries on technology should always be undertaken with an international panel including people from different countries and continents. However, for many topics, no such extreme results were found, but rather results which were at the same time congruent and diverging.

To conclude the Delphi section of this article, the international scope of technology foresight would appear to be important as specialist experts may not be available in medium-sized countries. Figure 4 illustrates the availability of experts in the case of biotechnology in Germany. Among the N = 73 respondents (first round) who are all experts in biotechnology, many did not answer particular sub-areas (mostly pertaining to tissue and organs). The largest number of active experts (*i.e.* those working in a sub-area) among all experts in Germany is found in molecular biology and, again, not in the sub-area tissue and organs.

Most sociologists of science assume that there is a positive relationship between involvement in a research area and assessments of that area, and that this relationship derives from the tendency of scientists to select problems in areas where there is high pay-off for successful solutions and a career. The tendency to overrate the fields in which a person works may be termed "bias". Shrum (1985) found not only a tendency to a positive bias towards fields in which researchers had been active, but also found this bias to be stronger in less innovative sub-fields. As market signals fail to be useful for business strategy in the long run, and expert assessment is not always objective, Delphi surveys may play a part in innovation management.

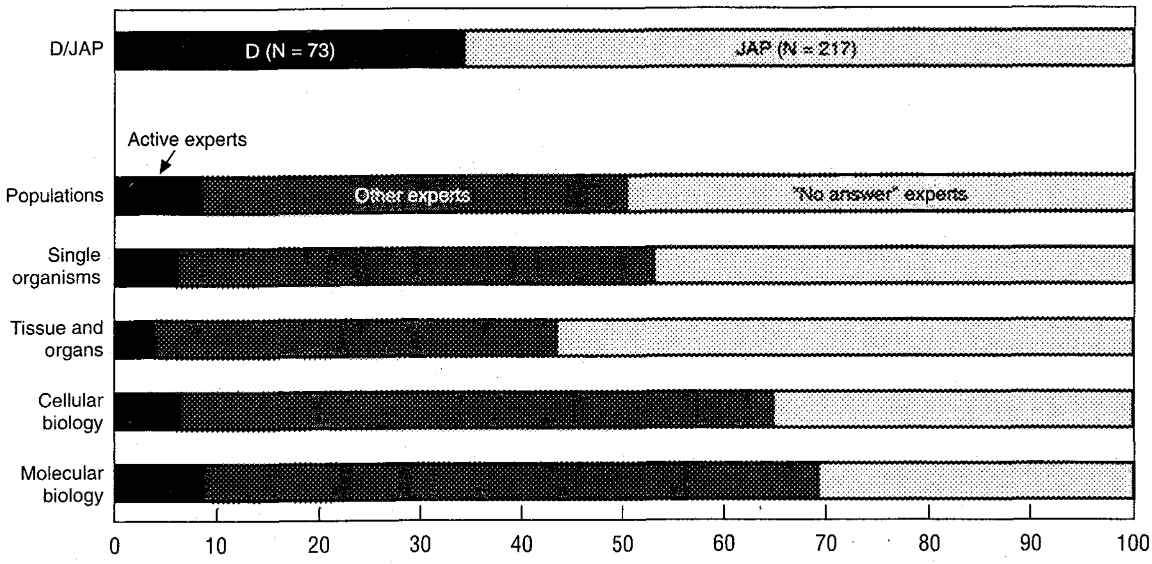
A test for Delphi expert bases in the energy area (Shrum's investigation also dealt with energy research) tends to support this view. As could be shown by a separate analysis of how the researchers in special areas judge their own working field in comparison to related fields in which they are not active, active experts

Table 3. **Discrepancies found between the Japanese and German surveys**

German No.	Japanese No.	Topic	Importance Germany	Importance Japan	Difference in importance
G2-71	J2-70	Practical use of work robots capable of handling virtually all types of jobs at home or in hospitals.	21	77	56
G9-50	J10-50	Practical use of technologies for constructing seaweed "pastures" in undeveloped areas such as sandy beaches and estuaries to exploit the potential productivity of marine organisms.	15	66	51
G14-44	J14-44	Development of passenger planes with a speed of Mach 4 (twice as fast as the Concorde) and a seating cpaital of 300 (triple that of the Concorde) that are capable of trans-Pacific flights in two hours or less.	18	67	50
G9-56	J10-56	Practical use of selective fishing methods for catching desired size and species of fish and of inductive fishing for catching in desirable water area through the development of technologies that are able to control the behaviour of a shoal of fish.	10	60	50
G5-18	J6-18	Construction of artificial islands for processing waste for offshore dumping in waters to about 100 m depth. (Refuse is completely disassembled and decomposed for the purpose of dumping harmless parts and recycling useful parts of the refuse.)	26	74	48
G7-25	J8-25	Realisation of nuclear power facilities (reactors, nuclear fuel cycle facilities) with a high degree of full automation through application of remote monitoring and robot systems.	23	70	47
G16-51	J16-51	Practical use of multi-purpose nursing robots that take care of the personal hygiene and bathing requirements of bedridden elderly and handicapped persons in a manner that suits each person needing care.	34	79	45
G10-58	J11-58	Practical use of optical computers, switching equipment and information processing, resulting in the emergence of a super information-intensive society based on optical applications.	24	70	45
G9-57	J10-57	Widespread use of super labour-saving fishing boats designed to automate a series of operations from searching for shoals of fish, dragging and lifting nets, to sorting fish by size and storing them consequently, allowing the crew to devote itself to monitoring.	13	57	44
G2-82	J2-81	Elucidation of human decision-making mechanism from the chemical and physical aspects of brains.	40	84	44

Source: Author.

Figure 4. **Distribution of expertise in biotechnology among German Delphi respondents**



Source: Author.

rate the importance of their own research speciality significantly higher than do other experts – both in Japan and in Germany. At the same time, top experts minimise technical constraints in Germany (this is less the case in Japan).

The Delphi databases from Japan and Germany, which are now available,[3] seem to offer rich opportunities for further analysis both in terms of priority setting for government technology policy and corporate innovation strategy, as well as for technology analysis.

IV. PATENT STATISTICS FOR SHORT-TERM FORESIGHT

Patent statistics are a well-known instrument for corporate innovation planning and competitor analysis (see Schmoch and Grupp, 1989). There are two facets to patent indicators: on the one hand, development success is documented; on the other hand, economic interest in certain future markets is indicated. Patent indicators are influenced by various factors and do not solely reflect output in technology or intellectual property rights. The issue of quality in patent indicators requires the careful separation of the influencing factors. Patent indicators of good quality for measuring applied research and development output, for example, are not necessarily good for detecting corporate regional strategies (Schmoch and Grupp, *op. cit.*). Less well established is the use of patent statistics for short-term foresight in technology policy.

A typical short-term foresight problem is how technological productivity relates to future market shares. What one is interested here in is the question of whether single countries (or companies) – via specialisation in specific high-technology fields – can correspondingly increase their world market shares in high technology areas. Thus, if the model of absolute technological competitiveness (Grupp and Münt, 1996) applies to all high-technology product categories (or technological areas) in the same way, we would expect a positive correlation between world market shares and technology intensity.

Patent statistics are an accepted indicator for codified knowledge from strategic and applied research and industrial development. As patent applications are legal documents that are valid in only one country, many foreign "duplications" of domestic priority patent applications are generated. The selection of patent data for foresight activities from a patent office does not always yield an indicator that is representative of world output of inventions. In order to demonstrate the usefulness of patent statistics for foresight on trade positions, annual averages of patents for the invention years 1986 through 1988 were selected for this article. These patents may be regarded as proxies for corporate attempts to protect their goods produced in 1990. Among others, Gehrke *et al.* (1994) and Amendola *et al.* (1993) found, in different types of investigations, that, because of the cumulative nature of innovation, patent statistics precede international trade by about three years. Accordingly, trade data from 1990 were selected.

As duplications of patents can be traced and matched to each other, so-called patent families may be defined centring around one invention and bringing together the foreign property rights in all countries of the world. The selection criteria in the foresight investigation which follows was that only those inventions where a foreign duplication was filed at least in the United States, Japan and with the European Patent Office were taken into consideration. Using this selection criteria, the "triad" model is applied, requiring protection of industrial property in each of the triad blocs, United States, Japan and Europe. As it is a condition that, in the United States, a patent is not only filed but also granted, the classification may be taken from the US equivalent and matched to the product group of potential application. Thus, the patents were assigned to products by a patent-to-sales concordance (Grupp and Münt, 1996). This is considered a major achievement as world output in technology is covered, instead of having to rely solely on US patent data (the standard procedure). However, it is not possible to elaborate on this method in this article.

In order to test the usefulness of the triad patent concept for foresight, we examined the world market shares of 17 OECD countries for all manufactured products in relation to various sets of patent data, including triad patents. Further, we assigned the US patents by inventors' countries (residence of inventors) as well as by assignees' countries (first application principle by company headquarters) to get an impression of the globalisation effects. The first set (USINV) represents the country of origin, the second the firm/country controlling the technology (USASS). Next, we selected patent applications at the Japanese patent office (TC), patent applications at the German Patent Office (DPA) and patent applications at the European Office (EPO).

From these datasets, we constructed three additional patent samples (all sets being adjusted to 1986-88 priority years including granted US patents; we did not use patent issue dates). We merged all domestic patent applications for the OECD countries (DOM), added the EPO patents with destination Germany to the DPA data (and denoted this set as GE for Germany/Europe), as legal protection on the German territory is warranted both ways, and finally selected the triad patents TP as described above.

By linear regression of the datasets (in each case the world patent share per set) with the world export share in manufactured goods we found the results compiled in Table 4. Two sets of patents are highly significantly correlated with future export performance, the triad patents (as expected), but also the European data. The European Patent Office requires fees which are considerably higher than at European national patent offices so that cost-effectiveness is only achieved if the application is designated to three or more countries under the European Patent Convention. From this, there seems to be a similar selection

Table 4. **Regression results for world export share (1990) and seven patent samples (priority dates 1986-88)**

Patent sample	R^2	t-statistic	Degrees of freedom
USINV	0.44	3.46**	15
USASS	0.43	3.36**	15
TC	0.15	1.62	15
DPA	0.45	2.57*	8
EPO	0.88	10.41***	15
DOM	0.27	2.38*	15
GE	0.64	3.79**	8
TP	0.62	4.90***	15

*** Highly significant at the 0.1% level.
** Significant at the 1% level.
* Weakly significant at the 5% level.
Source: Author.

process of the most important patents with relevance for world markets as with the triad model.

The US patent data explain future trade advantages reasonably well, and the fact that there is almost no difference between inventors' countries and assignees' countries lessens the strong distorting effect of globalisation. The forecast is reasonably accurate when all patents with protection in Germany are taken (GE), whereas when only those patent documents filed at the German Patent Office (DPA) are taken, thus neglecting the European access to protection, the forecast becomes weak. Future world trade is not well explained by domestic patents nor by patents granted in Japan.

From this, we can conclude that higher levels on certain segments of the world market, *i.e.* manufactured goods, merge with with higher levels of technological activity as evidenced by patent output in preceding years. However, due to the limitation of patent property rights to national markets, an analysis of high-technology trade advantage should be based on either European patents or triad patents.

Technology production as expressed by intellectual property rights seems to have a very important foresight function for structural advantages in the more market-oriented parts of high technology. The breakdown of technology given in Table 5 reveals that the foresight power of patent indicators is not uniformly good across areas. In addition, the time lag between patent statistics and trade data, that is the forecast window in years, differs across areas. Table 5 presents the results of disaggregated correlation calculations with various time lags for the 10 largest OECD countries.

In areas such as electronic data processing, patent statistics do not relate to world market shares as this field of leading-edge products is subject to quasi-monopolist trade flows. This is also the case for communications (several non-deregulated telecommunication markets), aviation and space and related turbines. In these product fields, patent statistics may not be used for short-term forecasting of market power. Consumer electronics and metal-working is more related to open markets, and the most significant forecast window is about three years, as indicated in Table 5. A longer lag structure is observed in selected areas of advanced electrical machines (*e.g.* lasers) and instruments.

One of the severe limitations of this section is that it tests the foresight power of patent statistics for countries' exports using cross-sectional data for several OECD countries allowing for various fixed time lags. However, the international trade classification was changed in 1988 and longer time series are, therefore, not comparable. In future years, the situation in this respect will improve. Although the correlations presented appear to be robust, this type of test falls short of a proper account of the dynamics by which technical change determines international

Table 5. **Foresight windows for selected technology areas**[1, 2]

	–5	–4	–3	–2	–1	0
Synthetic fibres				V		
Pharmacy		V				
Agrochemicals					V	
Advanced chemistry, nec		V				
Handling				V		
Metal-working			V			
Advanced machinery						
Service machinery						
EDP						
Electronic circuitry				V		
Advanced electronics	V					
Consumer electronics		V				
Communications, electronics						
Professional instruments	V					
Motor vehicles						
Railway						
Aircarft, spacecraft						
Turbines, power generators						
Number of correlations	**5**	**6**	**4**	**7**	**6**	**4**
Optimal time lag	**2**	**3**	**1**	**3**	**1**	**0**

1. Trade data: year "0" = 1990; triad patent data from 1985 (year "–5") to 1990 (year "0").
2. Black boxes: highly significant; grey boxes: significant; **V** denotes the most significant lag.

Source: Author.

competitiveness. However, the analytical use of patent statistics introduced in this section seems to be well suited for broader applications in policy foresight in the short term. Some trends in international market power over the next few years can be derived from patent analysis. National technology production would appear to be a major component of market success, at least for the market-oriented technologies and inspite of increasing intra-firm flows of knowledge. As is shown, patent statistic analysis can be performed in various ways. One has to be very careful when using patent data for foresight purposes. Most national datasets are biased towards the country of origin and cannot be used for this purpose.

V. ASSESSMENT OF THE UTILITY OF RECENT GERMAN FORESIGHT STUDIES

A clear disadvantage of using patent statistics for foresight purposes is the "short-sightedness" of this method compared to other methods. On the other hand, investigations using patent statistics can be carried out with on-line databases at regular intervals (for instance annually) with moderate costs and labour investment. Foresight exercises of the Delphi or panel type (relevance tree method) are time-consuming, and involve many experts and large amounts of funds. The latter type of activity may be updated at approximately five-year intervals, but certainly not on an annual basis.

In Germany, foresight exercises using patent statistics are carried out on an *ad hoc* basis by various actors, and by the Federal Government on an annual basis. The data on high-technology trade and patents is widely used in the German Federal Government, especially in the Federal Ministries for Research, Economic Affairs and Foreign Affairs. This analysis plays an important role in discussions on priorities for German technology policy, especially in the following four areas:

- analysis of the global position of German high-technology industries;
- as background information for the conception of programmes for the promotion of R&D;
- analysis and forecasts of the growth of markets dominated by certain technologies;
- the preparation of the Federal Government Report on Research.

Furthermore, a number of studies carried out by important industrial associations, for example the Federal Association of German Industry (BDI), the Central Association of German Chambers of Industry and Commerce (DIHT), but also the German Trade Union Federation (DGB), make extensive use of this internationally comparable foresight data. The analytical instruments presented here appear well suited for broader application in OECD countries. However, one serious problem is the lack of a correspondence between the international trade classification (SITC III) and the international patent classification (IPC).

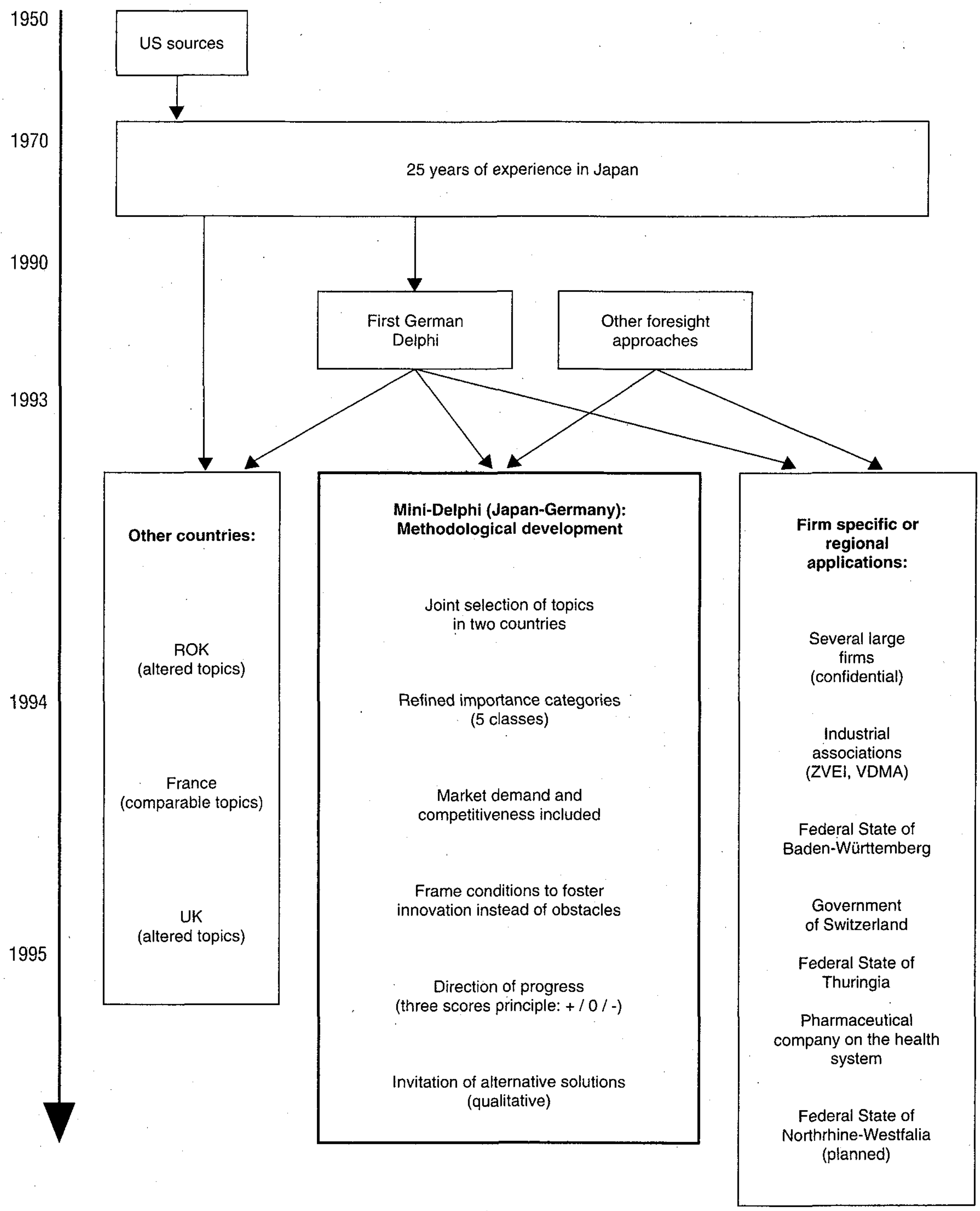
For some years, the Federal Ministry for Education, Science, Research and Technology (BMBF) has been closely observing developments in international patenting, in particular concerning technology-intensive goods involving R&D expenditure of over 3.5 per cent measured against turnover. The shares of the leading OECD countries in world markets for technology-intensive goods, their specialisation in these product categories, as well as the development of patent applications in the field of technology-intensive products, are studied and evaluated on an annual basis. An important finding from past years which met with wide public interest was the fact that, in 1989, the Federal Republic of Germany was, for the first time, surpassed by Japan as the world's largest supplier of R&D-intensive goods. In late 1991, BMFT pointed out that competition on global technology markets was becoming fiercer. In late 1992, German exports – in particular of R&D-intensive investment goods – were slackening, despite a 5 per cent growth in the world market.

The inclusion of the development of patent applications in the study of technological competitiveness provides an indication of the priorities awarded by an economy to application-oriented technology development. Thus, German microelectronic patent applications, which have long been below average, clearly show that relevant German developments for commercial use are under-represented at the international scale. The German position in these sectors reflects the low priority awarded by industry – at least in the past – to the development of new applications for microelectronics – a priority which is far higher in Japan and the United States. A closer look at the patent statistics for chemical and biotechnological products shows that, if products of "classical chemistry" were to be replaced by biotechnology products, the German chemical industry would face strong competition on the world market; while German industry is engaged in development in the fields of both classical chemistry and biotechnology, its foreign competitors focus on biotechnology.

The remainder of this section concentrates on the usefulness of the two other German foresight studies. At the Federal government level, in particular the BMBF has started to use the related materials from the two completed studies in-house when internal budget priorities are defined or redefined. Of course, the foresight studies are neither the only, nor the most important, source consulted in this context, but they do add a new type of information for priority setting, which is largely done on the basis of consultation and peer review. The Ministry has also organised this year several so-called "innovation talks" with representatives of industry and large research organisations; to enhance the commitment of the people involved, these talks are non-public. As was mentioned in Section II, the daily routines of BMBF agencies in the research administration are now more oriented to the future, in so far as the staff of these agencies were directly involved in the study on "Technology at the Beginning of the 21st Century".

As the first German Delphi study was modelled on the Japanese example, work is now underway to test some modifications to the methodology. In a so-called "Mini-Delphi" project, a different method of selecting the topics and modifications to assessment criteria are beingtested. As several German experts had expressed their opinion that the German Delphi study was too oriented towards Japanese problems and disregarded some major European issues, the "Mini-Delphi" exercise will give them the opportunity to tune the topics and the tone of

Figure 5. **Genealogical tree of foresight activities in Germany**



Source: Author.

the investigation towards European perspectives (the "Delphi genealogy" is presented in Figure 5).

