NORTH-HOLLAND

Technology Foresight for Wiring Up the National Innovation System

Experiences in Britain, Australia, and New Zealand

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ABSTRACT

Since 1990, technology foresight has spread rapidly. We begin by analyzing the reasons for this before examining the specific political background to technology foresight in the United Kingdom, Australia, and New Zealand. The article analyzes and compares the approaches to foresight in these countries, identifying the strengths and weaknesses of each approach. We then propose a new rationale for technology foresight, which centers on its role in "wiring up" and thereby strengthening the national innovation system, before arriving at a number of conclusions. © 1998 Elsevier Science Inc.

Introduction

We live in a fast-changing world. The last ten years have witnessed dramatic political changes in Eastern Europe, rapid economic development in Asia, and the spread of market liberalization around the world. As a result, we are experiencing increasing global competition. In addition, the related forces of the explosion and convergence of computing, communications and media technologies, and of international deregulation, are reshaping the world economy in as fundamental a manner as at any time in history. One consequence is that innovation, new technologies, and the scientific research underpinning them are becoming more important. Science and technology are now strategic resources to be deployed as effectively as possible. Technology foresight, as we shall see, provides a process for linking science and technology more effectively to wealth creation and improvements in the quality of life.

In this article, we consider experiences with technology foresight in Britain, Australia, and New Zealand. We first look briefly at the changing world context which has brought forth the need for technology foresight before examining the political back-

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Technological Forecasting and Social Change 60, 37–54 (1999)

655 Avenue of the Americas, New York, NY 10010
0040-1625/99/$–see front matter
PII S0040-1625(98)00022-5

ground to foresight in the three countries. The central part of the article involves an analysis of the main foresight exercises in each country. This is followed by a comparison of those exercises including an assessment of their respective strengths and weaknesses. We then put forward a new rationale for technology foresight—based on its role in wiring up the national innovation system so that it can learn and innovate more effectively—before arriving at a number of conclusions.

The Changing Global Context

As a result of economic liberalization in China, industrialization in East Asia, and the political changes in Central and Eastern Europe, there has been a dramatic increase in the number of "players" in market economies in recent years. One consequence has been an escalation in industrial and economic competition. For developed countries, these competitive pressures are accentuated by the enormous differentials in labor costs around the world, ranging from tens of dollars an hour (for total salary costs including the social costs of employment) in OECD countries to one dollar or so an hour in Eastern Europe, down to a few cents an hour in China. Furthermore, these labor-cost differentials are occurring at a time of globalization when firms can easily move production and finance from one country to another in pursuit of the lowest costs. As a result, companies and countries must innovate if they are to thrive, with knowledge-based industry and services becoming more crucial. This, in turn, means that technology and science are assuming ever greater importance. These competitive pressures are especially severe in Australia and New Zealand, situated as they are so close to a number of rapidly growing economies, several with substantially lower labor costs.

Besides globalization and growing economic competition, a second major "driver" is the increasing pressure on government spending. Ageing populations and rising expectations mean that the costs of health care and social welfare more generally have been rising steeply. Yet governments are under political and other pressure to balance their budgets, to decrease public spending as a percentage of GDP, and to cut taxes. In European Union countries, for example, that pressure stems from the sometimes painful efforts to meet the Maastricht criteria for entry into the common European currency (the "Euro"), while in the United States the pressure has come primarily from Congress. With public resources more scarce, the demands for greater public accountability and "value for money" have grown.

Science and technology, with their dependence on public funding, have not been exempt from these demands. At the same time, research costs in many areas have been rising. As a result, no longer can any country afford to try to do everything in science and technology. Choices have to be made. This is especially true for smaller economies like Australia and New Zealand. Hence, what is needed is some mechanism for making choices between competing alternatives in science and technology, and for linking science and technology more closely to the nation's economic and social needs, while recognizing that future developments cannot be simply programed from the present. Technology foresight offers such a mechanism [1].

Third, just as the nature of industrial production is changing with greater emphasis on networks, strategic alliances, supply chains and national systems of innovation, so the nature of knowledge production is evolving. Gibbons *et al.* [2] have argued that the knowledge production process is characterized by growing transdisciplinarity and heterogeneity (in terms of the producers of knowledge) with more of it being carried out in the context of application [3]. It is also becoming apparent that major innovations often occur when previously separate streams of technology flow together [4] or fuse

[5]. These developments point to the increasing need for communication, networks, partnerships, and collaboration in research, not only among researchers but also between researchers and research "users" in industry, government, and elsewhere. As we argue later, foresight offers a means for developing and strengthening those linkages.