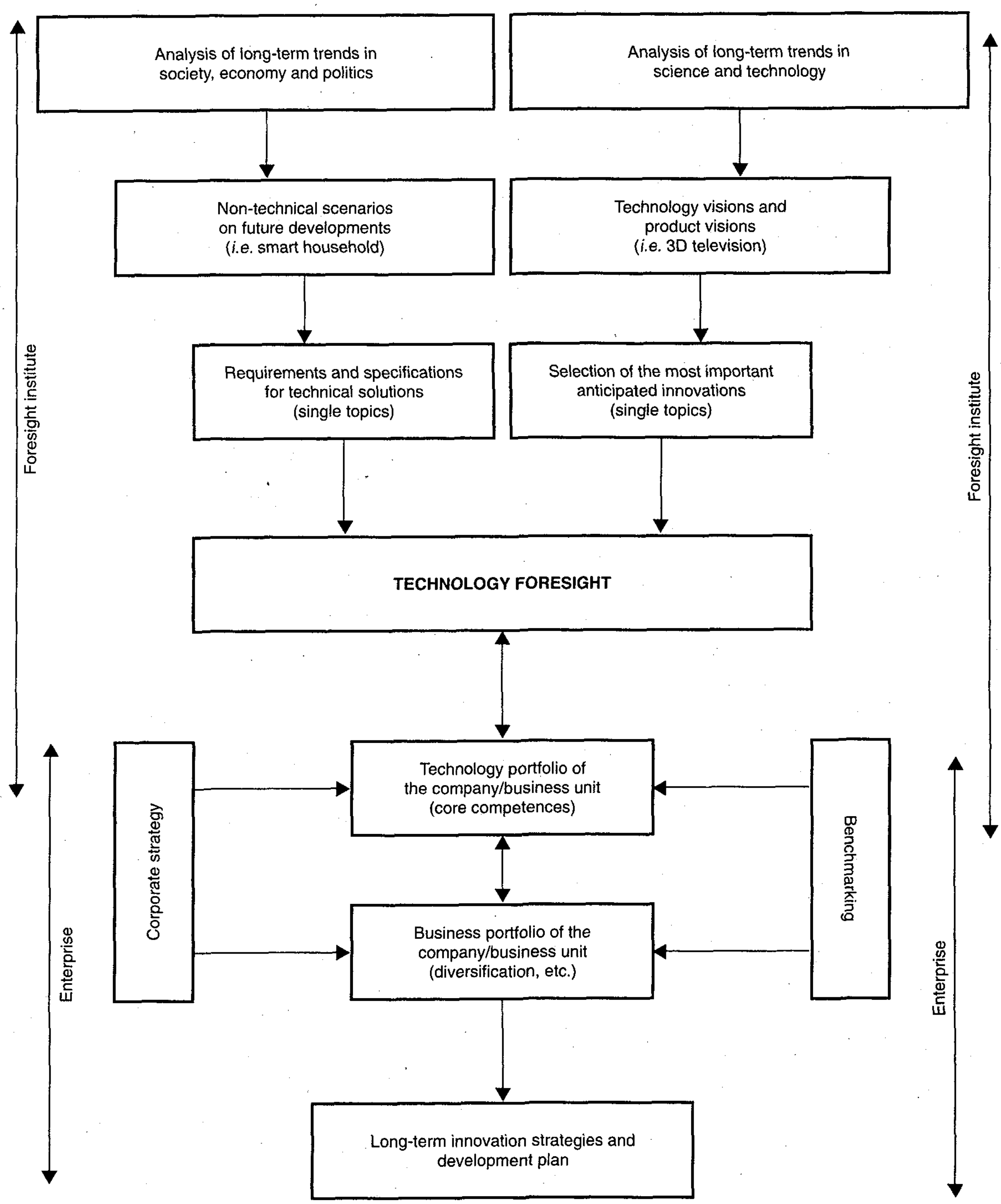
At the state (*Länder*) level, several government investigations into the regional impact of the foresight results and related policy studies are under way. One of the aims of these exercises is to verify to what extent the overall results from the national future studies are relevant to the science and technology policy of the states. In particular the federal states of Baden-Württemberg and Thuringia should be mentioned.

German enterprises reported considerable improvement in intramural knowledge base through participation in the Delphi survey. There is some evidence that in some companies participating in the Delphi exercise it was felt that too little effort was dedicated to strategic innovation management, and remedial action has since been taken. Some companies in both the manufacturing and service sectors have started their own intramural investigations by breaking down those aspects of the overall national studies relevant to the special interests of their firms.[4] Some smaller-scale comparisons of business portfolios to future-oriented areas are being carried out, sometimes assisted by external consultants or by the Fraunhofer Institute for Systems and Innovation Research, the institution which carried out the national studies. These activities remain for the most part confidential. The matching of foresight results to companies' innovation management generally follows the procedures presented in Figure 6.

One pharmaceutical company has prepared its own Delphi investigation into the future of physicians in residential areas and their ability to keep up with modern trends in both medical technology and pharmaceutics under the assumption of a computerised health care system.[5] Subject-tuned activities by industrial associations on behalf of their member firms are either in preparation (the case of a large industrial association of machinery and apparatus manufacturers, VDMA) or have been completed (the case of a large association for electrical instruments, ZVEI).

The foresight studies have had some observable impacts on German society. The Federal Ministry distributed, free of cost, thousands of foresight reports to interested parties. Furthermore, paperback editions of the reports are available to the general public. The Ministry has encouraged all interested parties to fully exploit the datasets and has made all data accessible in written and electronic form. Press releases to the media (newspapers, magazines, journals, TV and radio) have emphasised the importance of foresight in science and technology, and some small-scale exhibitions in museums are currently in preparation. The popular paperback version of the report, which sells very well, was also instrumental in further distributing the results (see Grupp, 1995).

Figure 6. **Principle procedures for exploiting government foresight activities in companies**



Source: Author.

The German public has a general tendency to be critical about new technology, often without any detailed knowlege of the subject. After the foresight studies, which are rich in visions of detailed trends in science and technology, were published, several "second thought" articles concerning public understanding of technology were published by scientific journalists. The message contained in these articles was that a dogmatic scepticism toward new technology as such should be replaced by public reservations about specific technologies. The need for a technology-specific public debate on the future of the so-called "science and technology nation" surfaced.

From the above observations, it is tempting to conclude that the foresight processes themselves are more important than the written reports, or at least equally important. It follows that an assessment of the usefulness of foresight activities should not be limited to the value of the reports alone.

In the public debate on German foresight activities, some misconceptions can be highlighted, as is always the case. Some sources harbour the notion of a "concerted effort", *i.e.* a co-ordinated approach to foresight by a single Ministry. This is definitely not the case in Germany, where no national foresight programme exists. As has been shown in this article (see Figure 5), various exercises exist, some of which are centralised, others decentralised (agencies, state ministries, industrial associations).

Another issue is the term "technology foresight", which is repeatedly used in the media. In the age of science-based innovations, the distinction between science and technology and between science policy and technology policy has ceased to be meaningful, if it ever was. In its revision of the *Frascati Manual*, the OECD re-uses the concept of "oriented basic research" as well as "pure basic research" and "applied research". Therefore, foresight activities touch on technology as well as on science and the grey zone between the two. The official title of the German Delphi report translates as "German Delphi Report on the Development of Science and Technology". The Delphi approach also integrates the notions of "market pull" and "technology push" in the formulation of the topics. There is a standard typology of terms, differentiating between "scientific exploration", "technical realisation", "first commercial application" and "broad diffusion under market conditions". The latter two categories dominate the survey. The Delphi project is, therefore, by the nature of the topics chosen, more market oriented, although the aim of arriving at turnover figures in the long term was not considered appropriate. In support of this notion, it can be observed that the main differences between the Japanese and German Delphi assessments do not occur with respect to the time scale (science and technology are international by their nature) but rather concern the priority and obstacle dimensions (*i.e.* the national framework conditions).

As the "Technology at the Beginning of the 21st Century" study includes a systematic investigation and synopsis of critical technology studies in the United States and Japan, some observers undervalue the results of the study by characterising it as simply a review of foreign foresight studies, which is definitely not the case: the exercise is an original foresight activity incorporating some six person-years of labour investment. The study follows the relevance tree approach by making extensive use of expert panels (see Section II). It also includes a systematic qualitative (through the scoring process) assessment of future markets for technology, but does not give monetary values as this was not considered feasible.

In Germany, in recent years there seems to be an increasing awareness of foresight activities. At the firm and regional levels, there is great interest in, and sometimes even enthusiasm for the detailed information on future trends which is now available. At these levels more general studies are not always useful as each company and federal state in Germany requires more selective information than is necessary at the national level. Therefore, the more detailed the results of national government exercises, the more likely it is that individual firms or regions can find items of relevance.

The hostility toward foresight evidenced in the 1980s no longer exists, at least not in the technology-oriented foresight areas. The scientific community still has reservations about foresight, but further activities on the science side of foresight are expected. The German Science Council recently agreed on new activities. In July 1994, recommendations for "research foresight" were passed, according to which a commission of the Science Council comprising 18 to 20 members will be formed. This commission will organise and perform prospective analyses using empirical techniques from science sociology in combination with more traditional methods such as peer review.

NOTES

1. The full report is available only in German, see Grupp (1993). Because of continuous interest by the public, a second edition was published in 1995. An abridged version in English may be found in Grupp (1994).
2. A "map of future technology" is reproduced in Grupp (1994, p. 385).
3. The German Delphi data may be found on the Internet. Dial http://www.dfn.de/bmbf/Delphi/ for a menu to guide you on.
4. The BASF company announced in a press release (Handelsblatt, 4 May 1994) that they were surprised that more than one-third of the Delphi items proved to be relevant for the company's strategic planning.
5. The compagny is Janssen-Cilag GmbH, Neuss, as was disclosed recently.

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TECHNOLOGICAL DYNAMICS FOR THE YEAR 2010 IN FRANCE (The Delphi Survey Approach)

CONTENTS

This article was prepared by Alain Quévreux of the French Ministry of Higher Education and Research. Mr. Quévreux is an economist and co-manager of the Delphi project in France. The article reflects the author's personal opinions and not those of the ministerial department in which he works. It borrows from and draws heavily upon the analytical work developed and carried out under contract by the team of Professor Héraud of the BETA laboratory in Strasbourg, as well as the data analysis undertaken by Professor Nanopoulos.

SUMMARY

This article presents the experience and analytical criteria that were harnessed in France to conduct a technological foresight survey using the Delphi method. It explores the underlying assumptions and conditions in which the exercise was carried out, thereby reinforcing the conviction that the method, once perfected, could be a useful tool for the selection of technological priorities. The basic precept is that the resultant database reflects a multiplicity of experience and directions and provides a starting point for a wide variety of attempted descriptions. There is good reason to believe that the information gathered is specific enough that concurring responses can project a realistic image of the future now taking shape, and of competing trends that could lead to any number of possible tomorrows.

Part two puts forward a variety of methods by which raw data can be turned into proposals that constitute feasible options for technology policies and orientations. They are spelled out on the basis of the findings and examples from the French survey, as well as comparisons between France, Germany and Japan.

Part One

I. AN EXPERIMENTAL OBJECTIVE

Foresight's task is to map out the knowledge of the experts and establish a forum in which to explore the competing avenues of thought that underlie the diversity and uniqueness of tomorrow's products, along with the creativity and pooling of knowledge they require.

In order to be able to chart a national strategy for research, the ministry in charge must constantly consider the orientation of national research from an upstream perspective. To supply input, it was decided in late 1993 to conduct a technology foresight exercise using the Delphi method. In such exercises, information is processed even before there is any clear understanding of the problems to be addressed. Because of the time frame involved, it is impossible to ascertain with any certainty the theoretical principles that will ultimately prevail. The method considers that technological development is a volatile system shaped by complex interaction between possible future encounters and past encounters, which can be traced back through the stated recollections of experts – providing there are no errors in formulating the questions.

This is why, in France, foresight of this type is viewed more as the study of fledgling technological dynamics and the clash of major global trends than as an exercise in prediction. The survey was conducted through the post by a specialised private pollster, SOFRES, using a sample of 3 400 experts and covering a thousand-odd technological topics. The methodology was to ask the same experts the same questions twice in succession, allowing them to revise their initial responses after being shown the complete results of the first round of questioning. Topics were divided into 15 fields, with questions spanning various stages of technological evolution, from the specification of objectives to large-scale use, and including development and practical application. The contextual diagram for each topic was dealt with separately from other questions; interactions were pieced together subsequently. Experts were asked about their knowledge of the topics and the importance they attributed to them (*i.e.* the priority they gave them in their work), there being a proven correlation between the self-assessment of leading experts and the importance they attach to each topic. Experts were also questioned with regard to how long they expected it would take for proposed scenarios to come true, how specific their forecasts were, the need for international co-operation, and any obstacles they might perceive.

It was on an entirely experimental basis that the Directorate-General for Research and Technology (DGRT) launched this survey. Having been derived from an exercise initiated by the Japanese Science and Technology Agency (STA) and taken up in 1993 by the German Federal Ministry of Research and Technology (BMFT), the survey was necessarily biased to a considerable extent by the Japanese cultural and scientific context. Nevertheless, because of the need for material that would make international comparisons possible from the outset, the questions used by the Japanese, and later the Germans, were reproduced verbatim. Three other features of its methodology militated in favour of Delphi: it is suitable for an approach based on technological niches; it reveals the constraints on each of the parties to the development of any given technology; and, last but not least, it focuses closely on the duration of technological developments and the chronology of applications. The dating procedure is used to determine actual time frames, relying on the experts – who alone have direct access to their own first-hand experimentation – to prepare a sort of self-assessment of their time. Here it is assumed that each of the experts, by looking back over their own experience, can determine which moments were decisive and consolidate them into a uniquely personal understanding enabling them to map out the exact chronology involved. With the Delphi method, the idea is to climb inside the black box rather than to make a futile attempt at evaluation from the outside.

The variety of responses dispels any illusion that there is only one right answer or any particular form of reasoning unique to a given scientific track and sure to lead to the proper solution.

Increasingly, Delphi is being recognised in France as an invaluable means of expressing consensus or disagreement between interested groups. While not intended as a direct input to government policy-making, it ought to be used as an initial point of reference. The method provides a forum for two types of dialogue: the first between experts and researchers from various backgrounds; the second between the scientific community and the public at large.

In Japan and Germany, 16 questionnaires were used. Owing to cultural considerations, the "lifestyles and culture" questionnaire was not included in the French survey. From a French viewpoint, not even in this type of questionnaire can culture be reduced to its socio-technical dimension.

The sample of experts to be questioned was chosen with help from databases belonging to the Ministry's Directorate for Scientific Information and to the organisation commissioned to do the actual polling. The *Télélab* base was used to identify public-sector experts, and the France Technologies directory for those in the corporate sector.

The first round of the French Delphi survey was completed in three months. The second, so-called "search for consensus" questionnaire took slightly longer because of the intervening summer holidays. It included aggregate results from the first round and gave all respondents a chance to alter their initial judgements in the light of views expressed by their peers. An additional question was added, about France's position in relation to its leading rivals. This global competition aspect is vital to a technology foresight survey, which encompasses areas of constraint far more diversified than those of scientific foresight.

II. A WIDELY ACCEPTED FORM OF FORESIGHT

Of the experts questioned, 45 per cent were from industry, 30 per cent from government research and 25 per cent from academic research. The high number of responses and a 33 per cent reply rate, fully comparable to the outcome in Germany, proved that the questions' Asian origins were not a major obstacle and that the survey itself was readily accepted. Neither did there seem to be any major differences in the extent to which experts from different backgrounds accepted the survey: response rates were similar for corporate, academic and government researchers. In all, 290 questionnaires, or 7 per cent of those mailed out, were returned to SOFRES blank, indicating a low rate of rejection. This initial finding would appear to confirm that a statistical tool is needed in the arsenal of technology foresight.

The many comments interspersed among the responses called overwhelmingly for scenarios to be more specific and technically precise. This is a clear indication that the French scientific and technical community has high expectations for this sort of exercise, which enables as many people as possible to make themselves heard. It has also become plain that, in the future, such projects will have to make the economic dimension more explicit (*e.g.* what would happen in a recession?) and, above all, shift the scenarios' "centre of gravity" to tie in more closely with underlying social priorities.

Lastly, a number of negative reactions clearly indicated that the French would like science to act with moral responsibility. Technological foresight must therefore look into the main ethical obstacles implicit in the break with current behaviour that is reflected in the technological dynamics emerging from the survey.

On the whole, however, the result is extremely important: technology foresight is recognised in France as capable of rationally performing much of the spadework for deciphering the future. The findings also reflect a realisation that there is no predetermined path for technical progress, but rather a range of scientific and technological options among which the nation must be in a position to make clear choices. The results do not assume that the history of techniques has been written beforehand and needs only to be revealed, but rather, on the contrary, that the players questioned are going to co-produce it, that

Table 1. **Numerical breakdown of experts by field**

Field	Initial sample	Phase 1 respondents	Phase 2 respondents
1. Process technologies – Materials	686	191	163
2. Electronics – Information technology	395	124	115
3. Life sciences	439	163	143
4. Elemental particles	89	30	27
5. Sea and earth sciences	158	74	65
6. Raw materials and water resources	70	25	21
7. Energy sources	158	62	53
8. Environmental sciences and technologies	264	114	103
9. Agriculture, forestry, fisheries	124	71	65
10. Productive activities	206	76	60
11. Town planning, architecture, construction	60	18	17
12. Communication technologies	133	40	33
13. Space	104	39	30
14. Transport	202	67	60
15. Medicine	300	179	167
Total	3 388	1 273	1 122
Response rate		38%	33%

Source: Author.

Table 2. **Comparative statistical coverage, by field, in the French, German and Japanese Delphi surveys**[1]

Field	France		Germany		Japan
1. Process technologies – Materials	163	(24%)	64	(12%)	203
2. Electronics – Information technology	115	(29%)	47	(8%)	151
3. Life sciences	143	(33%)	66	(13%)	181
4. Elemental particles	27	(30%)	22	(17%)	
5. Sea and earth sciences	65	(4%)	32	(12%)	255
6. Raw materials and water resources	21	(30%)	37	(11%)	89
7. Energy sources	53	(39%)	146	(24%)	144
8. Environmental sciences and technologies	103	(39%)	62	(12%)	119
9. Agriculture, forestry, fisheries	65	(52%)	52	(18%)	201
10. Productive activities	60	(29%)	55	(12%)	116
11. Town planning, architecture, construction	17	(28%)	36	(12%)	123
12. Communication technologies	33	(25%)	66	(14%)	115
13. Space	30	(29%)	29	(21%)	
14. Transport	60	(30%)	53	(9%)	182
15. Medicine	167	(56%)	38	(11%)	139
Total	1 122	(33%)	804	(13%)	2 266

1. The figure indicated is the number of respondents, after the second round (Phase 2). The figure in parentheses is the final response rate, computed by dividing the number of Phase 2 respondents by the number of experts initially contacted in the first round.

Source: Author.

technological dynamics based on feedback are preferable to excessively restrictive forward planning.

This validates the choice of a questioning process whereby each expert must explore the possibilities and plausibility of the paradigmatic situation in which he or she is involved. It is therefore wholly appropriate not to ask people to take an objective approach based on things that have either taken place already or will presumably take place sooner or later; what is important is people's convictions, based on their own experience.

III. DIFFICULTIES OF THE INTERNATIONAL APPROACH

The difficulties arise from the fact that the reasons for conducting Delphi surveys would seem to differ from one country to another. The perception in France is that in Japan the exercise is closely tied in with the long-term vision that academics have of their work; in Germany, people see a desire systematically to implement various methods of foresight; in Korea, the goal is clearly to extend the time frames of industry. It is probably in the United Kingdom that concerns for rationalising choices come nearest to the underlying French goals of exploring alternatives and setting priorities.

France is, in fact, the country most committed to making Delphi a standard, reliable tool for shedding light on technological choices and not limiting its role to the dissemination of information. This is why it is important to make the initial assumptions – which will help shape the messages used in the subsequent dialogue – as explicit as possible, since it is always difficult to differentiate between similar solutions. It is precisely this need to make difficult yet readily justifiable choices that underlies the desire to set up an extensive measuring instrument.

Setting priorities does indeed entail making choices, *i.e.* resolving conflict: whenever several technologies are in competition, it is highly likely that some will go off in incompatible directions. Such decisions can be especially crucial if each country favours a different solution and therefore runs the risk, should it fail, of being totally cut off from the subsequent technological innovations. How, and for how long, should options be kept open? It is this type of public decision that needs to be facilitated.

Since no individual, nor any panel of experts, can have a comprehensive view of available knowledge, what can be done to pick the right technology at the right time? The underlying assumption is that options lending themselves most readily to decision analysis of the "if X, then Y" variety would be the most feasible. They can then be ranked high in priority even though, in the end, political considerations will weigh just as heavily, yielding decisions that reflect society's priorities and political choices. Nevertheless, by distinguishing technical issues from purely political considerations, decisions are made more transparent and more legitimate.

For example, comparisons between France and Germany highlight the impact of differential specialisation in particular technical segments. It can be seen that the French are less familiar with utilitarian technologies than their German counterparts. It is therefore in moving from scientific reproducibility to industrial reproducibility that a problem arises; this lesson is already well known in France, but Delphi has confirmed that it is still relevant.

Apart from these technological issues relating to the initial utilisation and practical application phase, there is considerable convergence between the assessments of the French and the Germans at all other levels of technological maturity.

In life sciences as well, the indices of international co-operation are broadly similar between France and Germany. The highest scores in both surveys are often for topics in which man plays a pivotal role, reflecting the primacy of man over technology in Western societies.

IV. WHAT WILL TOMORROW'S TECHNOLOGY CONSIST OF?

The outcome of Delphi is a database with 30 000 responses to exploit. From there, it will be necessary to develop sorting options that are compatible with the human mind's own capacity to sift.

BETA-CNRS has set up and tested a system for overall analysis of the results, the goal being to refine systematic analysis of a base of technological contexts that are incomplete, inexhaustive and disparate. Segmentation analysis has sought to map out a step-by-step path to the most probable constraints on any given dynamic of technological development. While this representation has obviously been formulated to be as significant as possible, it may be flawed by significant gaps, if not errors in judgement. It must subsequently provide the basis for dialogue between researchers in government and those in private industry.

The database is rich enough that it would be feasible to sort it in special ways for certain specific populations (at least in the fields drawing the most responses), *e.g.* segmentation/differentiation of the results between large firms and small and medium-sized industries (SMIs). BETA's work consists of taking standardised processing modules and producing indicators specific to each technological segment. The goal is to devise a battery of data processing procedures to generate multiple drafts of perceptions of the future, thereby ensuring against any lack of imagination. It must be borne in mind that the Delphi method was invented by the Rand Corporation to extricate itself from the lack of imagination – deliberate or not – of the ensconced representatives of pressure groups who regularly showed up whenever experts were being consulted, undoubtedly because they themselves were the foremost experts.

Questions and criticism relating to the subjectivity of responses have spawned a debate over reliability. Without claiming to resolve the issue here, it is possible to elaborate on the intellectual mechanisms at work: the method neither contradicts nor endorses the experts' responses, but rather maintains a sympathetic and constructive neutrality towards all points of view. It recognises that an expert is an aware thinker who incorporates into a limited subset that he himself has constituted the relevant portion of all the existing information accessible to him. His work as an observer/participant is to consolidate the fragmented information available at a given time on a given subject – a subject that is "his".

The nature of their jobs causes researchers to turn their vigilance into routine, systematic exploration to acquire information that can support their own work. It is this characteristic that is being harnessed.

Delphi assumes that experts adapt on their own to key local conditions, forging personal strategies that combine the constraints of apprenticeship and differential development that underlie their professional identities. It is therefore not unreasonable to consider that the outcome will reflect reality, but with a Doppler effect that shifts the image of that reality as a function of the gravitational forces pulling on the trajectories of the experts being questioned. This is why it is important to survey a large number of experts and not just leading specialists in any given topic.

The method calls upon experts who are aware of the limitations of their forecasting abilities and have trained themselves to design systems in which each element plays a single role, carefully isolated from outside interference so as to minimise the devastating impact of unforeseen circumstances. All therefore cultivate an ability to make firm judgements on the basis of weak signals known to them alone. It is all this that Delphi strives to consolidate, without ever claiming to grasp the complete chain of cause-and-effect that will produce the technology that will ultimately be used.

Little by little, then, a model for analysing synthetic perceptions begins to take shape. It emerges through a back-and-forth motion between the knowledge of experts and the expectations of the groups or corporations in which they are immersed.

It is time to acknowledge and take account of the vast diversity that underlies technological development. Not everyone is in it for the same reasons, and everybody has a different time frame. The stability of long-term trends is fundamentally linked to the coexistence of competing scientific avenues and of participants pursuing different objectives.

V. DELPHI: TOWARDS A TECHNOLOGY OF INSTRUMENTATION FOR DECISION-MAKING PROCEDURES

The basic assumption is that after two rounds of questioning, which amount to a pre-processing of information, there necessarily emerge elements of perception, acknowledgement and categorisation of these technologies that are still imperceptible to non-experts and perhaps even to experts.

The second assumption is that awareness of the stakes involved grows keener in a consensus-seeking exercise that consolidates the recollected work experience of a statistically significant, scattered cross-section of specialists, in an interdisciplinary forum whose authority is acknowledged by all.

This is consistent with the goal of obtaining a close approximation of the underlying technological dynamics. The system officially draws upon the experts' stated recollections, since it is, in fact, their memory of their own work that is being mobilised. This method therefore opens the door to possibilities that could not be projected from the state of the art alone, since they transcend the whys and wherefores of existing knowledge.

From these dynamics, it is then necessary to extract concrete information on enhancing the capacity to translate hypothetical probabilities into actual selection criteria.

An illustrative result: analysis of the topic "Utilisation in mechanical devices (aircraft, engines, turbines, etc.) of intermetallic alloys resistant to extreme temperatures" can lead to the formulation of hypothetical scenarios. In this case, by stretching the interpretation, the outcome can be translated into affirmations of a distinctly industrial nature that could serve as a basis for discussion with professionals in the sector:

- The role of high-tech SMIs is vital to rapid technological success.
- Co-operation (and international co-operation in particular) is a key success factor in helping to overcome technical obstacles.
- Nonetheless, many of those who expect an application to come on stream in the relatively short term do not want to co-operate (they probably feel capable enough, and far enough ahead, to proceed on their own, in-house).
- The "cost" factor is an obstacle fairly commonly cited by SMIs, especially by those that identify their foreign competition.
- Obstacles involving investment and the organisation of R&D also show up in academia.

If high-tech SMIs are deemed instrumental in bringing the topic under discussion to fruition, they should be helped to develop ties of international co-operation. If it is considered that French universities ought to play a role, then they should be given greater funding for the necessary investment.

How does one go from here to the categorisation of experts? This third topic of Delphi 1 (Process technologies – Materials) was chosen as an experiment in order to undertake a thorough analysis of the population of respondent experts. Through such a typological approach:

- aggregate results relating to a given topic (*e.g.* the concept of a median date, aggregate indicators of importance, dispersion of the citing of obstacles, etc.) can be qualified by bringing to light contrasting elements within the population of experts and their responses; and,
- possible scenarios can be identified by viewing each of these conceivable visions of the future, since each of the main groupings of experts corresponds to a relatively consistent approach.

We chose 60 experts from the 70 who responded on this topic, the selection criterion being complete answers to all of the questions relating thereto.

– The first segmentation experiment involved projected timetables for realisation, *i.e.* it focused on the question, "Who thinks they will be first to succeed, and under what conditions?"

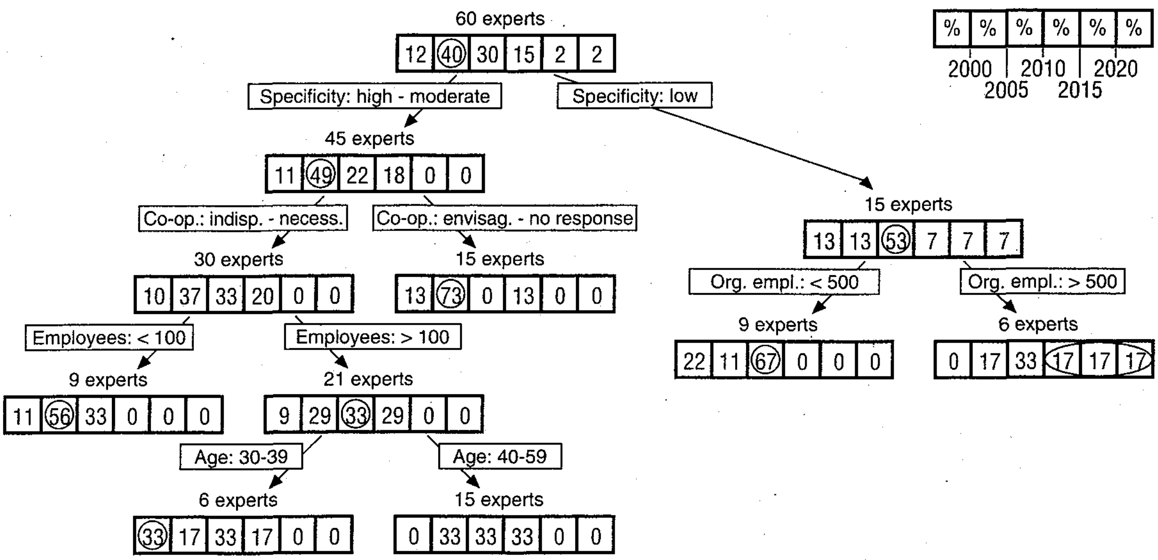
The following diagrams give the overall distribution of the 60 experts over the six periods under consideration.

A series of dichotomous segmentations was performed on the 60 experts, each intended to ascertain the most distinguishing criterion between two subgroups, based on dates of realisation.

The first split involved the degree of specificity: 45 were specific or highly specific; 15 were not specific.

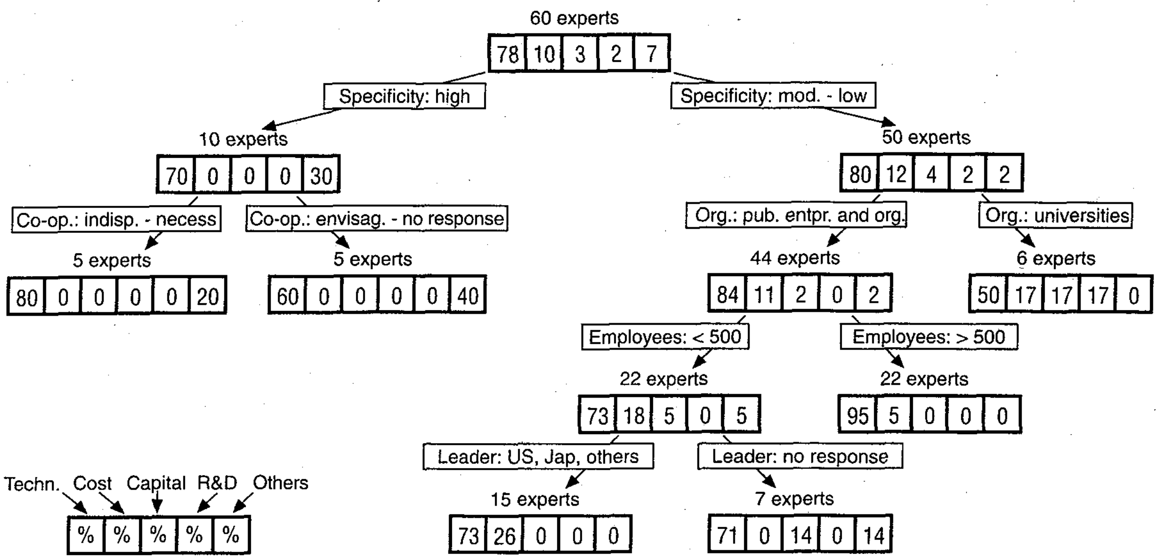
Looking at the 45 most specific experts, the main difference between them involved their perceptions of the need for international co-operation. Among those who expected rapid realisation, there were two groups: experts who wanted things to be carried out entirely in France and were confident in their ability to do so; and just about as many other experts who felt they could succeed within the framework of international co-operation. In this category, the need for co-operation was perceived even more strongly by those who worked for entities

Figure 1. **Segmentation procedure applied to date of realisation**
Field 1 – Topic 3



Source: Author.

Figure 2. **Segmentation procedure applied to obstacles**
Field 1 – Topic 3



Source: Author.

employing fewer than 100 people. Since the respondents to Delphi 1 were business enterprises, the people involved were SMI engineers and researchers.

- A second approach was taken to the same topic, this time concentrating not on the date but rather on the obstacles encountered. In other words, it focused on the questions, "What is stopping us from moving faster?" and "Who needs what help?"

The results of the corresponding diagram may be summed up as follows:

- A majority of experts (78 per cent) cited technical obstacles with regard to this topic, but the highest score (95 per cent) was attained by a sub-population of 22 experts whose degree of specificity as to timing was moderate to low and who were associated with large enterprises or organisations. This corroborates the above analysis and confirms that it is, in fact, in high-tech SMIs that the most effective technological dynamic is to be found.
- Cost appears to have been a factor mainly for experts in small firms who, in addition, perceived that foreigners had taken the lead in this field.
- Difficulty in raising funds and organising R&D were cited as obstacles relatively seldom, but they were mentioned more frequently by academics.

Categorisation of topics

A Delphi database can also be viewed as a system of reticular extensions that can be activated in order to develop knowledge by associating the topics of a single expert, or to achieve overlapping development by associating the views of various experts on the same cluster of topics.

It is possible to establish categories for topics within a given field, and even for those in different fields if they encompass similar topics. This analysis is particularly applicable to the detection of timing profiles: two topics will be deemed "closely related" if the aggregate response of all experts as to the date of realisation leads to highly similar distribution curves. This method was applied in Delphi 1 on process engineering and materials.

It is also possible to pinpoint similarities in responses concerning types of obstacles. Defining categories of topics makes it easier to build foresight scenarios. While Delphi is not strictly a scenario method, there is no reason why coherent systems of events cannot be pieced together from the vast amount of data contained in the base. From this standpoint, the Delphi approach can be seen as the first step in a foresight exercise aimed at building scenarios.

Topics can also be categorised on the basis of affinities revealed by the experts. If it is assumed that there is an affinity or an affiliation between two topics when a given group of experts say that their knowledge of both is "very great", then an affinity matrix can be constructed for the population of "leading experts". From this matrix, factor axes are extracted, thereby mapping out a synthetic representation of the overall organisation of the technological field. In addition, topics that share a great many experts with numerous other topics may be considered as relating to generic technologies or as having something else in common that it would be worthwhile to identify. This was done for Delphi 8 on environmental technologies.

To detect uncertainty and characterise the degree of specificity of the survey's vision of the future, topic by topic, another option is to construct entropy indices to synthesise disparities between responses (*i.e.* consensus or disagreement among experts) as well as indicators of knowledge and the specificity of individual projections. This was done for Field 1.

The conclusion to be drawn from all these developments is that more work is needed on joint formulation of the issues to be submitted to public debate. The gradual emergence of an interpretation is what creates or solidifies the experts' highest-level thinking. It is obviously heavily dependent on the ability to make judgements and to utilise them soundly and reliably to shape collective knowledge.

Here the desired instrumental effect is seen as the development of a transfer faculty to give content to areas where there are gaps in our knowledge, rather than to produce stable responses, limited to the fields of knowledge of established disciplines.

Part Two

It is interesting to note the fields in which each country's experts feel that technical obstacles are the least important. Such a ranking can be considered an index of technological advancement or of basic industrial capabilities that do not necessarily correspond to today's established specialties. Another possible explanation would be the characteristic short-sightedness with which one underestimates fields one knows little about.

FRANCE	Agriculture, forestry and fisheries Sea and earth sciences Productive activities Processes and materials
GERMANY	Town planning, architecture and construction Transport Environment Space
JAPAN	Town planning, architecture and construction Sea and earth sciences Space Environment

Here we shall give only a few brief examples of the detailed analysis and processing that can be carried out on raw data from the survey. It was demonstrated above that a single topic, if covered by a large enough number of responses, can be a gold mine of information, and that the possibilities for cross-analysis are vast.

VI. FINDINGS WITH RESPECT TO THE ENVIRONMENT

Specificity of projections

The various experts seemed to be specific about the timing of projects that involved deterioration of the ozone layer. Projected realisation dates for these common topics, which were often close together, were extremely similar for the

Germans and the Japanese, and always a little farther off for the French. As a rule, the experts were specific about innovations they expected to occur between 2000 and 2005.

International convergence

The experts of all three countries believed that over 80 per cent (and up to 90 per cent for the French) of the innovations proposed by the survey would take place between 2000 and 2010. The French and the Japanese broke down almost identically with respect to far-off innovations (*i.e.* those after 2010) and did not envisage any that might occur after 2020. With regard to the global environment, the legislative aspect showed up as a typically French concern.

Specifically, the French and the Japanese had seven topics in common, relating to the destruction of the ozone layer, global warming, water quality and waste. The experts of these two countries would therefore seem to have highly specific ideas about many of the same topics, and, more generally, expect them to come to fruition soon and at much the same time; here too, the specificity index was rather high.

For their part, the French and the Germans put ten topics in the same category, projecting virtually the same timetable, but one that was still slightly longer for the French, probably because of the amount of time elapsed between the two surveys. Two miscellaneous ecological topics were included. As a rule, the French and the Germans were specific when it came to regional environmental issues, which is consistent with the fact that that is the sub-field of which their stated knowledge is the greatest.

As for the Germans and the Japanese, there were four topics for which their indices and realisation dates were virtually identical – a fact that ought to be emphasised as indicative of a clear consensus on a number of hotly debated subjects (*e.g.* the ozone layer, the greenhouse effect, water quality and waste).

All three countries agreed on the importance of question 8.16 ("highly advanced technique using artificial coral reefs to reduce the percentage of CO_2 in the air"), but they differed widely as to the project's timing, the French expecting it in 2013, the Japanese in 2018 and the Germans in 2021.

Impediments to development

The organisation of R&D was cited less as an obstacle by the French than by German or Japanese experts.

International co-operation

Topic 31, relating to international standards for controlling air and water pollution, was one that the experts felt called particularly for co-operation, but the three countries did not cite the same obstacles to creating them. For the French, the hurdles were essentially regulatory and, to a lesser extent, technical; the Germans agreed, but they pointed to major cost constraints as well; for the Japanese, however, the chief obstacles were a lack of funding and technical difficulties. The objectives of co-operation were thus not exactly the same for all three countries.

On Topic 11, dealing with global warming, the three countries agreed that international co-operation was needed to assess the impact of the greenhouse effect on world farm output. This was expected to take place around 2005.

VII. FINDINGS WITH RESPECT TO PROCESS ENGINEERING AND MATERIALS

Divergent French and German approaches

No topic was ranked among the ten most important in both the French and the German surveys. In the German experts' opinion, few technical problems impeded topics belonging to the sub-field "process engineering", while their French counterparts felt otherwise. Where French experts pointed to technical obstacles, the Germans cited cost. Conversely, with regard to topics relating to "optical, magnetic and electromagnetic properties", it was the French who reported cost as an obstacle and the Germans who referred to technical problems.

Topics belonging to the theme "optical, magnetic and electromagnetic properties" dominated the German ranking of the most important topics, accounting for five out of the top ten, as opposed to only one in the French ranking.

It is interesting to note that the leading experts on a given topic, be they French or German, are more apt to rate their own country as being ahead in its work than experts having a lesser degree of specialisation.

Moreover, the French will more readily rate their home country on a par with others than the Germans, with the result that the French did not comply with the instruction to cite only two countries in their responses. One possible interpretation is that French experts are reluctant to accept the idea that sometimes they may not lead the world. In terms of government decision-making, this means that it is very difficult in France to propose catch-up strategies based on imitating things that were not invented domestically. The French style of catching up is more a matter of trying to reinvent – even if it means never catching up.

Selection procedure for topics in Field 1

A thorough review of topic-selection methods was undertaken. It confirmed that, in a major survey of the Delphi variety, a synthesis in terms of topic categories and (at least implicit) bases for various scenarios could be drawn from the large number of opinions expressed. The objective in doing so is to propose a representative cross-section of the diversity of technological dynamics and the underlying coherency. This provides an interesting opportunity, since the survey theoretically aims rather for exhaustive coverage of a vast range of topics, and to build a consensus among experts.

Initially, it was necessary to limit the analysis to topics for which there was a sufficient number of respondents and leading experts. Subsequently, topics with a high importance index were selected, although they also had to meet the conditions of the previous filter. In addition, it was important to note which topics had the greatest number of experts.

Accordingly, we used a two-stage threshold of relevance:

- Lower filter: to eliminate topics with an insufficient number of responses (at least 20 experts replied that they had some knowledge of the topic, and at least one respondent categorised him/herself as a leading expert).
- Higher filter: to select topics on which many leading experts responded (in this case, between four and eleven, on 18 topics) and the indices of knowledge, importance, specificity and co-operation were high (47 topics).

Possibility for retrospective assessment of the relevance of the questioning

Selection based on the various indices (importance of the topic, specificity of responses, the experts' knowledge, etc.) prompted a great deal of attention to the sub-field "properties of materials", in which 31 of the initial 59 topics crossed the threshold. This was especially true for the theme "chemical and biological properties", with 12 out of the original 14 topics. This theme would therefore have warranted a greater number of topics in an ideal questionnaire for French experts, given the importance they themselves attribute to such issues.

Analysis of the degree of consensus/disagreement

It is significant that a high degree of consensus was reached for most themes, the only ones on which consensus was low being topics relating to the thermal properties of materials. Lastly, topics under the theme "process design and synthesis" attracted both high and low scores for the degree of consensus.

The timing and specificity of visions of the future

A method making more complete use of the degree of expertise and stated specificity was utilised for the 108 topics of Delphi 1: data on realisation dates were processed in order to incorporate the experts' own assessment of the quality of their responses.

We call this variable the "entropy index". It reflects each respondent's stated degree of specificity and the extent of consensus obtained from all responses to the question: the vaguer the individual visions (low degree of stated specificity) and the lower the extent of consensus (high dispersion of responses), the higher the value of the index.

In all, we have a coherent mass of information at our disposal to categorise the 108 topics with respect to timing and entropy. With each topic, we can associate a firm median realisation date and an aggregate degree of specificity that takes account of both individual uncertainty and divergent opinions.

This enables us to segment the results into three categories:

- topics with realisation dates that are in the near future and specific;
- topics with dates that are far-off and vague;
- topics with dates that are in the near future but vague (63 per cent).

It is possible to take this further by analysing the fringes of the point cluster:

- Topics with a low entropy/median ratio give an overall impression of specificity and consensus in the construction of responses.
- In contrast, a high entropy/median ratio should prompt more detailed analysis of the causes for the lack of specificity: is a high degree of entropy attributable more to individual hesitation (stated specificity) or to differences of opinion between experts?

VIII. METHODOLOGY FOR GROUPING INNOVATIONS: A TEST IN THE REALM OF LIFE SCIENCES

General assumption

The quest for coherency and cross-fertilisation is an indication of the efficiency of a country's scientific and technical development. Together, all of the techniques, methods, procedures, knowledge and know-how form what is often referred to in the literature as a "generic technology". If a generic technology is to develop, it is important to avoid bottlenecks and thus to ascertain and catalogue future techniques and innovations apt to undergo related development.

Cognitive assumption

Leading experts are only leading experts on topics that are closely connected with their own individual work. Consequently, if an expert has extensive knowledge of two subjects, then those two subjects are related.

To start with, a matrix is set up, with topics listed in rows and the 90 respondent leading experts in columns. First, it is possible, for each leading expert, to describe the nature and the number of associated technologies.

A number of observations can then be made:

- to determine the technologies most commonly worked on;
- to detect connections between technologies;
- to categorise the technological spectra covered by the experts.

Next, a second matrix is created, representing the degree of proximity between technologies. From this:

- Technologies can be associated with one another (using Main Component Analysis and analysing results using indices of proximity).
- Cross-disciplinary technologies can be detected; these are the ones with the highest proximity scores on any given line or column (the matrix being symmetrical, of course).

Current work will endeavour to demonstrate two types of results.