In summary: technology foresight has come to prominence during the 1990s because it fulfils a number of functions:

- It provides an approach for making choices in relation to science and technology and for identifying priorities;
- it offers a mechanism for integrating research opportunities with economic and social needs and thereby linking science and technology more closely with innovation, wealth creation, and enhanced quality of life; and
- it can help to stimulate communication and to forge partnerships between researchers, research users, and research funders.

In short, foresight opens up the possibility of negotiating a new and more fruitful relationship or "social contract" between science and technology, on the one hand, and society on the other [6].

Political Background to Foresight in the Three Countries

BRITAIN

In 1983, the UK Cabinet Office and the Advisory Council on Applied Research and Development (ACARD) commissioned the Science Policy Research Unit (SPRU) to carry out a study on the approaches adopted to identifying exploitable areas of science in France, Germany, the United States and Japan in both government and industry. The resulting SPRU report [4] advocated that Britain should learn from overseas experiences with foresight, and in particular from Japan, and should try foresight on an experimental basis. Unfortunately, 1983 was not a propitious time to suggest that the UK government should assume a new responsibility—Mrs. Thatcher being keen to reduce the role of government rather than to add to it.

By 1992 however, the philosophy of the UK government toward technology policy had changed following the replacement of Margaret Thatcher by John Major, and the Cabinet Office commissioned a new study from SPRU. This reviewed technology foresight activities in the UK, and provided a brief update of developments in Germany and the United States (building upon an extensive review of foresight conducted by SPRU for the Dutch Government in 1987–89 [7, 8]). It also identified a number of foresight options for Britain [9]. The following year, a Government White Paper on Science, Engineering and Technology [10] set out the need to link the UK science base more effectively to wealth creation and improvements in the quality of life. It argued that researchers who receive funds from the public purse have a duty to identify potential users or beneficiaries of their research, and to explore with them their longer-term needs in relation to science and technology. To achieve these aims, the White Paper launched a large-scale Technology Foresight Programme, which we examine later.

AUSTRALIA

While, in general, there has been little targeted planning for technology or industry development in Australia over the past 20 years, there has been a recurring concern about the adequacy (or absence) of national priorities for science and technology. This concern has usually been linked with issues regarding the availability and allocation of resources, but it has not, in general, been translated into a strong priority-setting system.

Partly, this is due to the defense put forward by the scientific community, who pointed to the ubiquitous value of basic research and the serendipitous nature of the connection with wealth generation. Other factors include a general government aversion to intervention and a lack of industry interest or pressure. All this has resulted in a reliance largely on structural priority setting to shape the science and technology system—for example, the Cooperative Research Centre scheme, which requires collaboration between universities, government research agencies, and industrial firms but which does not identify specific priority areas.

The recurring concern with priority setting can be illustrated by an examination of the activities of the Australian Science and Technology Council (ASTEC) which, since 1977, has been the primary source of advice to the Commonwealth Government on matters relating to science and technology. In the 20 years of its existence, ASTEC has examined issues of national direction and priority setting at a general level no less than eight times (for example, [11]). Yet while some of these reports led to specific initiatives, and priority setting has been adopted within research-funding organizations, no national system of priority setting has emerged [12]. Indeed, the foresight project described below was specifically prohibited from addressing national priorities. This history has strongly influenced the extent and form of the introduction of foresight into science and technology planning in Australia.

NEW ZEALAND

Beginning in the late 1980s, there has been a radical restructuring of the New Zealand S&T system, largely in pursuit of the government policy of separating suppliers and purchasers (for a discussion of the political and economic background to these changes, see [13]). In the process, the Department of Scientific and Industrial Research (DSIR) was disbanded and replaced by: (a) the Ministry of Research, Science and Technology (MORST); (b) a Foundation for Research, Science and Technology (FORST); and (c) a set of government-owned companies called "Crown Research Institutes." These three have separate functions. The Ministry is responsible for providing policy advice to the Minister of Science, the Foundation disburses resources from the Public Good Science Fund in accordance with Ministerial guidelines (acting as the "purchasing agent" to purchase science "goods" from researchers on behalf of the government and the nation), while the institutes (initially ten but now nine) compete for funds to carry out research likely to benefit New Zealand.

In recognition that the separation of policy, funding, and the execution of research might result in fragmentation and an excessively short-term orientation, a priority-setting exercise was embarked upon in 1992, and this was repeated in 1994–95. The latter led to a Statement of Science Priorities setting out a funding trajectory for each of 17 socio-economic sectors. It was followed by the development of "RS&T: 2010"—the Government's Strategy for Research, Science and Technology in New Zealand to the Year 2010. It relied on the traditional tools of strategic planning—a SWOT analysis, and the formulation of a vision, goals, objectives, actions, and performance indicators. In August 1997, with a new Minister and Chief Executive, a two-year "Foresight Project" was announced to review priorities for "public good" science and technology in the transition to a knowledge society.