- The first is related to Main Component Analysis, whereby topics are aggregated into homogeneous units. When a topic that is theoretically extraneous (according to its Delphi title) turns up in a unit, this provides invaluable information by showing that there are direct or indirect (cross) links of proximity between the topic in question and the rest of the unit. In addition, within units, it is a good idea to examine the periods of likely realisation and detect topics that are either leading or lagging, in order to prevent any bottlenecks having to do with science or a technology's social acceptability. Lastly, proximity between units can be detected. For instance, the fact that Topic 15 of Life Sciences is located near to the "Cells" unit raises the question of whether the fight against cancer should involve the use of new technologies such as biological reactors through which new biogenic substances can be produced independently of cell cultures.

Main Component Analysis can also be used to check the coherency of the groupings thought up by the experts who designed the questionnaire. While it ought therefore to yield coherent results, it can sometimes raise unexpected questions involving technological proximity.

- The next undertaking involves cross-disciplinary technologies and efforts to detect "dominant" topics, *i.e.* those which, within the area of research under consideration, have the greatest number of direct or indirect links with each other. Once these topics are detected, it is interesting to catalogue closely related topics, paying special attention to any cases that seem especially noteworthy. An example of this is the fact that many topics having to do with artificial membranes have strong links with topics relating to the fight against cancer.

Other topics can have few leading experts in common while at the same time having many experts in common with one or more topics that are themselves closely linked to one and the same other topic. This latter topic, apparently disconnected from the unit in question, is nevertheless in its orbit and ought, in the future, to be incorporated into it.

Eventually, one should be able to use this indicator to categorise the overlap between technological developments arising from useful duplications. Farther into the future, it should also be possible to plot the experts' subjectivity curve.

Tie-ins with Life Science Topic 40 (Development of preventive cancer drugs)

The analysis is interesting in that the titles of the topics grouped together in the questionnaire offer quite a bit of information having to do with protection against cancer. Apart from topics that are naturally quite closely related, there is a whole range of topics linked to the development of new technologies (artificial membranes, the production of substances having molecular assembly capabilities, development of a method to synthesise active transport membranes that are similar to biological membranes, development of biosynthesis techniques for the production of organisms able to reproduce), as well as topics connected with a better understanding of molecular phenomena. The analysis therefore provides a certain amount of information that, while not yet fully exploited, would appear vital to making the fight against cancer a priority for industry.

Analysis such as this should be extended to all fields of the Delphi survey, since, for example, advances or delays in the realm of materials may well have an impact on biotechnologies.

CONCLUSION

Clearly this study suggests new directions and raises questions that can be transformed into specific input for technological or industrial policy after consultations with the community of experts and interest groups concerned. While no miracles or magical results should be expected from this kind of approach, the method can lead to unexpected discoveries which can help clarify the ins and outs of situations about which information is necessarily incomplete, and clear-cut, objective decision-making impossible. It is in just such situations, where formal logic fails to yield a decision, that the quality of public debate, the transparency of intentions and taking conflicting interests into account form the basis for effective co-ordination – co-ordination that places in the hands of democratically chosen authorities the responsibility to make choices on the basis of enough input as not to be wholly arbitrary. This work contributes to that objective.

Statistical findings and data analysis form a base whose structure is conducive to far-reaching dialogue between experts from various backgrounds and fields of research.

Pollsters have gathered together to share their experience, both at the initiative of individual countries and multilaterally at OECD. Such contacts should be encouraged, with new, increasingly well structured and co-ordinated Delphi surveys helping pave the way to harmonious organisation of technological research and development, both at the level of each country and world-wide.

SOME RECENT FORESIGHT EXPERIENCE IN AUSTRALIA: THE AUSTRALIAN SCIENCE AND TECHNOLOGY COUNCIL

CONTENTS

This paper is based on a presentation made by Professor Michael Pitman to the OECD *ad hoc* Meeting of Experts on Government Foresight Exercises in Paris (14 September 1994). The material presented to the *ad hoc* Meeting has been substantially expanded and updated to include the results of the Council's work during the past year. Mr. Chris Birch of the ASTEC Secretariat assisted in the preparation of this paper.

SUMMARY

This paper describes the activities of the Australian Science and Technology Council (ASTEC) in its current foresight study *Matching Science and Technology to Future Needs: 2010.* The ASTEC study has experimented with an approach to foresight that stresses the identification of Australian national demands or needs as a way of structuring a foresight process. The methodology and some preliminary results are reported.

I. INTRODUCTION

ASTEC is a principal source of independent advice to the Australian Government on a wide range of policies and programmes related to science and technology (S&T), which are of concern to Commonwealth departments and agencies, higher education institutions and private enterprise. It works closely with the Prime Minister's Science and Engineering Council and other major bodies providing policy advice to the Australian Government. ASTEC is in a unique position to provide foresight advice to the Government because of its independent status, its broad, longer-term perspective and its links to the S&T community and to industry.

ASTEC's role is to contribute significantly to enhancing the strategic development of Australia's science and technology system and to strengthening the linkages between government, the research community, industry and the community in general. Foresight, by its nature, was considered by the Council as an area of great potential within this role.

The Council's intention to undertake a foresight study was endorsed by Senator Cook, the Minister for Industry, Science and Technology, and Minister Assisting the Prime Minister for Science. The foresight study has formed the main part of ASTEC's 1994-95 work programme, and will be completed by December 1995. The agreed terms of reference of the study are shown in Box 1.

Box 1. **Matching science and technology to future needs: 2010 – terms of reference**

Given the government's objective to improve Australia's long-term economic competitiveness and our social and environmental well-being, by maximising the contribution from science and technology; and, noting the importance of adopting a forward looking approach:

A. Examine possible national and global changes to the year 2010, specifically:
   i) Australia's key future needs and opportunities which rely on, or could be significantly affected by, scientific developments and the application of technology; and
   ii) potential mismatches in the supply of and demand for science and technology in Australia.

B. In addressing A:
   i) engage in an extensive consultative process in accord with international best practice in foresight designed to match science and technology to national objectives;
   ii) encourage the collective identification of important themes for future science and technology planning in both the public and private sectors; and
   iii) increase awareness and understanding of the value and methods of future-oriented analysis.

C. Provide an information base which can assist government and industry to make better informed decisions on the development and application of science and technology.

The Australian Government has set a number of broad goals for the Australian science and technology system (CCST, 1994). These are briefly:

- maintaining a high-quality science base in universities and government research agencies;
- recognising the central role of science and technology in achieving national objectives, including international linkages;
- encouraging greater innovation by business, including through strengthening its R&D activity;
- developing human resources for science and technology; and
- promoting science and technology in the wider community.

Within these broad parameters, priority setting in the Australian science and technology system is generally carried out at the level of research performers and funding agencies. For example, the CSIRO, the major publicly-funded research conducting agency in Australia, has used a feasibility/attractiveness matrix approach based on a socio-economic objective classification (see for example, CSIRO, 1993). A centralised system of priority setting is currently not favoured by policy makers in Australia. Rather, the pluralist nature of science and technology system is stressed.

The primary aim of the ASTEC study, as set out in the terms of reference, is to develop an information base for the diverse components of the Australian S&T system in government and industry. This study will assist the various elements of the system in their own long-term planning decisions, including on the adoption of appropriate foresight methods.

The study has produced four reports to date: an introduction to the study (July 1994), a background report (August 1994), a report on overseas foresighting activity (September 1994), and a report on key issues for Australia to 2010 (March 1995). A final report to Government on the whole of the study is planned for December 1995. In addition, reports on ASTEC "Partnerships" will be forthcoming.

The following sections provide an overview of the methodology of the study (Section II), a review of progress to date (Section III), and some preliminary findings in selected areas to illustrate the type of information that has been developed at the time of writing (Section IV).

II. THE STUDY METHODOLOGY

From the outset, the ASTEC study has sought to draw upon overseas foresight approaches, but to develop an approach suited to Australia's conditions. An early decision was made to place an emphasis on the identification of "future needs". This approach seeks to place prospective Australian and global scientific and technological developments, as revealed for example by the Japanese and German Delphi work, into a broad Australian economic, social and environmental context.

ASTEC approached the study as a collaborative exercise, involving science and technology users, providers and policy advisers in both the private and public sectors. The information, judgements and analysis sought from these sources has been used to identify how responsive Australia's science and technology policy is to longer-term social and economic priorities.

A particular feature of the study has been the direct involvement of Council members as managers of the various components. This has proved to be a successful way of dealing with the scale and complexity of the study. While making substantial demands on members' time, it has ensured that each aspect of the study receives close and individual attention. Co-ordination has been achieved by detailed reporting at the Council's monthly meetings and by the establishment of a small executive committee to oversee progress.

In designing its process ASTEC was conscious of international experience, and in particular the value of "process" benefits from foresight and their ability to foster the "5-Cs" identified by Irvine and Martin of: communication, concentration on the longer term, co-ordination, consensus and commitment (for example, see UK Cabinet Office, 1993). In particular, ASTEC also sought to build commitment to the aims of the study from government and the science and technology community, and undertook considerable consultation throughout the study.

Foresight exercises such as those conducted in the United Kingdom or Japan and Germany have required considerable resources, and produced much valuable information. As a result of ASTEC's relatively limited resources, it was determined to use the outcomes of these studies as much as possible.

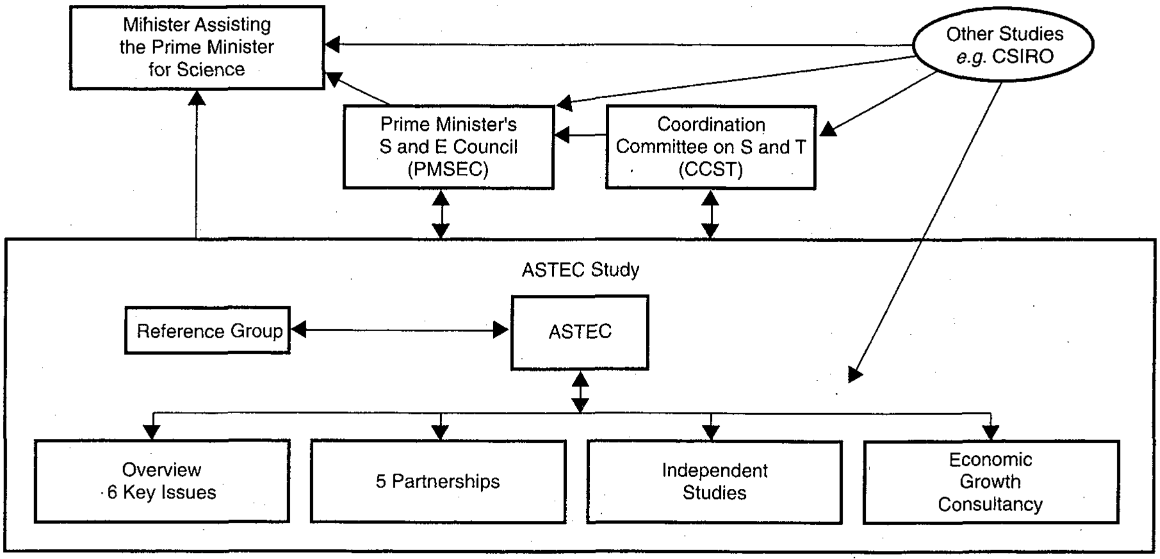
Figure 1 provides a simplified diagrammatic representation of the organisation of the ASTEC study, and its advisory links to the Minister Assisting the Prime Minister for Science, the Prime Minister's Science and Engineering Council, and the Co-ordination Committee on Science and Technology. It shows four streams of work within the study.

The first – the *Overview* – involved a broad approach to balance both "science and technology push" and "demand-pull" or future needs. This was achieved using an issues-based approach with intensive consultation. Through *Key issues,* the Overview identified perceptions of important long-term issues for Australia, and their underlying forces of change. From this, views were gathered about science and technology's role through workshops, round tables and reviews of existing studies. Through these processes ASTEC has identified potential mismatches in the supply and demand for science and technology in Australia to 2010.

The second – *Partnerships* – comprised five detailed and targeted foresight exercises in collaboration with other interested parties on specific areas of interest and relevance. The Partnerships were established in a selection of areas, chosen because they are both long-term issues and illustrative of the potentially broad applicability of foresight. They were:

- *Urban water life cycles* – the provision of adequate and safe water in urban environments in an environmentally sustainable way;
- *Information and communications technology* – futures for broadband interactive networks;
- *Health* – neurodegenerative disorders of the aged;

Figure 1. **Organisation of the ASTEC foresight process**



Source: Author.

– *Shipping* – maritime futures for Australia; and
– *Youth* – preferred and expected views of the future.

The third – *Independent studies* – reviewed the expanding experience of foresight in Australia and internationally to ensure that the knowledge of other groups was taken into account. In Australia, these studies included Australian Research Council research discipline reviews (NBEET, 1993 and 1995), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) scenarios for 2020 (Eckersley and Jeans, 1995), and other work, including several scenario workshops held by CSIRO Divisions. Internationally, information was analysed from important studies such as the United Kingdom Technology Foresight Programme (UK Office of Science and Technology, various), and the Japanese and German Delphi work (NISTEP, various). This was complemented by a series of interviews with the Chief Executive Officers of major Australian enterprises.

The fourth – *Economic growth consultancy* – comprised an ASTEC commissioned study of the impact of science and technology on economic growth as a means of assisting in ranking the priority of science and technology issues.

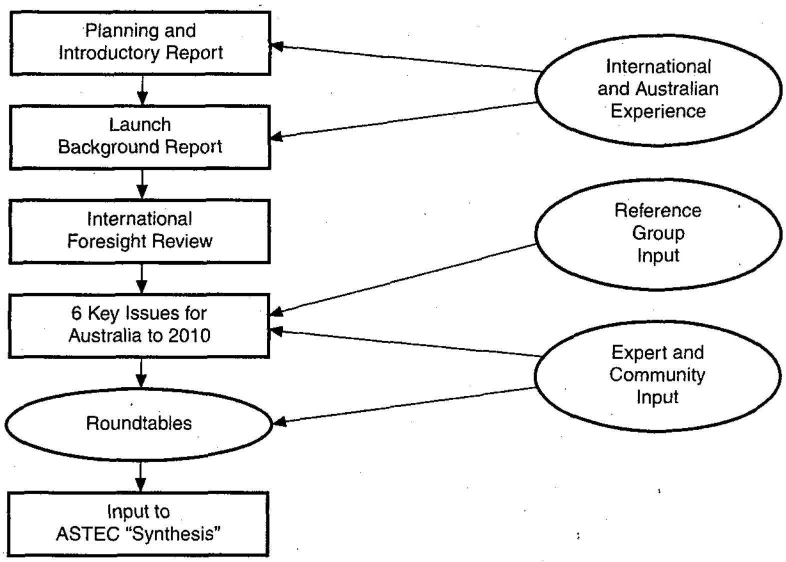
III. PROGRESS TO DATE

The Overview – a broad context

The Overview provided the co-ordinating element of the study, and brought together information from many diverse sources. The Overview also provided a broad-brush view of implications arising from prospective changes to 2010 for Australian industry, society and government, and for the Australian science and technology system. The general features of the overview are shown in Figure 2.

ASTEC issued an introductory booklet in mid-1994 outlining the scope of the study and its planned structure (ASTEC, 1994*a*). The study was officially launched in August 1994 with the release of a literature review of foresight and an outline of ASTEC's work programme in a *Background Report* (ASTEC, 1994*b*). Approximately 3 000 copies of the *Background Report* were distributed. The report included reply sheets to gather information about views on key issues facing Australia to 2010, independent studies being conducted, and people who wanted to be involved. This process was accompanied by a media campaign to raise public awareness.

Figure 2. **Features of the Overview**



Source: Author.

This process gathered information, and raised awareness of the forthcoming foresight activities. The *Background Report* was followed in September 1994 by the release of a review of international experience (ASTEC, 1994*c*), focusing on "process" aspects of foresight, but with some indication of the type of information generated. This report sought public input on methodological approaches used in other countries, and views on how foresight might best be conducted in Australia.

In the following months, ASTEC identified key issues for Australia to 2010 through a comprehensive process of consultation, particularly:

- a Reference Group of 30 well-known Australians from science, technology, industry, education and community groups, each identifying three key issues for Australia to the year 2010;
- wide community consultation via responses to the *Background Report,* and targeted consultations with industry, government and research organisations; and
- a review of literature and recent results from other bodies. This included international future studies and Australian work by the Business Council of Australia and the CSIRO.

Many of the contributions came from areas and people not traditionally perceived to have a direct interest in science and technology.

Responses from the Reference Group led to the identification of several provocative scenario elements. The combined future visions of the Reference Group point towards Australia becoming a much more open economy that is tightly linked to the world through global information flows. Many traditional occupations will either disappear or change radically. While Australia will play a unique role, with the potential to become a key nation in the Asia-Pacific regional economy, it will also come under increasing social and environmental pressures forcing it to develop innovative ways of generating wealth while ensuring environmental sustainability. It must also come to grips with a rapidly ageing population where there was concern that gaps between the "haves" and "have nots" will continue to grow.

Community views indicated a number of concerns about Australia's future. A high level of concern about the quality of the environment was evident with over two-thirds of responses listing environmental issues as a priority to 2010. For most of these, their sole priority was the convincing need to fix environmental degradation and implement ecologically-sustainable development. Another concern is Australia's place in a changing world. Australians no longer see themselves as isolated from the problems of the world. Also, the community was concerned about the ability of Australia to become a "clever country": one that can find better ways of developing and making use of technology, and one that has a sense of control over the use of science and technology to meet community needs and wishes.

These perspectives were then integrated with those of other studies. For example, the Prime Minister held a National Strategy Conference, "Shaping Our Future", convened by the Economic Planning Advisory Commission (EPAC) in November 1994 (EPAC, 1994 and 1995). The Conference identified a broad consensus on national ambitions, and it also considered future opportunities for Australia and long-term strategies to assist the achievement of national goals. The basic vision for Australia that emerged was of a country that is creative, productive, inclusive and ecologically-sustainable.

ASTEC reviewed the issues and, through a workshop process, identified its "key issues" based on ranking within a matrix of national need and potential contribution from science and technology. In March 1995, the Chairman, Dr. Williams, released *Matching Science and Technology to Future Needs: Key Issues for Australia to 2010* (ASTEC, 1995*a*). This report presented six key issues to 2010 which ASTEC had identified as critical to shaping Australia's future. ASTEC's key issues focus on those future needs where science and technology is likely to have a particularly strong impact. They provide a framework for examining the critical skills, technologies, networks and support structures that Australia will need between now and 2010.

ASTEC's *Key issues* for Australia to 2010 are shown in Box 2.

After announcing the *Key issues* and distributing over 3 000 copies of the report, each of the six Key issues was explored through a foresight Roundtable chaired by different ASTEC members. These Roundtable discussions involved 20 to 50 people in a half-day structured process using scenario techniques. The discussions at the round tables were used to better define the Key issues and to identify the science and technology implications for Australia of a range of prospective changes.

Box 3 provides an example of the greater refinement of issues developed under the key issue of "The need for innovation and entrepreneurship: 2010". These issues were discussed by the Prime Minister's Science and Engineering Council in June 1995. At that meeting ASTEC suggested several challenges to 2010 and policy suggestions to address them.

Outcomes of round tables such as the above provided input to ASTEC's "synthesis" process. The synthesis process will also draw together information from the other components of the study: *Partnerships, Independent studies,* and the *Economic growth consultancy.*

Box 2. **ASTEC six key issues for Australia to 2010**

The need for innovation and entrepreneurship. A key challenge of the 21st Century will be to manage the increasingly rapid pace of change. Innovation and entrepreneurship will help us to respond to new needs and opportunities as they arise.

The need for a technologically literate society. The 21st Century will see an increase in the pace with which we introduce technology into our society. The appropriate response to more technology is not to ignore it, but to accommodate it, respond to it and shape it. We need a society that can make informed choices.

The need to capture opportunities from globalisation. As we move toward the global economy of the 21st Century, countries are becoming more interdependent. Global process are creating a new distribution of wealth, skills, technology and production. Australia must identify and capture the opportunities in this evolving world.

The need to sustain our natural environment. Our physical environment is our greatest natural asset and a major inheritance for our children. Increasing development and population growth in the 21st Century must be managed in the context of a sound scientific understanding of the value of our natural environment as the basis for Australia's longer-term prosperity.

The need for continuous improvements in community well-being. To realise a more inclusive, cohesive, confident and productive society in the 21st Century, Australians will need to face many new challenges. Science and technology can help solve current problems, deliver continuous improvements in community well-being and meet new challenges such as ageing.

The need to build a forward-looking science and technology system. The strategic direction, and the skills and knowledge generated by science and technology, will impact on our ability to meet our future needs. Our science and technology system must look ahead to the 21st Century and be open and responsive to early, and possibly weak, signals of change.

The Partnerships – targeted, collaborative foresight

Partnerships are characterised by a committed group of organisations who together are examining sectoral issues to 2010. They are using individually designed foresighting processes to identify scientific and technological opportunities and requirements over the next 15 years. Partnerships aim to demonstrate that:

– foresighting is useful to a wide range of groups in their long-term planning;

Box 3. **Key issue: the need for innovation and entrepreneurship: 2010**

- Shaping Australia's long-term opportunities
  - possible institutional structures to take ongoing responsibility for oversighting technology foresight in Australia, and whether an existing institution could take on this role.
- Managing risk and uncertainty to grow new businesses
  - considering foresight in a broad perspective, including how foresight can help Australia's new companies to develop and how foresight might be of value to the finance sector.
- Supporting the technologies of tomorrow
  - initiatives to address the need for long-term research on critical technologies, *i.e.* Australian strengths in areas of long-term growth, and the potential role of new or existing schemes, *e.g.* the Co-operative Research Centre programme.
- Creating infrastructure for national and global networks
  - "Innovation Advisers" as network facilitators, and agents for advice. An important issue is mechanisms to develop the skills and technological information bases required by such advisers.
- Enhancing R&D in government enterprises
  - ASTEC suggested a review of the potential role of government enterprises in fostering innovation, including through R&D, into the 21st century.
- Educating innovative managers for the 21st century
  - The recent Karpin Task Force report into management in Australia (Karpin, 1995) concluded that the lack of enterprise and entrepreneurial studies at school, in vocationally education and training and in higher education, forms part of the reason why there is not a strong small business culture in Australia. ASTEC supported the Karpin Task Force recommendations.
- Delivering on Regional leadership in 2010
  - ASTEC suggested a broad-based consultative mechanism be implemented to develop a national dialogue on intellectual property rights. There is also a need to maintained international S&T programmes under review to ensure that Australia does not miss opportunities with its regional neighbours in the Asia-Pacific.

- specific science and technology capability will impact on realisation of preferred futures;
- broad participation in foresighting results in cohesive sector strategic planning; and
- foresight methodologies can be tailored to individual sector/area needs.

Five partnerships have been established.

The *Urban water life cycles Partnership* involves leading water research groups and industry bodies in an examination of the technology and skills required for the urban water management of the future. In Australia, the world's driest inhabited continent, population growth in urban areas will place considerable pressures on water supply delivery and waste management. The partnership is using techniques such as scenario building to investigate possible futures for urban water services, and explore the science, technology, and training required to implement innovative solutions. The partnership is also providing an opportunity to complement water research and planning with developments in other relevant fields like urban planning, epidemiology and information technology.

The partnership aims to use foresight techniques to identify investment opportunities in science and technology to provide cost effective, adequate, and safe water for urban communities, in an environmentally sustainable way, in the coming decades.

The *Information and communications technology Partnership* involves the Australian Photonics Co-operative Research Centre and the Australian National Training Authority. It is examining the technology and skills required for the broadband interactive networks of the future. It is focusing on the longer term to see how interactive broadband networks may develop. Particular attention is being directed to the science and technology required to make broadband interactive networks possible.

The objectives of the partnership are to foresight the science and technology underlying the development of broadband interactive networks in Australia and overseas, and the demand for such networks; to identify opportunities for Australian development of innovations in this area; and to identify skill needs for this area to 2010.

The *Health Partnership* involves ASTEC, the National Health and Medical Research Council and the Council on the Ageing, Australia. The partners are examining science, technology strategies and skills required for the effective management of neurodegenerative disorders in older people to 2010 and beyond.

The impact of the systemic diseases of the 20th century industrial age on the elderly, caused in part by smoking, alcohol and food, is most likely to be overtaken in the 21st century by a different group of disorders. It is likely that neuronal fallout or neurodegenerative disorders will constitute the major problem for the elderly in 2010. Demographic projections reveal that the section of the population currently identified as being most prone to these disorders, the aged, has been forecast to increase markedly by 2010. It is likely that this will impact not only on the quality of health care delivery available to older people by 2010 but on their carers (presently predominantly voluntary and unfunded). This change in Australian demographics will also have an economic impact on health care delivery to all Australians. The partnership will give particular attention to the science and technology required to make independent living for those afflicted achievable by 2010 (ASTEC, 1995*b*).

The *Shipping Partnership* has eleven partners covering all areas of Australian shipping. The partnership is examining the technology and skills required for an innovative Australian sea transportation system for the future. Particular attention is being directed to potential science and technology developments through collaborative work among the interested parties in the Asia-Pacific region.

The objectives of the *Shipping Partnership* are to foresight the science and technology underlying the development of an innovative and competitive ship building, ship repair and support industry in Australia and the Asia-Pacific region; to identify opportunities for Australian innovations to be used in sea transport in the Asia-Pacific region; to identify skill needs for this area to 2010; and to identify other opportunities particularly in the Exclusive Economic Zone (EEZ) context, which would give rise to sea transportation requirements.

A Delphi foresighting survey is being undertaken by the Australian Bureau of Statistics and it is expected that the results of the first round will be available in October 1995. A second round will be completed by the end of 1995.

The *Youth Partnership* is exploring the views of young people (aged 15-24) on probable and preferred futures for Australia, and the role of science and technology in shaping those futures. It has identified the key issues to the year 2010, from the perspective of youth and will analyse how science and technology can be best used to meet young people's needs and wishes.

The *Youth Partnership* differs from other surveys on youth attitudes and views on science and technology as it has involved young people in defining their preferred future for Australia. How young people see Australia's future can have an important bearing on their expectations and outlook on life, and their attitudes to matters such as education, vocational training, work and government. Thus it can affect their own personal well-being and Australia's performance in setting and achieving national goals.

The *Youth Partnership* carried out eight foresight workshops with a wide range of youth groups. These include school students, university students, unemployed youth and disadvantaged youth. Results to date indicate that:

- 80 per cent want a greener, more stable society where the emphasis is on co-operation, community and family, more equal distribution of wealth and greater economic self sufficiency. An international outlook, but strong national and local orientation and control. Technologically advanced, with the focus on building communities living in harmony with the environment, including greater use of alternative and renewable resources.
- Less than 20 per cent want a fast-paced internationally competitive society with the emphasis on the individual, wealth generation and enjoying the good life. Power has shifted to international organisations and business

corporations. Technologically advanced with the focus on economic growth and efficiency and the development of new consumer products.

Interestingly, 60 per cent believe that the future for Australia to 2010 will be closer to the "growth" scenario than the "green" scenario.

Independent studies

In addition to international foresight experience, there have been a number of future-oriented studies of science and technology in Australia. Indeed, ASTEC has developed some of these (ASTEC, 1981, 1991*a*). An example of a major recent effort has been the work of the CSIRO in developing approaches to setting research priorities.

The CSIRO approach has been to adapt a two-dimensional ordering of research priorities, developed by the US Industrial Research Institute, to Australia as a whole. The "feasibility" and "attractiveness" matrix developed suggests that a strong emphasis should be placed on research that is highly attractive (*i.e.* the likely benefits of successful research are high), and highly feasible (*i.e.* there is a likelihood of achieving a high level of technical progress in Australia). Lesser support would be given to research that is low in attractiveness and feasibility. An important aspect of CSIRO's approach has been to stress the issue of Australia's ability to capture the benefits of technological progress. This matrix approach was also used by the UK Technology Foresight Steering Committee to identify "generic" priorities for the United Kingdom.

CSIRO has also introduced a scenarios project into its strategic planning process. A number of its leading scientists are creating "best case" scenarios for the year 2020 that describe possible developments in different areas of science and technology and their impacts over the next 25 years. These represent a personal, not corporate, perspective and are intended to highlight the importance of scientific and technological advances to Australia's future and the choices and challenges they present (Eckersley and Jeans, 1995).

Valuable information about the future development of the Australian science and technology system is provided by the Australian Research Council funded Discipline research strategy studies. These strategies have been prepared for the following disciplines (see NBEET, 1993 and 1995):

- Earth sciences;
- chemistry;
- educational research;
- physics; and
- astronomy.

While each strategy takes a different approach, they contain profiles of each discipline and identify priority areas for work. For example, the Earth sciences review sought to define a vision for Australian Earth sciences that would see greater rates of progress in the areas of:

- assessing the geology and resource potential of the Australian continent based on state-of-the-art technology in geological and geophysical mapping;
- understanding the Australian regolith – its nature, extent, mode of formation and application to problems in soil science, mineral exploration and environmental studies;
- understanding the geology and resource potential of Australia's marine Exclusive Economic Zone;
- improved exploration techniques for Australia's undiscovered mineral, petroleum and groundwater resources;
- expanding knowledge of the nature and evolution of Australia's continental crust using integrated geological, geophysical and geochemical methods;
- understanding Australia's water resources and their management including groundwater and integrated catchment and aquifer management; and
- expanding knowledge of Australia's palaeoenvironments, their relationship to ecosystems and their use for testing models of climatic change.

ASTEC also conducted a number of interviews with leaders of selected firms from a variety of sectors. These indicated that:

- the dominant trends to which companies are responding are environment and globalisation;
- major technologies which companies are seeking to incorporate are information and communications technology, and to a lesser extent biotechnology;
- in the relatively small Australian market, foreign-controlled multinational enterprises tend to concentrate on local applications, with relatively few examples of global product mandates.

Economic growth consultancy

As part of the study ASTEC engaged a consultant to test the hypothesis, based on new growth theory, that there is the potential to boost Australia's economic growth through government policy initiatives which facilitate scientific research and development and the transfer of new technology.

The consultant was asked to review measures of economic welfare and comment on their appropriateness and to identify the effect of science and technology on economic growth in aggregate and by industry sector, seeking to identify those factors within science and technology that have the most impact on economic growth.

There was also a requirement to assess the adequacy and effectiveness of existing policy measures and to identify policy initiatives to facilitate science and technology and its impact on growth and welfare.

A preliminary draft report has been provided to ASTEC. It argued that Australia has achieved substantial gains over the past decade in applying science and technology to generate economic growth. While Australia's innovation system is far from adequate to support the transformation of the economy into one able to compete successfully in a range of knowledge-intensive industries, good progress has been made in this direction. Thus, in taking steps to foster improvements, the natural starting point is to build on those policies that have contributed to this success.

The consultant identified these as the existence of powerful incentives for private business to undertake research and development, principally the 150 per cent taxation incentive and the syndicated research and development programme, the strong focus on the commercialisation of public sector research results, continuing support from the Commonwealth budget for research and development, and industry policies specifically encouraging research and development, such as the "Partnerships for Development" programme and the "factor (f)" pharmaceutical industry programme.

Enhanced measures were recommended by the consultant in each of these areas, together with policies to address three areas of deficiency in the present arrangements, incentives for public businesses to undertake research and development relevant to their business needs, a foresight programme, and a new emphasis on the internationalisation of Australia's research and development base. However, the recommendations to address the areas of deficiency have yet to be developed in detail.

In the draft report, the consultant then sought to quantify how the increased performance of research and development (R&D) could be achieved by a combination of these measures, concluding that R&D expenditure could be expected to grow at an average annual rate of 11 per cent (in constant prices) between now and 2002-2003, compared to a base case (the continuation of current policies) of 4 per cent. The increased rate of growth over this period would result in R&D expenditure as a proportion of GDP being 2.5 per cent in 2002-2003, compared with base case expenditure of 1.7 per cent, an increment of 0.8 per cent.

The consultant drew upon new growth theory to illustrate the effect that this increase in R&D might have on GDP. Projections based on estimates of the past contribution of R&D on economic growth indicate the potential for additional annual growth of up to 0.75 per cent. The cumulative gross effect of this higher rate of growth over the period to 2002-2003 would be 6 per cent of GDP, or A$ 37 billion in 1994-95 prices. It is noted that the success of R&D expenditure in producing economic growth is dependent upon whether current subsidies are adequate. It also depends on what mechanisms are used to administer funds (*e.g.* tax concessions or grants, etc.) and in what areas they are provided. These factors play a critical role in determining the benefits of further investment in R&D and present the greatest challenge to policy makers.

IV. SOME PRELIMINARY FINDINGS

These processes, as described above, identified recurring forces of change. They were:

- globalisation;
- information and communications technology;
- environment; and
- genetics and biotechnology.

The first three of these forces are strongly impacting on the present, and are expected to continue to grow in significance over the next 15 years. Of these, "globalisation" and the "environment" are of a "demand-pull" nature, reflecting changing world views, policies, and needs for science and technology. "Information and communications technology" (ICT) highlights the growing impact and future potential of the convergence of a number of technologies into a digital "revolution". ICT has the potential to see the emergence of a new "techno-economic paradigm" (*e.g.* Freeman, 1994). The fourth, "genetics and biotechnology" is still in its relatively early stages, but over the next 15 years is expected to emerge strongly as a technological force.

Interestingly, as shown in Box 4 below, ASTEC's four cross-sectoral *Key forces* are closely related to three of the "Generic science, engineering and technology priorities" identified in the United Kingdom Technology Foresight Steering Group report (UK OST, 1995).

An important force identified for Australia is "Globalisation". ASTEC considered that globalisation was a particularly important force of change for Australia. Australia's unique environment and cultural identity have been shaped by a history of relative isolation. But this is changing. Technology is overcoming distance, and the Asia-Pacific is emerging as a economic growth area. 2010 is the target for removing tariff barriers in the industrialised countries of APEC. For relatively small economies like Australia, globalisation places a focus on diffusion of knowledge rather than creation of knowledge as factors in productivity growth. ASTEC commissioned a study on globalisation, which identified a number of opportunities

Box 4. **UK "Generic" science, engineering and technology priorities and ASTEC Key forces**

UK "Generic" SET priorities	ASTEC Key forces
Harnessing Future Communications and Computing Technology	– *Information and Communications Technology*
A Cleaner World	– *Environment*
Processes and Products from Genes to New Organisms	– *Genetics and Biotechnology*
Social Shaping and Impact of New Technology	
Getting it Right: Precision and Control in Management	
New Materials, Synthesis and Processing	– *Globalisation*

for Australia, each of which imply particular science and technology needs (Tegart, 1995).

Issues in areas related to the UK priorities of "Getting it right: Precision and control in management" and "New materials, synthesis and processing", were also identified in the ASTEC study. However, they did not emerge as strongly from the ASTEC study and will be addressed by ASTEC within the framework of potential responses to the *Key forces.* "Social shaping and impact of new technology", and UK "Infrastructural priorities", such as skills, finance and policy, will be also addressed by ASTEC in its framework of potential responses.

For each of the *Key forces* of change, ASTEC examined its definition, opportunities and threats for Australia, and implications for the science and technology system were identified.

ASTEC also noted that there is a considerable degree of convergence between the "critical" technologies or priority areas identified in international foresight work and the four *Key forces.* ASTEC also noted a number of cross links between them. For example, globalisation is strongly facilitated by developments in ICT.

As part of resolving opportunities for Australia, ASTEC considered it essential to look at the alignment of Australia with the broad directions of future S&T as outlined in international studies. To do this it is essential to bring into focus the general shape of Australia's basic science and technology profile.

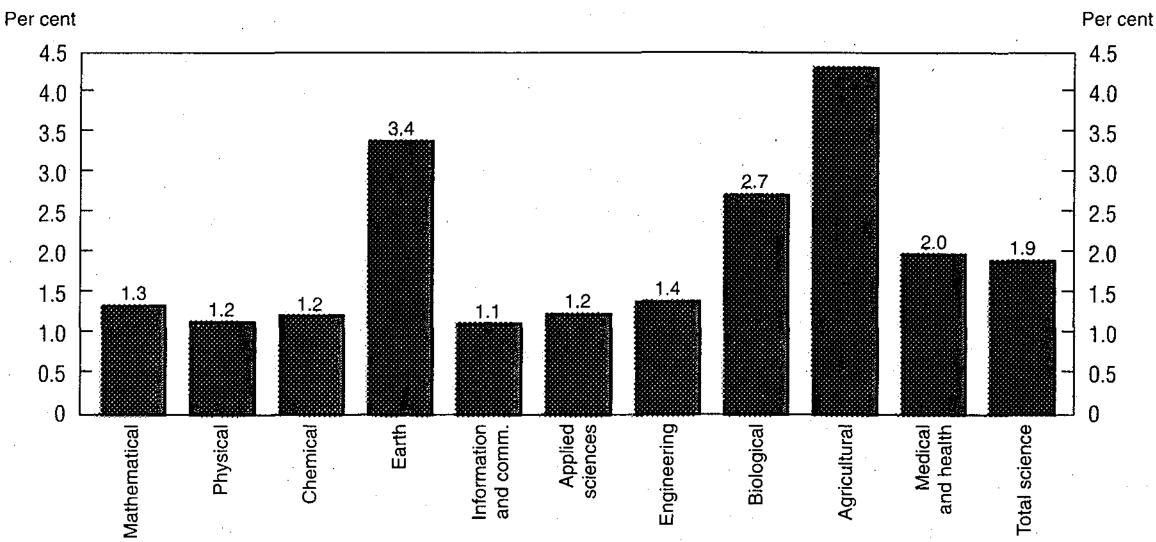
The more recent international foresight discussions emphasise broad generic technologies, projected some distance into the 21st century. They often assume a complex industrial and manufacturing economy, and a substantial research and development investment in high technology. This may not align with the social and economic base of smaller countries. Accordingly, it is important to consider the current Australian science and technology base.

Figure 3 is based on the Australian National University "Performance Indicators Project" database and shows the distribution into the fields of the Australian Standards Research Classification of Australia's share of publications included in the Science Citation Index (SCI) for the two-year period 1990 and 1991 (Bourke and Butler, 1995).

Figure 3 indicates that Australia's share of the international journal literature in the basic sciences is strongest in agricultural sciences, Earth sciences, biological sciences and medical and health sciences. These strengths in areas relevant to the *Key force* of "Genetics and biotechnology" suggest that Australia is well positioned to develop genetic and biological applications, including Health care applications.

However, Australia has a relatively lower share of publications in the basic science fields of physical sciences, chemical sciences and mathematical sci-

Figure 3. **Australia's share of SCI publications by ASRC field of science, 1990 and 1991**



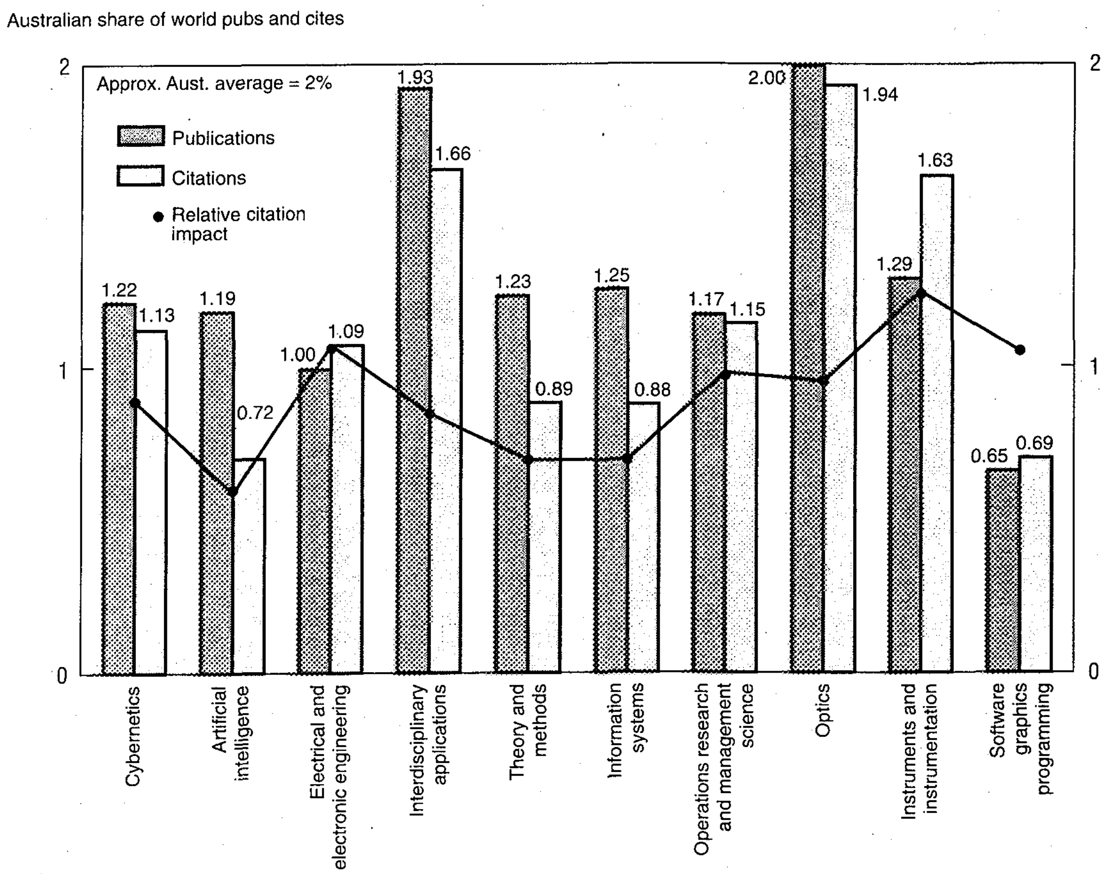
Source: Author.

ences, and in the more applied fields of engineering, and information and computing sciences.

At first presentation, this indicates a relative weakness in the science base underlying the *Key force* of ICT. However, a more in-depth view reveals niches of strength. This is shown in Figure 4, where the Australian presence in Optics and the Inter-disciplinary applications of ICT is shown to be comparatively high.

ASTEC has been recently commissioned by the government to undertake a detailed assessment of the adequacy of Australia's science base to contribute to

Figure 4. **Australian share of world publications and citations in information and communication technology**
Averages for the period 1981-92



Note: The relative Citation Index is the ratio of share of publications from Australia and the share of citations they received. A ratio of greater than one indicates that the *impact* of the publications in the international research community is higher than expected.
Source: Author.

the development of ICT and related services. This separate study will also report in late 1995.

The examination of consequent science and technology needs produced a draft ASTEC list of important science and technology areas for Australia. These are shown in Box 5 (not in a priority order). ASTEC has subsequently been identifying important S&T skills and requirements for these areas.

From the work we have done to date, it appears that we may need to make adjustments in our science and technology system to be able to cope with, and benefit from, prospective changes at the beginning of the 21st century.

Some suggestions being explored include addressing how our S&T system might develop as a more global enterprise. Such a system might have international "virtual" research teams and universities, and a greater degree collaboration and multi-disciplinary networking. Such a networked system will place pressures on ensuring that researchers and "knowledge workers" have appropriate training and skills in areas often neglected in S&T training, such as management, intellectual property negotiation, and an understanding of the financial system. This also points to a need to integrate the S&T system more closely with finance and legal systems.

We need to consider "critical" science and technologies, and areas where a sensitive "forward-looking" S&T system can detect and shape important conjunctions between the opportunities presented by technology and social and economic demands and needs.

Box 5. **Important areas of future science and technology for Australia**

- Agri-industry, *e.g.* high value-added and processed "clean green" foods.
- Value-added mineral products.
- Engineering infrastructure and specialist consulting services.
- Information and communications technology.
- Materials technology.
- Biotechnology.
- Environment management.
- Renewable and other energy supplies and technology.
- Transportation.
- Education facilities and services.
- Health facilities and services, medical research and pharmaceuticals.
- Travel and tourism.

However, the greatest challenge to emerge from ASTEC's consultations is that the community wants Australia's science and technology system to become more inclusive, ethical and communicative in order to link better with their social, economic and environmental needs. This suggests considerable changes for the science and technology system in the 21st century.

V. CONCLUDING REMARKS

This paper has presented a brief outline to the ASTEC study *Matching Science and Technology to Future Needs: 2010,* and some indicative early results. The final report on the whole of the study is planned for release in December 1995.

Annex

THE AUSTRALIAN SCIENCE AND TECHNOLOGY COUNCIL

The Australian Science and Technology Council (ASTEC) was established as a statutory authority in 1979 under the Australian Science and Technology Council Act 1978.

ASTEC is a principal source of independent advice to government on a wide range of policies and programs related to science and technology, and of concern to Commonwealth departments and agencies, higher education institutions and private enterprise. It works closely with the Prime Minister's Science and Engineering Council and other major bodies providing policy advice to the government.

The Council which is chaired by Dr Don Williams, currently has ten members broadly representing all areas of the science and technology community, many with strong industry links.

ASTEC is empowered to operate by conducting inquiries, gathering information, engaging consultants, appointing committees and producing reports.

Members

Dr. Don Williams
(Chairman of ASTEC)
South Australian Ships Pty Ltd

Professor Ron Johnston
(Deputy Chairman of ASTEC)
Director, Australian Centre for Innovation and International Competitiveness
University of Sydney

Professor Lyn Beazley
Department of Zoology
The University of Western Australia

Mr. Donald Blesing
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Professor Ann Henderson-Sellers
Director
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Dr. Jim Peacock
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TECHNOLOGICAL FORESIGHT STUDIES IN THE NETHERLANDS

CONTENTS

This article was prepared by Asje van Dijk, Rob van Esch and Marja Hilders. Asje van Dijk works as a private consultant, Rob van Esch and Marja Hilders work at the directorate for Technology Policy of the Dutch Ministry of Economic Affairs (respectively as deputy director and policy consultant).

I. INTRODUCTION

Japan has been engaged in extensive foresight activities since 1970. In that year, the Science and Technology Agency (STA) undertook its first 30-year forecasts of the future of science and technology (S&T). The aim was to construct an overview of all S&T as background intelligence on long-term trends needed for broad direction setting, rather than specific priority identification. Based on a Delphi-technique, several thousand experts were surveyed. The forecasts were repeated approximately every five years. Beside these STA forecasts, the Ministry of International Trade and Industry (MITI) produced ten-year visions and several other ministries, industrial associations, individual companies and think-tanks performed foresight activities and scenario studies.[1]

The successful technological and economic performance of Japan stimulated European governments to discuss their own passive, more following industrial and S&T policies. Governments slowly recognised that the identification of potentially important technologies at an earlier stage could create big competitive advantages; especially in the field of S&T where the advantages come from fast developments and quick reactions. Although the critics argued that governments were not in a position to "pick winners", practitioners showed that foresight is a way to draw possible pictures of the future on which stakeholders can formulate their own strategies and from which collective action can emerge.

This growing awareness within the S&T fora and the Dutch political arena resulted in a decision to commission an extensive review of foresight activities in eight OECD countries (1987-89). This comparative study by Irvine and Martin[2] showed that several foresight activities had been initiated and that the results were promising. Identifying emerging technologies turned out to be an important activity within the eight countries, undertaken by a lot of actors but with governments hesitating to become involved.

For the Dutch Ministries of Economic Affairs and of Education and Sciences, the study was an impetus to set up foresight projects. With research costs rising and the number of scientific opportunities expanding, they needed well argued decisions for priority setting. On one hand, limited budgets and capacity forced them to set such priorities. On the other hand, they were convinced of the intrinsic value of foresight as a planning method in direction setting and targeting limited funds.

The Dutch Ministry of Economic Affairs set up its first foresight experiment for technology in 1989 on mechatronics. The Ministry of Education and Sciences created a Foresight Steering Committee (FSC) in 1992, which is responsible for the identification of scientific and technological priorities.

Although the two types are complementary, a main difference between both activities is the time horizon of the technology foresight (five to ten years) and the FSC (ten years and more). Another difference is the scope; the technology foresights focus on the application possibilities of emerging technologies within industry; the FSC deals with scientific and societal developments in general, reflecting the wider socio-political context.

In the next paragraphs, we will concentrate on the foresight studies of the Ministry of Economic Affairs for the practical reason that we were/are professionally involved.

II. AIMS AND OBJECTIVES

Dutch foresight studies are scenario analyses designed to outline potential applications of new or existing technologies which can be expected to be widely applied in the Netherlands within five to ten years.

The Ministry of Economic Affairs defined three objectives for foresight studies.

- The principle aim is to generate information for strategic technology policy. A small country cannot expect to be a leader in all areas of technology, and restricted budgets must be allocated as effectively as possible. Foresight studies can be helpful to identify priorities in technology policy and facilitate the decision-making process. They should interpret technological trends and identify the opportunities and consequences of a wide range of applications in industry and the service sector. The government's aim is to encourage this process.
- The second aim is to provide enterprises (in particular SMEs) with useful information on relevant technological developments. Technological developments are often complex and subject to rapid change. Furthermore, the relevant information is usually not easily accessible and has to be gathered from many different sources. Few SMEs have the manpower or resources to conduct a systematic search for new technological applications. Foresight studies can provide them with an early warning system. Since 90 per cent of Dutch enterprises have less than ten employees, and only 1.4 per

cent have more than 100, SME's represent a major target group. Although some of these firms are highly innovative, this does not apply to the majority. The 25 largest companies conduct 85 per cent of all R&D activities, with the five multinationals accounting for 55 per cent.

- The third objective is to stimulate the development of networks relating to specific technologies. Networks linking parties such as industry, universities, educational institutions and intermediate organisations in the public and private sector can serve as vehicles of innovation. They promote the exchange of information, new ideas and co-ordination of activities. Networks are essential in this respect. Successful competition depends on internationally co-ordinated action between different players. In a knowledge-intensive economy, networks between industry, the knowledge infrastructure (research and education) and intermediate organisations play a significant role in the generation and dissemination of knowledge.

III. PROCEDURE

Dutch foresight studies, unlike those undertaken in some other countries, go beyond simply listing priority technologies. They also involve in-depth analyses of some of these technologies, and an assessment of the outcomes.

Step 1

The first step is to draw up a list of promising technologies and to set priorities by expert interviews. These lists contain some 75 areas of technology, compiled by an external consultant from studies undertaken in the Netherlands, the United States, Germany and Japan. The lists are not intended to be exhaustive, but serve as a tool that can be consulted by experts. They are asked to assess the technologies in terms of economic importance, innovative potential, applications, maturity and quality of knowledge. These assessments not only provide an invaluable insight into different areas of technology, but also give an indication of the innovative potential of various sectors of industry.

On the basis of the assessments, analysts draw up a short list of some 15 technologies which are then evaluated in terms of the following criteria:

- the technology should have progressed beyond the embryonic stage (*i.e.* should have proved successful in new products and applications);
- several different disciplines should be involved;
- the technology should be expected to realise its potential within the coming five to ten years;

- the benefits should be accessible to a wide range of economic sectors;
- industry, the knowledge infrastructure and intermediate organisations should be strongly represented in the development and application of the technology;
- relevance of innovation to SMEs, producers and users.

The forum is asked to assess the short list in the light of the selection criteria, in order to select two or three technologies for in-depth analysis. Employers' organisations, trade unions, branch organisations and other government ministries are also consulted at this stage. This is essential in order to create commitment among the parties involved.

Step 2

This step involves an in-depth analysis of the selected technologies by a consultancy, which is also asked to compare the Dutch situation with that of other countries. The analysts identify the different players and define bottlenecks/threats and opportunities. They also determine the strategic potential needed to avoid bottlenecks/threats in order to create networks and disseminate the technology. The analysis is supervised by a committee of eight to ten representatives of the relevant parties. These include companies that produce and use the technology, research institutes and technical universities. Their involvement helps to create a commitment which lays the foundations for networking at a later stage.

Step 3

The third step involves the presentation of the results at a strategic conference, attended by 80 to 100 delegates from various industries, the knowledge infrastructure, advisory councils and intermediate organisations. These conferences are intended to inform the relevant parties, test the results, generate consensus, help to create networks, etc.

Step 4

The fourth and final step is the implementation of the results. The government, the private sector, universities and educational institutes plan and organise follow-up activities on the basis of input from the studies and strategic conferences. These activities vary, but largely deal with issues such as the disparity between the market and the knowledge infrastructure, lack of awareness of the technology's potential among SMEs and barriers to the transfer of knowledge.

IV. RESULTS

So far, technological foresight studies have been performed on the following seven topics:

- mechatronics (1990);
- adhesion (1990);
- chipcards (1990);
- matrix composites (1992);
- signal processing (1992);
- separation technology (1993);
- production technology (1995).

Details of each study can be found in Annex.

V. EVALUATION

Between October 1994 and February 1995, "Research voor Beleid BV", a Dutch consultancy agency, evaluated the impact of the first six foresight studies. With regard to the three objectives of the foresight studies, mentioned earlier in this article, the conclusions were the following:

- To provide information for technology policy development and priority setting. The evaluation showed that the enlightenment function of the first three foresights was high and that the conclusions were translated to government policy. In the later studies this follow-up was insufficient. The evaluation suggests this is due to inadequate translation into market-aspects: (dis)advantages, costs and benefits.
- Technology foresights provide information as an early warning system for relevant stakeholders from industry, research, education and intermediaries. The evaluation showed that for two foresight exercises this objective was realised (mechatronics and chipcards). The other foresight exercises had far less impact on SME. An explanation for this can be that in the follow-up a catalyst is indispensable; without such change agents the translation of the information to certain target groups within the SME will be insufficient. Intermediaries can operate as change agents in initiating pilot projects, information and transfer activities.
- The third goal of the foresights was to stimulate network creation. The evaluation concluded that in three of the six foresight exercises, this could be effected due to the follow-up activities which mobilised stakeholders to keep involved in projects.

VI. CRITICAL FACTORS

Five factors are formulated which are really critical for the success of a foresight study. We will discuss these factors one by one below. Some of these factors tell something about the desirable contents of the foresight study, others about the process of designing such a study.

Critical factor 1

The technological foresight study aims at a technology that is relevant for enterprises trying to establish and penetrate new markets. Relevant may mean ripe for applications, but not necessarily! Relevant does mean that the study gives distinct insights in whether it is wise or not wise to use the new technology.

Essential ingredients to succeed in this attempt are:

- economic criteria on the level of individual enterprises; and
- translation from abstract technologies to product (families) and processes.

Critical factor 2

The technological foresight study aims at appealing themes. Themes are chosen on the basis of a certain "gut feeling" of the little group of opinion leaders from industry and science. Some opportunism causes no harm. "Diffuse" themes (*e.g.* signal processing) may be chosen, but should be clearly defined. The theme should be represented via schemes and language that are very familiar to the target group of enterprises. Otherwise the study will not be read at all.

Critical factor 3

It is questionable to focus the attention too much on individual SMEs. The chance that they get directly involved is rather small, even when many market changes can be detected. Exceptions in the high- and medium-tech segments can be major players, as we saw in the Dutch foresights. A more effective strategy is to interest the intermediaries (Innovation Centres, sector and branch organisations, etc.) and large customers. These customers can "pull" along commercial lines the SME's in co-makership relations.

Critical factor 4

No major personnel changes take place during the process. After finishing the technological foresight study, (some) members of the research group, the commission of experts and/or the ministry are still active in disseminating the study and its results.

Critical factor 5

During or immediately after finishing the technological foresight study, one of three specific follow-up activities are formulated, *e.g.* in the form of multi-client projects with SME's. This is an integral part of the participants' tasks and enhances their commitment.

VII. WHAT'S NEXT?

During the last couple of months, we have been discussing how the process of the foresight studies must be changed to account for the results of the evaluation. The main changes will be the following:

- The studies will be even more than in the past targeted at knowledge transfer to SMEs. Currently, therefore, we have split the foresight study into two parts:
  - a kind of technology radar, covering newly emerged technologies which appear to be of great economic relevance. Such a radar will be of use for various kinds of fields within technology policies (*e.g.* to find out which technologies can be used to help solving societal problems);
  - the second part is the *pièce de resistance* of the foresight study. We are going to match the topics within SMEs and technologies that can be used to deal with these topics. Intermediary organisations – such as Innovation Centres, who's main task it is to disseminate technologies to SMEs – will play a major role in this process. We expect to cover the question of which technologies can be of use, with the technology radar and consultation of experts.
- Follow-up activities must – as it were – be embedded in the foresight studies from the start. Just doing research without successful dissemination of the results is only useful for researchers!

Therefore, again we will strive for intense co-operation with intermediary organisations from the start. They are in close contact with SMEs, they know how to sell knowledge, so they can judge preliminary results of research on dissemination-aspects.

Follow-up activities can take various forms, they must be chameleon-like, adapting to the difference in their surroundings. So, a strategic conference is no longer an explicit part of the foresight process. It can be, but it doesn't have to be.

VIII. EPILOGUE

During the consultancy agency interviews with people involved in the foresight studies to evaluate them, everybody underlined their positive attitude to these studies. With relatively small amounts of money, foresight studies can be of great use and thus become very effective. Yet, this potential has not completely been realised during the six studies which were evaluated recently. Therefore, we are going to implement some modifications in the foresight process. We are reasonably sure that these changes will enhance the effectiveness of the foresight studies.

NOTES AND REFERENCES

1. See also the summary of the *ad hoc* meeting of experts on government foresight exercise at the OECD, Paris, 14 September 1994 (Martin, see this volume).

2. J. Irvine and B.R. Martin (1989), *Research Foresight: Creating the Future,* Ministry of Education and Science, Zoetermeer, the Netherlands.

Annex

FORESIGHT STUDIES SO FAR

Mechatronics

The mechatronics study identified several obstacles to large-scale application of this technology. They included insufficient awareness of the potential gaps in education and training, and lack of funding for further innovation and development among SME's. After the strategic conference, the Ministry's technology group drew up a working plan which served as a blueprint for follow-up activities. One activity involved forming a panel consisting of representatives of industry, branch organisations, higher vocational training institutes and government. The panel's main task is to introduce mechatronics to Dutch industry and stimulate its application. Another follow-up activity involved the development of methods to introduce mechatronics to the engineering industry, initiated by *Metaalunie,* the employers' organisation for SMEs in this branch. This was undertaken in collaboration with two university experts and members of the supervisory committee. A good example of activities that increase knowledge are courses in mechatronics introduced by three technical universities.

Adhesives

After the conference, the Ministry of Economic Affairs and the Ministry of Education and Sciences both provided support for the creation of an Adhesion Institute at the University of Delft. This institute conducts research, independently and in conjunction with industry, and functions as a knowledge and advice centre for industry. The study of adhesives technology highlighted the following issues: the lack of a knowledge dissemination system; the need for a "Who's Who in adhesives"; and inadequate knowledge of application possibilities in many industries. Both the study and the strategic conference emphasized the need for an industrial information agency. Although plans had existed for several years, they had yet to be put into practice.

Chip cards

The strategic conference on the chip card study concluded that this technology should be approached from the "pull" side. It is not the government's task to stimulate large-scale, complex infrastructural applications. Pilot projects could have a stimulating effect. In the absence of any driving force to take the initiative or responsibility for doing so, it took more than a year to set up follow-up activities in this field. The Ministry finally decided to set up a chip card panel, similar to the mechatronics panel. The chip card panel's task is to introduce chip card technology to wider sections of Dutch industry and society, and to stimulate further development and application of the technology. The Ministry also included chip card technology in its Telematic Guide Programme, designed to stimulate the application of telecommunications technologies. Pilot projects for chip card applications have now been launched as part of this scheme.

Matrix composites

One of the problems identified in the field of matrix composites was a lack of knowledge regarding potential applications of these materials. The branch organisation for the electronics industry, FME, is now organising meetings to inform its members about the potential of matrix composites. The umbrella organisation for SMEs, the Royal Dutch Union of Small and Medium-sized Enterprises (KNOV) initiated a project for the transfer to SMEs of knowledge available at technical universities in relation to matrix composites and adhesives. Many different organisations are involved in the project. Apart from the KNOV, they include five branch organisations, for the automotive, coach work, tyre, metal and construction industries, Delft University and the national network of Innovation Centres. The project is sponsored by the Ministry and the ABN/AMRO Bank.

Signal processing

Signal processing is a broad field which has much in common with data processing. There is a vast range of potential applications in many different sectors. With the rapid developments in sensors, telecommunications and micro-electronics, new applications are emerging all the time, for example in signal processing hardware, software and design accessories. Signal processing technology also affords promising applications in image processing, instrument systems and telecommunications.

Separation technology

Separation technology involves a group of technologies applied for the separation of materials (*e.g.* by distillation or centrifuging), during the production process or at the end-of-pipe stage. These technologies also make a substantial contribution to optimising product yields and to eliminating environmental pollution. Since the strategic conference in March 1991, follow-up activities have focused on reducing odour emissions in the snack processing industry. Also, the Dutch Platform of the Processing Industry (NAP) adopted a method to identify promising technologies, the pilot project being on separation technology.

Production technology

The foresight study into production technology tries to enlighten how technologies and management techniques may contribute to:

- reducing the time-to-market;
- improving the control of the production-process;

these factors being main competitive factors, as the steering committee (of the study) indicated. Also, environment is being identified as a new competitive factor, that offers opportunities in addition to costs.

The study focuses on the link between the design and the manufacturing process and takes into account factors that relate to company characteristics.

One major conclusion is that, with respect to the choice and implementation of new technologies, management involvement and management support are essential. The choice of a technology requires a tailor-made approach, taking into account strategic considerations and, of course, the *status quo.*

After a stimulating strategic conference, with a lot of suggestions as how to stimulate company awareness; how to improve education tailored to companies needs; and how to improve the involvement of the knowledge infrastructure, follow-up projects are currently being set up.

For instance, the Innovation Centres and TNO have embarked on a project "Modern Production" informing small and medium-sized companies of new technologies and their opportunities. The scheme allows for improvement projects for individual companies, which will be monitored by a small group of fellow-entrepreneurs.

HETEROGENEITY AND CO-ORDINATION: THE EXPERIENCE OF THE DUTCH FORESIGHT STEERING COMMITTEE

CONTENTS

This paper was written by Dr. B.J.R. van der Meulen, staff member of the Dutch Foresight Steering Committee and senior researcher at the Centre for Studies of Science, Technology, and Society of the University of Twente, the Netherlands. Since 1988 he has been involved in studies on the development of foresight activities and in the organisation of foresight activities. He has published frequently on the development of research systems and related issues such as evaluation, foresight and the role of institutes. Recent publications include *Research Institutes in Transition* (with A. Rip), Delft 1994, and "Understanding Evaluation Processes in Research Systems in Transition", *Science Studies*, 1995, forthcoming.

I. INTRODUCTION

The Dutch government set up a Foresight Steering Committee in 1992 with the objective of improving foresight and to prepare the ground for national science and technology priorities. The committee can be seen as the next step in the steady introduction of foresight into the Dutch research system. In this article the development of foresight in the Netherlands and the experiences of the Foresight Steering Committee are reviewed. In contrast to other countries, foresight in the Netherlands has developed into a highly decentralised process with little top-down co-ordination. The article describes this process and presents methodological experience. Five design issues which are critical for the organisation of a foresight study are elaborated. Some of the advantages and disadvantages of this approach to foresight are discussed. The main advantage is that such an organisation fits in with the strong sense of checks and balances that typifies the Dutch research system. Hence, it would seem that a stable organisation of foresight suits the specific needs of the research system. The main disadvantage of such a process is that it gives little opportunity for explicitly developing a national research strategy.

The current international discussion on foresight focuses on broad national exercises, aiming at the identification of emerging technologies and research priorities. When taking part in the discussion, it is easy to forget other possibilities of foresight organisation. Martin and Irvine (1989), in their seminal work on foresight, *Creating the Future: Foresight in Science,* presented a typology of foresight based on seven dimensions, each dimension having from two to seven possible values. Narrowing the discussion on foresight to only a few of the items of this typology should be avoided for two reasons:

- First, the quintessence of a successful foresight exercise is not the application of a technique, but the design of an exercise which fits the specifities of the national innovation system. Hence, foresight exercises should be tailor-made. Differences in approaches and methods are necessary learning experiences and will be more effective than standardisation in the long run – despite the inherent risks of failure.
- Second, the general function of foresight is to provide the information necessary for the development of strategic policies. In a national system of

innovation, the various actors may have different strategies. Government might concentrate on emerging technologies in order to keep pace with the global technology race. A university might concentrate on stimulating scientific quality and improving its resource position. The information needed to develop such strategies may overlap, but it is certainly not identical.

In discussions on foresight, the Japanese Delphi studies are often cited as the guiding archetype within the foresight paradigm. However, the strength of Japanese foresight lies in the fact that foresight has penetrated the entire national system of innovation, and in the complementarity of foresight activities at all levels of the innovation system – the national level being only one of those levels.

"[It] is clear that the integration of research foresight activities at different levels has brought [Japan] significant advantages. Holistic exercises like the STA thirty-year forecast give a comprehensive overview of the emerging trends and opportunities, informing the national policy guidelines set by the Council for Science and Technology as well as the macro-level foresight undertaken by individual agencies like MITI in producing periodic sectoral visions and other scene-setting exercises. The latter provide a context for more focused meso-level foresight which is often oriented to identifying promising research opportunities. [...] Foresight at a micro-level is more closely linked to such decisions and is often conducted within a framework for establishing consensus not only on priorities but also on the technical goals for research." (Martin and Irvine, 1989, p. 172.)

The Netherlands have a relatively long tradition of foresight, in both science and technology. For a long time most foresight studies were organised at the field level – a field being either a discipline, a technology or a sector of society. In general, these field-focused foresight studies aimed at the identification of new scientific and technological developments and the linkage of these developments to societal needs. More recently, the integration of these field-focused foresight studies has become an issue because of the objective of setting national priorities and posteriorities for public S&T efforts. In 1992 a Foresight Steering Committee was set up by the then Minister of Education and Sciences to co-ordinate foresight studies and integrate results. Nevertheless, heterogeneity in foresight studies continues as the information needs of the actors in the field for which the foresight exercise is being carried out are still more important than the need for the integration of results.

In this article I will use the experiences of the Dutch Foresight Steering Committee (FSC) to review the organisation of foresight activities in the Netherlands and to discuss the pro and cons. At present, the Foresight Steering Committee happens to be the central actor in foresight in the Netherlands. Its organisation, role and functioning is in interesting contrast to other foresight processes:

- it has organised a highly decentralised process, with little management;
- it has a time schedule of four years;
- it has no dominant methodology, but uses a mix of approaches;
- it is deeply entrenched in existing science policy processes and structures.

In order to understand the context in which the FSC operates, Section II presents a short history of foresight in the Netherlands, followed by an overview of the experiences of the FSC (Section III). The overview starts with some general information about the FSC, its activities and the methods used. Next, criteria for the design of foresight studies are listed (Section IV). The concluding section critically evaluates the value added of the FSC by comparing the initial aims with the expected results.

II. A DUTCH HISTORY OF FORESIGHT

Dutch science and technology policy has had long experience with field-focused foresight (*verkenningen,* in Dutch). From the seventies onwards, one can point to both successful and unsuccessful foresight exercises and programmes in Dutch science and technology policy. Most of these studies were carried out by *ad hoc* panels focusing on developments in a specific area, discipline or technology. As a policy instrument foresight has been accepted for many years. Nevertheless, until recently, there was very little methodological or institutional stabilisation.

One of the reasons for this is that the objectives of *verkenningen* changed with changes in science and technology policy. To avoid confusion it is sometimes appropriate in this review to use the Dutch words *verkenningen* and *Verkenningscommissies* instead of the English terms "foresight" and "foresight committees". In Dutch science and technology policy, the term *verkenningen* is not limited to just foresight. Rather speculatively, it could be claimed that foresight was able to mature despite policy changes, budget cuts and other disturbances in the relationship between government and research organisations precëisely because it comes within the broader category of *verkenningen.*

In the mid-seventies the first attempts at foresight were initiated as part of the objective of linking scientific research to social issues. *Verkenningscommissies* were set up to advise on research in education, science for policy and spatial planning. Although the reports invoked some discussion on the development and organisation of these fields of research, the effects were limited. With hindsight, the reports had little to do with foresight as it has developed over the last few years. However, from these initial attempts, three strands developed which were important for the development of foresight in the Netherlands, and which still continue.

Foresight was originally included in the mandates of sectoral advisory councils for research. A National Council for Agricultural Research already existed and other councils were subsequently created.[1] The policy importance of these councils derived from their emphasis on co-ordination and the diagnosis that science policy-making was being hindered by the strong vertical linkages between government departments as patrons and "their" research clients in public research institutes, universities and sometimes also in industrial research and development. In order to overcome the biases inherent in such on-going interaction, sectoral advisory councils for research now have a tripartite composition of researchers, research users and government officials.

Only five Sectoral Advisory Councils have survived: those devoted to agricultural research, environment and nature research, development-related research, health research, and physical planning research. The Council for Energy Research was not able to find a niche for itself and was discontinued around 1980. A council on sea research was recently discontinued. A council for research for industry was proposed at the same time as the policy instrument, but was never set up. However, recently, the creation of a sectoral advisory council for chemistry has been proposed.

The remaining Sectoral Advisory Councils are quite successful, although they have no research funds to allocate and thus depend on their quality of foresight and their relation with funders (that is Ministries with research budgets for the respective sectors). They prepare quadrennial reports giving information on overall policy and research directions. Their main impact is through a variety of studies published in the interim, and the interactions and networking that are part of foresight activities. The main reason for the success of these institutions is that they provide a forum for interaction, mutual positioning and agenda building. In Dutch political and scientific culture, this has given them a viable role, despite some criticism that the reports are too general and not implementable.

The second strand of foresight studies developed in the context of technology policy. Initially, in the early eighties, technology foresight was implicit in the selection and preparation of *innovative oriented research programmes.* The goal of these national programmes was to stimulate strategic research in promising technological areas. In the late eighties, technology foresight became a separate activity, aiming at improving government technology policy and stimulating industry awareness of new technological developments. Within technology policy, foresight is linked to issues such as "globalisation", international technological competition, and the support of technological innovation in SMEs (Van Dijk *et al.,* see this issue).

The third strand of foresight developed mainly in the context of science policy for the sciences, but appeared to be sensitive to the changes which took place in the policy relationship between government and the universities. At the end of the seventies, science policy became more discipline-oriented and *verkenningscommissies* on chemistry, physics, biochemistry, biology and, later, biophysics and mathematics were set up. These committees were mainly made up of academics, and their reports focused on university research. As far as foresight was part of these exercises, all the reports claimed that research in the area was of great social and industrial relevance considering the development of science and society. However these claims were global and provided few opportunities for a research policy apart from merely increasing the budget. Although the Ministry put pressure on each committee to be outward-looking and selective in its claims, the committees set very few priorities and concentrated on university research.

Moreover when, in the eighties, Dutch university funds were severely cut back, some of the *verkenningscommissies* became even more linked to university policy. "Evaluation" became a major part of the activities of the committees, and the element of prospective analysis was reduced to almost zero. Indicative of this change is the fact that committees set up in the mid-eighties with the explicit task of evaluating university research and implementing budget cuts in the areas of the humanities and the social sciences were also called *verkenningscommissie.*

At the end of the eighties the science policy department of the then Ministry of Education and Sciences re-implemented foresight as a policy instrument for science policy. The department commissioned several studies and eventually decided to set up a Foresight Steering Committee to co-ordinate and initiate foresight studies and advise on results.

In addition to these three strands visible within the research system from the early eighties onwards, a fourth strand developed in the early nineties. For several reasons the two national research organisations – The Netherlands' Organisation for Applied Scientific Research and The Netherlands' Research Council – initiated foresight processes to improve their own research policy. Both were more or less forced by the government to articulate their strategies more explicitly as the allocation of resources became linked to a *strategic dialogue.* In addition, The Netherlands' Organisation for Applied Scientific Research has become more dependent on contract research, and foresight has become a necessary part of its marketing research. In the case of The Netherlands' Research Council, foresight has become a necessary tool to fulfil its mission as a research council responsible for setting the national research agenda and improving the quality and relevance of research.

Verkenningen and foresight are only one aspect of the history of Dutch science policy. An overall picture is beyond the scope of this article, but it should be stressed that the way foresight has developed and is organised more or less reflects the typical pattern of the Dutch research system. The Netherlands' research system has fewer top-down characteristics than that of France, the United Kingdom, or even Germany.[2] There are a great many institutions, councils, as well as independent bodies (which also have to be taken into account), which contribute to agenda-setting, mediate between resource allocation and performance of research, and oversee parts of that research. All national research systems have today an "intermediary level" between the "top", *i.e.* the state with its responsibilities for funding, structure of the system, and authoritative goals, and the "bottom", *i.e.* the research performing institutions. In the Netherlands, the intermediary level is crowded and appears to function well (even if a lot of time has to be spent on consultation and mutual accommodation) (Van der Meulen and Rip, 1994).

Balances between organisations differ from field to field. In some, such as physics, scientists and their research organisations take the lead. In others, strategy development is an interactive process between science and industry. In agriculture and environmental research, the respective ministries hold a strong position. These differences imply a complex overall system of checks and balances, with little possibility of central co-ordination or national priority setting. Even The Netherlands' Research Council, which claims the role of setting national research strategies – and is probably in the best position to do so – can only set priorities within its own budget.

III. THE FORESIGHT STEERING COMMITTEE

In the eighties *verkenningen* within the third strand moved away from foresight activities towards a role of evaluation and policy advice. In order to improve the prospective element in the *verkenningen,* several studies were commissioned in order to assess possible foresight schemes. The Foresight Steering Committee was established in May 1992 by the Minister of Education, Culture and Sciences.

Formally, the Foresight Steering Committee has two tasks. Its first task is to shape and supervise a foresight process which has the support of all the relevant parties – particularly researchers, research organisations and universities, research users, government departments and intermediate bodies. In addition to this co-ordination function, the committee integrates the results of all foresight activities and advises the Minister of Education, Culture and Sciences on options for its science and technology policy.

Initially, these tasks were considered to be complementary. However, in its first option paper, the committee reported the tensions between the two: "*...members were aware of the potential problems that could crop up between the* *committee's general consultative function and its task of indicating specific options.*" (Foresight Steering Committee, 1992)

The committee tried to relieve this tension by giving priority to the first objective and adding the objective of developing a framework for appropriate foresight activities. Nevertheless, in policy documents the government still stresses the second objective. In his recent *Science Budget* (which also contains a overview of current science policy issues), the Minister made himself dependent on the foresight process by announcing the advice of the Foresight Steering Committee on most issues. So, the tension remains and is still visible in current practice.

The tension became particularly manifest at two periods. First when the government issued a new law on university funding which gave the Minister some discretion to set priorities on the basis of the outcome of the foresight process. Committee members were criticised by colleagues for serving the government in intervening in universities. The second occasion was when the new government announced new budget cuts in university funding. At that time the Foresight Steering Committee faced some reluctance by the research community to co-operate in foresight. Researchers feared that a foresight committee would again take the role of co-ordinating budget cuts, rather than that of foresight.

The committee consists of 13 members. It is chaired by a former deputy director of the science policy department of the Ministry of Education, Culture and Sciences and former member of the Scientific Council for Government Policy. The majority of the members are university professors and Board members of universities and bodies at the intermediate level, such as the research council or the Royal Dutch Academy of Arts and Sciences. Only one member is from industry, and two are from the Board of The Netherlands' Organisation for Applied Scientific Research. The committee has a small staff of three employees (full-time equivalent), including the secretary.

The committee's scope is broader than simply carrying out technology foresight. It has also initiated foresight activities in medical research, the social sciences and even some in the humanities. Although its focus should be on both science and technology, it is currently more oriented to science policy and to universities as the main research organisations. In addition to several *ad hoc* round tables, extensive foresight activities have been initiated for chemistry, energy research, medical research, geology, agricultural research, "traffic and transport", economic research, law studies and educational research. Foresight exercises are in preparation for micro-system technology, manufacturing technology, "information and communication", and biology.

The responsibility for these foresight studies has been delegated to committees and organisations in the field in which the foresight exercise is being carried out. The committee has a budget to initiate and support foresight studies, but the aim is to make those involved in the foresight activity as responsible as possible. In the same way as programming and evaluation, foresight should be considered as a necessary component of research policies and should not be imposed on the research community from the outside. Partners in the field-focused foresight studies include Ministries, advisory councils for research, The Netherlands' Research Council, the Royal Academy of Arts and Sciences and also, recently, the Society of Dutch Companies.

In December 1992, in its first report, the committee described a methodological framework for future work and presented the results of some round tables on current science policy topics. The second report was issued in May 1994 and reported first experiences as well as some results. Although some of the conclusions are stated affirmatively, the text is an interim report. The final report of the committee is expected in May 1996, at which time not all the foresight activities will have terminated. The committee has recently deliberately initiated new foresight activities in order to avoid an interruption in the foresight process. One of the comittee's objectives was to initiate an ongoing process.

IV. A FRAMEWORK FOR DESIGNING FORESIGHT STUDIES

In its first six months of existence the committee developed a framework for foresight activities designed to overcome the major problems of earlier foresight studies: less selectivity in priority setting, and too inward looking. In addition it was hoped that the framework would enable different areas of science to be weighed against one another. However, an internal attempt by the committee to use the framework to weigh different areas failed and, in its second report of May 1994 the committee was more modest about its ambitions to set priorities *and* posteriorities among fields.[3]

Two guiding principles are at the core of the framework. The first is that the selection of research priorities should be based on an analysis of the value of research for society. This implies that an essential component of the foresight studies should be the assessment of the possible contribution of research to socio-economic objectives. To structure these analyses, the possible value of research is captured by three key words:

- *Knowledge base:* indicating the necessity of research to promote good education and training and for keeping up at international level so that scientific and technological developments from abroad can be absorbed rapidly.
- *Core activities:* indicating that research might contribute to the functioning and innovative capacity of profit and non-profit sectors of society.

- *Societal issues:* indicating that research might contribute to the understanding, handling or even solution of societal issues such as sustainability, globalisation of economies, unemployment, development of Third World countries.

The gist of this concept is that, on the one hand, it forces scientists and research organisations to think about the way they should, could, or do contribute to society, and about ways to improve that contribution. On the other hand, it prevents scientists (and sponsors!) from too eagerly relating research to *ad hoc* problems and forgeting the knowledge base. Balancing long-term and short-term relevancy is one of the crucial aspects of research policies aiming at increasing interaction between researchers and users of research.

The concern about long-term relevancy leads to the second guiding principle: the aim of stretching the time horizon of research strategies; the uncertainty of future developments; and, thus, the necessity for flexibility. From the methodological point of view, this has translated into the adoption of scenario methods developed by Group Planning of the Shell company. Typical characteristics of this scenario method are:

- Scenarios are written in the context of the area for which a foresight exercise is being carried out. A foresight activity should increase sensitivity to possible external developments.
- Generally, three scenarios are prepared, rather than just one or two. Using one scenario suggests too much predictability in the future. The use of two scenarios encourages participants in the foresight exercise to keep to the middle of the road.
- The result of a scenario exercise is not expert advice, but rather sensitivity to possible developments and *options* for research strategies. The responsibility for the possible implementation of these options is left to the actors concerned. They are also informed about other factors shaping research strategies, such as research capacity and competencies, budget constraints and institutional developments.

The framework is used as the starting point for considering what a sensible foresight process would look like in a particular field. As the committee itself states: "the framework is not a pre-determined law because every foresight study is, and remains, tailored to the specific situation and requirements in a scientific field." The bodies conducting the current field-focused foresight exercise have the power to programme the foresight process in an autonomous way. As a result, the scenario analyses differ, and the "Shell approach" is not always chosen.

Due to the shift in focus from a central framework to the specificities of the field in which the foresight exercise is to be carried out, methodological attention has also shifted to design criteria for foresight studies. At least five critical design issues can be identified, each of which should be addressed in order to increase the likelihood of a successful foresight exercise.

Design question 1: On what field and on what actors does the foresight exercise focus?

The goal of a foresight study aims is to inform the actors as to possible relevant future developments. In order to write appropriate scenarios for these actors, it is essential that the objective of the foresight activity and the focus actors are well defined. For instance, the approach is different when the foresight of "chemistry" focuses on the chemical industrial sector and its research needs, or when it focuses on chemical research and its possible contribution to society. In the first case, contributions of research from transport technologies, mechanical engineering, international business studies should be assessed, together with those from certain domains of chemistry. In the latter case, the chemical industry is only one of the sectors to which research contributes, along with the food industry, the drug industry and national and international environmental policies.

Design question 2: What are the key problems encountered in formulating research priorities?

One of the main reasons for stimulating research organisations to improve their strategies is the need for priority setting. The question, then, is why these priorities have not already been set, and why external pressure from government or a foresight steering committee is necessary to induce the process of priority setting? A trivial reason is lack of foresight competence or resources to organise such a process. After all, foresight results can be considered as public knowledge which should be organised in the public domain.

However, conflicts of interests, institutional problems, conservatism or reluctance to face expected consequences might be other reasons explaining why priorities have not been set. In this case, merely initiating a foresight process and adding additional information might not be sufficient to improve research strategies. In the foresight process, steps should be built to deal with such barriers. In some cases this might imply that audit-like exercises or institutional reorganisations are more pertinent than a foresight study.

Design question 3: Who should implement the results of a foresight exercise?

Foresight results are intended to act as input in strategic policies – but whose strategic policies? The easy answer is the strategic policies of *all* the actors in the national system of innovation: governments, industry, research laboratories, universities, the public, etc. However, if research agendas are to be affected, it is obviously appropriate to concentrate on those actors that set the agendas. These are the focus actors in the foresight process. Consequently, the kind of information that is processed, the actors invited to discussions, round tables, etc., and the way results are reported, depend on the choice of the focus actors.

Design question 4: Who is competent to articulate (industrial) research needs?

The guiding principles set out in the framework developed by the Foresight Steering Committee imply that competence in articulating the research needs drawn from the scenarios is crucial. Current science and technology policies often take it for granted that research users are capable of articulating their needs. However, in the current processes so-called users are often selected for their social status, rather than for their experience in using research. Moreover, articulating research needs for science and technology policies requires a time horizon which is often not possible in industry or in society at large. In certain areas – especially those that are clearly driven by science and technology – scientists might be best capable of articulating research needs.

Design question 5: What information is needed and how should it be obtained?

Foresight processes are essentially information processes and the selection of proper methods of information gathering and processing is essential for a valid and legitimate outcome. Note that such methods as Delphi techniques, scenario studies, round tables and questionnaires are also essentially aimed at the exchange of relevant information. Sometimes the primary aim of these methods is to elicit expert knowledge from a dispersed community. In other cases, the methods are used to diffuse information and create awareness or breed consensus. Each of these objectives has implications as to which techniques are chosen, and how and when they are used.

Of course, the answers to these design questions differ from case to case. What is interesting is that in order to answer these questions, in-depth knowledge of the foresighted area must be combined with foresight expertise. If one of these areas of expertise is lacking, the result is a foresight process that is either frustrated by methodological faults or is too superficial to bring any value added to the strategic information already known to the focus actors.

V. IN CONCLUSION: RESULTS AND PROSPECTIVES

The Foresight Steering Committee of the Netherlands was set up within a research system in which the idea of foresight was accepted, but which lacked institutional and methodological stability. The Foresight Steering Committee has succeeded in creating this stability. Because of the thickness of the intermediate level, it is difficult to claim a certain function, especially in the case of newly created bodies. However, institutionally, the Foresight Steering Committee has evolved to become the "natural" actor in the initiation and co-ordination of foresight studies.

The framework it has developed has also proven its worth. Experience thus far indicates that the scenario method is sufficient to stretch the time horizon of the participants in the foresight studies. Moreover, the conceptualisation of the possible contribution of research to socio-economic objectives has been an impetus to the external orientation of foresight processes. Those involved in the studies now have a shared paradigm in which different views and options on the relevance of research can be discussed and in which research needs can be articulated.

The shift from a foresight process aiming at setting national priorities to a decentralised process aiming at improving research strategies at the organisational and field levels has some clear advantages. The foresight processes can be designed according to the information needs and problems of those actors able to influence research agendas. Therefore, it is likely that the results can be implemented at the level of research organisations and thus affect research agendas. The most important advantage, however, is that, through the direct involvement of key actors in the foresight process, foresight has become an integral part of their research policies. This, in the long run, is the best guarantee of good research policies.

However, the disadvantages should also be mentioned. First, it is obvious that decentralisation hinders the development of national strategic research priorities. It can be argued whether national research strategies to which all actors in a national innovation system have to conform are to be preferred. It has become clear that the foresight process will contribute less to such a strategy than was originally expected.

A second disadvantage is that decentralisation gives many opportunities for obstructing foresight initiatives to those unwilling to co-operate. The experience of the Foresight Steering Committee when the government announced budget cuts illustrates the fragility of the relationship between government and researchers, and how far the ultimate success of a co-ordinated foresight exercise depends on this interaction.

In May 1996 the committee will issue its third report, in which it will integrate several foresight studies and draw conclusions at the national level. Of course, it is beyond the scope of this article to draw out the main contents of this final report. However, one of the issues will be the future organisation of foresight in the Netherlands. The mandate of the committee ends at the end of 1996. It is certain that co-ordinating foresight activities will remain a function of the national innovation system. Within the past few years foresight has developed as a means of improving the self-organisation of the national system of innovation. If the government wants to maintain one of the main strengths of this system – that is, its sensitivity to the need for checks and balances – it will support decentralisation of foresight studies and locate the responsibility for the co-ordination of foresight at the intermediate level. However, pleas for a national research strategy and an increase in top-down steering in the research system can still be heard. If foresight were again to be linked to these ambitions, most of the efforts of the Foresight Steering Committee will have been rather useless and, with hindsight, will probably be judged as a failure.

NOTES

1. The National Council for Agricultural Research has been in existence since the mid-fifties as a "participants organisation", *i.e.* an organisation set up jointly by government, researchers, and users of research, rather than a council established by the government.
2. In an article on the development of research systems, Rip and Van der Meulen (1995) have identified several research systems according to the extent to which the institutional infrastructure was geared to "steering" research to certain goals and the extent to which it suited the aggregate socially distributed agendas. Like Japan, the Netherlands ranks high on aggregation and low on steering.
3. Remarkably, in the Netherlands there is a lot of support for the idea to complement priorities with *posteriorities.* It is clear however that legitimation for priorities is much easier to obtain than for posteriorities, not only socially, but also cognitively: if a certain unpredictability in science is found to be inevitable or even valuable – which I think it is – it is difficult to claim that certain research is not worthwhile.

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TECHNOLOGY FORESIGHT IN THE UNITED KINGDOM

CONTENTS

This article was prepared by Grahame Walshe of the Office of Science and Technology, United Kingdom.

I. INTRODUCTION

The United Kingdom Technology Foresight Programme was first announced in 1993.[1] In June 1993 a Technology Foresight Steering Group, chaired by the Chief Scientific Adviser at the Office of Science and Technology, was appointed. Work started on increasing awareness of foresight during the autumn of 1993. Then, in the first months of 1994, 15 sectoral panels were appointed to undertake the main analytical phase of the Programme over 1994-95. These 15 Foresight panels reported their findings in March-April 1995. Thus, Technology Foresight is fairly new in the United Kingdom; but a few general lessons have already been learned and they are worth recording.

First, the optimal design of national foresight processes will to a large extent depend upon ultimate objectives. In the United Kingdom the objectives enshrined in the White Paper (Chapter 1) are *wealth creation* and *improvements in the quality of life* and these imply an expectation of action to implement Foresight findings. All of the people who have been engaged in Foresight *analysis* in the United Kingdom, having completed their initial assessments of future trends and technologies, are now involved in action to take forward their findings.

Second, very few impartial observers believe that accurate technological predictions are possible. This is primarily because developments on the demand side (needs and wants) tend to dominate over supply side developments (scientific and technological possibilities); and these demand trends are difficult to predict in terms of content, scale and timing. There are several different futures possible and the preferred strategy seems to be to "map" the actions which will help us to reach the future position which seems most desirable. Many corporate foresighters thus talk about developing "Foresight Roadmaps" which can be regularly updated as new routes become possible and new destinations appear to be desirable.

Third, the members of a UK Study Visit to Japan in March 1994 were very impressed by the four levels of foresight in that country:

- the holistic overview provided by the Delphi surveys conducted by the National Institute of Science and Technology Policy (NISTEP);
- the Departmental initiatives of MITI and other government bodies;

– the “association” foresight exercises, grouping together corporations and other interested bodies; and
– foresight in individual firms and, indeed, within divisions of firms (such as NEC).

These several different levels of foresight, each connected with the others by means of overlapping personnel, provide a very powerful communication and awareness framework. The United Kingdom is trying to encourage similar developments as one aspect of its Programme. It hardly needs adding that each level of foresight has different implications for subsequent policy actions.

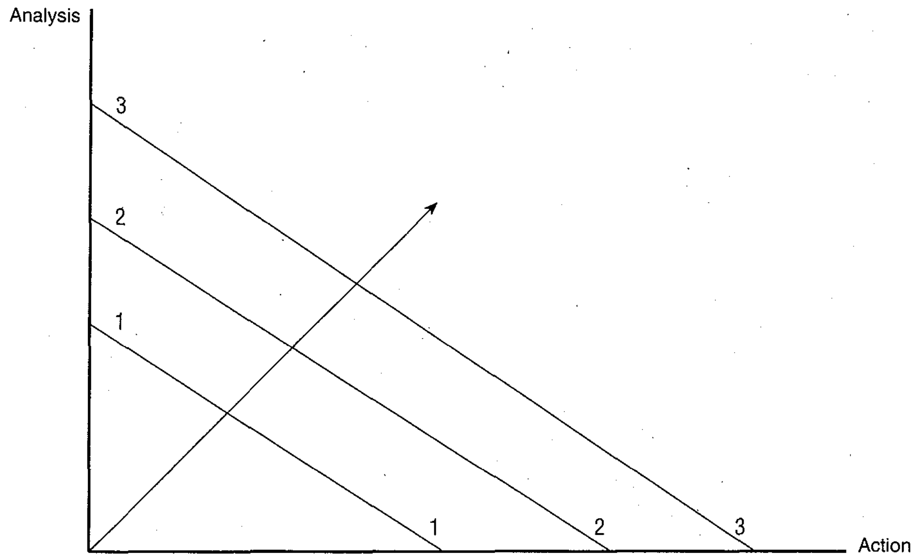
Fourth, while the first three points above emphasize *action,* there must be a high standard of analysis preceding action, otherwise costly mistakes might be made. Up until fairly recently the UK Foresight Programme has been concerned with analysis. However, there can be little doubt about how Foresight results will be employed; as the White Paper said [para. 1.18 (2)]: “Technology Foresight, jointly conducted by industry and the science and engineering communities, will be used to inform Government’s decisions and priorities.”

In general, it may be supposed that national foresight systems differ in terms of their *analytic* and *action* content. Some countries prefer to emphasize careful analysis with elaborate consultative processes and fine-tuning of findings to reflect all shades of corporate and academic opinion. In contrast, other countries seek to stress the actions required to engage large and small firms in implementing foresight findings quickly and resolutely. While countries will be placed at different points along an analysis-action continuum, *all* countries will want to improve their foresight processes over time.

The country foresight “map” might be as in Figure 1. The United Kingdom is shown as maintaining a useful balance between analysis and action; and it is hoped that, over time, the United Kingdom can improve its Programme – its credibility, visibility and impact. Other countries may wish to decide where they are located on this foresight map. The precise processes and methods for undertaking foresight will clearly differ by country.

Economists working on national systems of innovation tend to conclude that innovation is location – or country-specific. That is, each country’s pattern of innovation activity is related to its own institutional structure, the strength of its academic establishments, the standing of the independent contract S&T sector, the ability of government to define and implement a coherent S&T agenda, and so on. That is true also of foresight which may be regarded as but one part of the “glue” binding together national innovation systems. It may be observed that some foresight methods lend themselves more readily to subsequent policy

Figure 1. **A foresight map**



Source: Author.

actions. For example, scenario analysis can easily be extended to specify the steps which must be taken in order to achieve desirable outcomes.

II. THE UK PROGRAMME

The UK Foresight Programme started with an awareness phase in 1993. This entailed mounting a series of regional seminars to discuss possible methods and begin constructing a database of those individuals and organisations interested in participating in the Programme. This phase of the Programme has been reported separately in two methodological publications.[2]

Subsequently, 15 sector panels were appointed in early 1994 to organise foresighting in a broad range of economic activities, including the key service sectors of *financial services,*retail and distribution, and *leisure and learning.* The inclusion of these three sectors – responsible for up to two-fifths of GDP in the United Kingdom – is seen as a distinctive feature of the UK Programme, and

Figure 2. **Foresight sector panels**

Agriculture, natural resources and environment	Health and life sciences
Chemicals	Information technology and electronics
Communications	Leisure and learning
Construction	Manufacturing, production and business processes
Defense and aerospace	Materials
Energy	Retail and distribution
Financial services	Transport
Food and drink	

Source: Author.

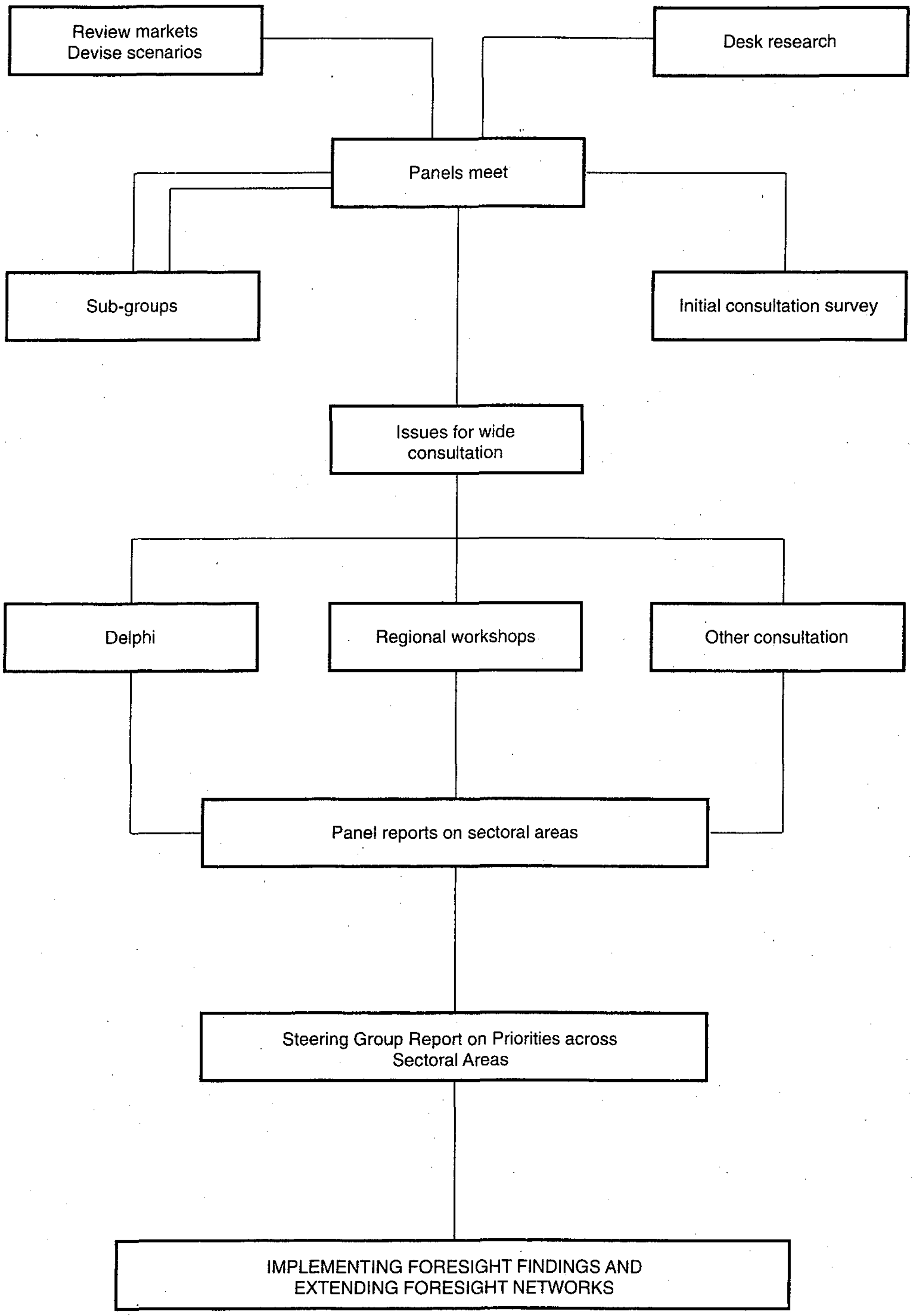
exemplifies its market (rather than technology) orientation. Figure 2 lists the 15 foresight sectors.

The fifteen foresight panels had a mixed membership of business, academic and government experts. They used an eclectic approach to foresight methodology with only loose central control of the precise methods adopted. It was thought inappropriate to try to force such a diverse set of sectors to embrace a centrally determined methodology. Nevertheless, there were four elements of the Programme which all foresight panels employed, namely:

- An initial survey of trends, products and technologies which helped the foresight panels assess their ideas on future demand and supply side possibilities. This was very helpful in developing issues for discussion during the consultative phase of the Programme.
- A Delphi survey which consulted the business and academic communities on the likelihood of key developments over the next 10-20 years, and elicited opinions on the need for collaboration, UK strengths and weaknesses, and possible constraints on developments.[3]
- Regional workshops also designed to consult on the key issues.[4]
- A final report of panel findings specifying priority recommendations for action.[5]

Figure 3 sets out in diagrammatic form the broad structure of work carried out by the foresight panels.

Figure 3. **Main foresight stages: March 1994-March 1995**



Source: Author.

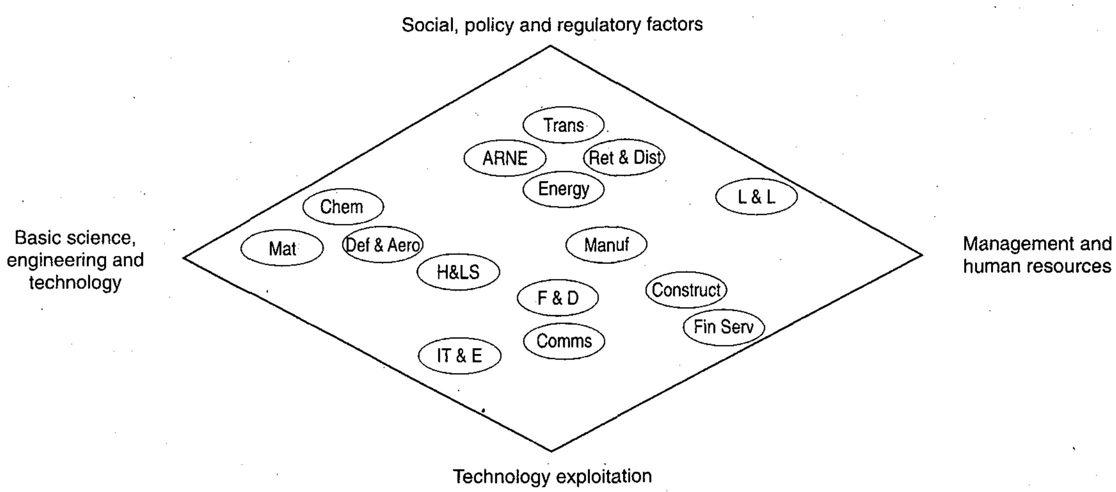
III. FORESIGHT PANEL FINDINGS

There were over 350 recommendations made by Foresight panels so there is a considerable challenge in devising a coherent implementation programme. The Foresight panels concluded that in order to improve wealth creation and quality of life a wide range of actions would need to be pursued:

- some of these proposed actions are expressed as *science, engineering and technology* (SET) priorities;
- but many other priorities seek to develop *workforce skills;* or
- to *transfer and exploit already available technology* more widely throughout the economy; and
- to *reshape social, policy and regulatory frameworks.*

Figure 4 shows how each of the Foresight panels might be positioned in respect of these four themes. For example, it is clear that the Financial services sector would benefit greatly from advances in security and privacy technology to combat financial fraud; but it is also imperative that the sector fully exploits the information technology already at its disposal (*e.g.* in neural networking) and to do

Figure 4. **Principal sectoral drivers**



Note: The four corners of the diamond represent the main sectoral drivers, all of which impact on each sector. The relative position of a foresight sector indicates the most significant drivers influencing wealth creation and quality of life in that sector.
Source: Author.

that it needs a ready supply of technologically adept and IT-literate people for its workforce.

IV. FORESIGHT STEERING GROUP

The Foresight Steering Group was charged with extracting general conclusions from the 15 panel reports and making recommendations. This was not a straightforward task because the foresight panels had already performed a thorough assessment of the main market and technology trends over the next 10-20 years. The Steering Group did not therefore see a need to subject the work of the panels to critical appraisal – after all, the panels were composed of, or had consulted, the leading experts in each field. Rather, the Steering Group sought to add value to the work of the panels by drawing out generic themes from the various priorities put forward by panels. A generic topic has been defined as:

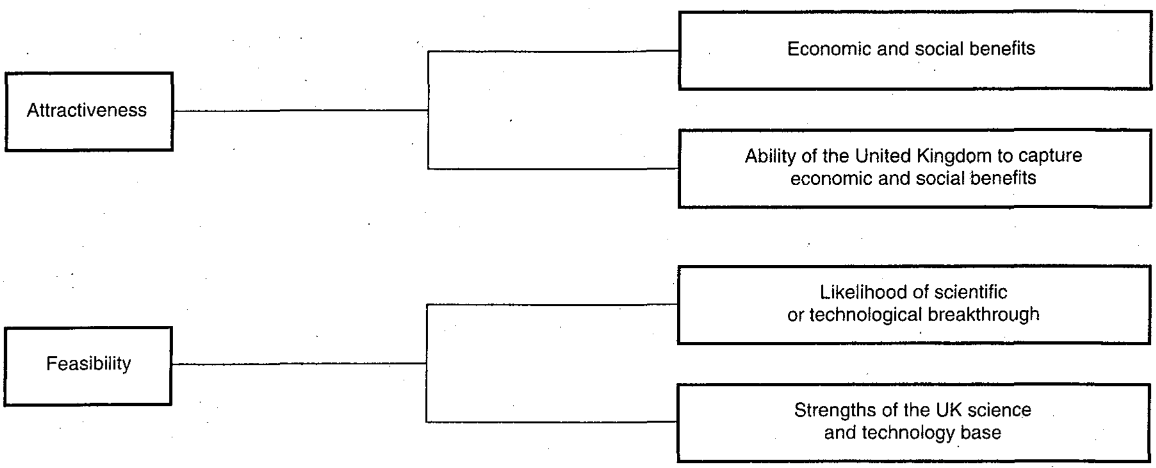
> **"a concept, component, or process, or the further investigation of scientific phenomena, that has the potential to be applied to a broad range of products or processes."**[6]

These generic topics arose largely as cross-sectoral issues and as the most common priorities which a number of panels independently identified. The topics range from those recommended by the majority of panels – for example, sensors and remote monitoring devices – to those where only two or three panels have prioritised action – for example, diet and health.

The Steering Group was helped in its work by using the prioritisation criteria devised by foresight colleagues in the United States and Australia, namely, *attractiveness* and *feasibility* criteria. These are shown in Figure 5. The criteria are intended to suggest where the most propitious demand-side circumstances might apply; and where the balance of probability suggests a supply-side breakthrough might occur. The criteria also require a considerable amount of benchmarking material to be gathered together in respect of both the business and the academic communities.[7]

The Steering Group identified some 27 generic science, engineering and technology (SET) priorities in three broad categories: key, intermediate and emerging. Familiar topics in the fields of biotechnology and information technology have been given top priority status alongside less familiar topics such as *security and privacy technology* (to counter the very rapidly growing crime industry, particularly financial crime) and *management and business process engineering,* where the United Kingdom must remain competitive with world leaders. Figure 6 shows all twenty-seven generic SET priorities.

Figure 5. **Steering group prioritisation criteria**



Source: Author.

Figure 6. **Generic priorities in science and technology**
Relative assessment of attractiveness and feasibility

Key priority areas	Bioinformatics Communicating with machines Genetic and biomolecular engineering Health and lifestyle Optical technology Security and privacy technology Sensors and sensory information processing Software engineering Telepresence/multimedia
Intermediate areas	Catalysis Chemical and biological synthesis Design and systems integration Environmentally-sustainable technology Information management Management and business process engineering Modelling and simulation Risk assessment and management Workplace and home
Emerging areas	Automation Biomaterials Clean processing technology Demographic change Energy technology Materials Materials processing technology Process engineering and control Product and life cycle analysis

Source: Author.

The Steering Group also identified eighteen infrastructural priorities. These ranged from action to improve the training of teachers – especially in mathematics and physics, where it is believed that the young have become disenchanted with these subjects primarily because of poor teaching – to improvements in regulatory frameworks, for example, in copyright protection and the communications infrastructure. Clearly, there will be a need to obtain commitment from a wide variety of government departments if these priority recommendations are to be more than just a "wish list".

V. IMPLEMENTATION ACTIONS

As suggested at the outset, the UK Programme is characterised by a strong focus on follow-up actions. It is believed that determined and vigorous implementation of foresight priorities will achieve important objectives, namely:

- increase the *visibility* of the Programme, perhaps engaging the wider public audience;
- obtain *credibility* for the foresight exercise among key decision makers in industry and academia;
- sustain the continuing *commitment* of the Foresight panels and the broader foresight community to the process; and
- contribute to increased *wealth creation* and improved *quality of life.*

There are seven points to make about the follow-up action currently achieved or underway:

- All the *Foresight panels* will remain in being with a revised remit. The new remit has an emphasis on dissemination and partnership-building appropriate to the implementation stage.
- *New funding for foresight:* an additional £6 million for the LINK[8] programme to reflect foresight priorities was announced in February 1995. Since then, seven new LINK programmes reflecting foresight priorities – for example, *applied biocatalysis, waste minimisation in industry,* and *improved exploitation of hydrocarbon reservoirs* – have been announced.
- An extra £40 million has been set aside for a *Foresight Challenge.* With the matching private sector contributions this will amount to at least an extra £80 million injected into foresight. The OST consulted on the terms of the Challenge during the summer of 1995. The Challenge was launched in September 1995 and the successful bids for the funds – which will be judged on a competitive basis – will be announced in early 1996.
- *Government departments* will be closely involved in foresight implementation. The Department of Trade and Industry has an extra £70 million to

follow up foresight findings, expand pre-competitive R&D in the light of foresight priorities, and spread the foresight message to SMEs. The Department of Health and the Department of the Environment both have explicit mechanisms for reflecting Foresight in their forward strategic plans. The Ministry of Defence now routinely consults the CEOs of major defence firms to discuss future technology trends; and it has established a new forum with DTI/OST to identify and develop joint civil-defence technology priorities in the light of foresight findings. Each Department of State has been invited to appoint an Action Manager who will be responsible for facilitating the take-up of foresight priorities in policy areas.

- The *Research Councils* have responded enthusiastically to foresight: at the end of June the OST published a first report by the Research Councils on how they are reflecting foresight findings in their forward programmes. For example, the BBSRC and EPSRC are jointly funding a new *bioinformatics* initiative worth £10 million over four years; and the MRC has developed two new LINK programmes – *Integrated Approaches to Healthy Ageing* and *Genetic and Environmental Interactions in Health* – for which it is currently seeking partners.
- *Professional bodies and trade associations* are keen to take foresight forward: the Institute of Materials and the Institute of Physics already have dissemination and implementation plans dovetailing with the central strategy. The Chemical Industries Association and the Royal Society of Chemistry are working alongside the Chemicals panel to seek practical ways of implementing particular foresight priorities. The Institution of Electrical Engineers has plans to disseminate foresight findings through its local centres and to map its sectoral interests across all the foresight panel reports with a view to encouraging selective follow-up actions.
- There will be a *Progress Report* on how foresight findings are being taken up by both private and public sector bodies in December 1995.

These are just a few of the first steps in foresight implementation. A more comprehensive framework for action by a wide range of governmental and non-governmental bodies needs to be specified, with realistic timetables set out over the next two to three years. The real challenges will be to get private industry to engage in fruitful partnerships with academia, and obtain a gradual spread of the foresight culture. This is an ambitious agenda but one which all the foresight partners will relish because the prospective gains are critical to UK prosperity over the longer term.

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4. See Scientific Generics Ltd. and W.S. Atkins (1995), *Technology Foresight Programme: Sector Specific Regional Workshops.*
5. See Annex for a complete list of the final reports published by HMSO.
6. Source: Title 15 of the United States Code of Federal Regulations, Section 295.2(b), under 15 USC 271 *et seq.* and Section 5131 of the Omnibus Trade and Competitiveness Act of 1988 (PL 100-418).
7. For an interesting account of how these criteria were employed in an Australian setting see Australian Co-ordination Committee on Science and Technology (1995), *National Goals and Priority Setting By Government Science and Technology Agencies,* Department of Prime Minister and Cabinet Office of the Chief Scientist.
8. A collaborative programme to invest in pre-competitive R&D.

Annex

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Ad hoc Meeting of Experts on Government Technology Foresight Exercises
OECD, Paris, 14 September 1994

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