The UK Technology Foresight Programme

The UK Technology Foresight Programme (TFP) was launched in 1993 with a budget of approximately £1 million. The aims were (a) to increase UK competitiveness,

(b) to create partnerships between industry, the science base and government, (c) to identify exploitable technologies over the next 10–20 years; and (d) to focus the attention of researchers on market opportunities and hence to make better use of the science base. The program has been organized by the Office of Science and Technology (OST) in cooperation with other government departments, and has involved extensive use of consultants [14]. It has been overseen by a Steering Group made up of leading figures from industry, universities, and government. In addition, 15 panels (again consisting of experts from industry, academia, and government) have directed the foresight efforts in different sectors.

The program has had three main phases. In the first "pre-foresight" stage, a number of "Focus on Foresight" seminars were held to explain to the industrial and scientific communities what foresight is and why it is important, and to seek their views on how best to carry it out. A "co-nomination" exercise was also conducted in which experts were asked to identify other experts in their area. The resulting database was used in helping to determine the membership of the 15 sector panels, and in constructing a pool of experts on whom each panel could draw for information and advice.

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

Let us consider two examples. The Health and Life Sciences panel emphasized four long-term issues: ageing populations, exploiting opportunities from molecular genetics, responding to evolving healthcare structures and health economics, and IT in medicine and life sciences. From their analysis, they arrived at nine key recommendations relating to infrastructure development, integrative biology, neuroscience and cognitive sciences, ageing, genetics in risk evaluation and risk management, drug creation and delivery, advanced recombinant technology, diagnostic applications of molecular biology, and medical information technology. A second example is the Construction panel which again focused on four long-term issues—cost reduction and international competitiveness, upgrading infrastructure and ageing housing stock, environmental and social trends and pressures, and education and training. The key recommendations concerned customized solutions from standard components, business processes in construction, constructing for variable life, social and environmental consequences of development, competitive infrastructure, learning networks, the exploitation of IT, fiscal changes, and developing an innovation culture.

The Steering Group synthesised the findings of the 15 panels, identifying a total of 27 generic technological priorities which they grouped into six categories:

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

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

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

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

The third phase of the program—that of "post-foresight" or implementation—has a number of components including (a) shaping new government R&D priorities (in ministries, Research Councils and the Higher Education Founding Councils); (b) influencing company R&D strategies; (c) improving partnerships between industry and the science base; (d) influencing wider government policy (e.g., toward regulation); and (e) drawing lessons for the next Foresight Programme (scheduled for 1999/2000). Although the implementation phase is still under way at the time of writing, various process benefits of foresight are already apparent, as we describe below. In addition, the government has established a Foresight Challenge Fund of some £30 million which, with matching funds (in fact, rather greater amounts) from the private sector has funded two dozen foresight projects based on partnerships between public-sector research organizations and firms. The spending patterns of the Research Councils have been appreciably altered in the light of the priorities emerging from the Foresight Programme, and the same is true (although to a lesser extent in certain cases) of the government departments which fund R&D.

However, it is a little too soon to judge how successful the task of implementing the foresight findings and turning the ideas into action will eventually prove in the longer term. It also remains to be seen whether this national-level or "holistic" foresight will succeed in stimulating foresight to take place at the meso-level (e.g., industrial associations) and the micro-level (in individual companies and research organizations). Nevertheless, one recent report on the program was able to point to a range of successful initiatives that had their origin in the program [15], while another gave examples of how foresight is becoming embedded in companies [16]. Certainly, the level of success is such that the new Labour Government has begun planning for a second major foresight program in 1999/2000.

The Australian Foresight Exercise

The major foresight exercise in Australia was carried out by ASTEC between 1994 and 1996 [17, 18] at a direct cost of around A$1.5 million. Prior to that, the only substantial exercise had been that conducted in 1990 (and repeated in 1993) by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to identify research priorities within CSIRO from the national standpoint [19]. The approach involved assessing 16 major socio-economic categories against four criteria: (a) potential economic, environmental and social benefits; (b) Australia's ability to capture those benefits; (c) R&D potential; and (d) CSIRO's capacity to realize that potential. This framework was used to adjust the allocation of resources within CSIRO, but it has been criticized for being too open to subjective influence and too cumbersome to respond to rapidly changing needs [20].

The ASTEC study was entitled "Matching Science and Technology to Future Needs: 2010." The terms of reference negotiated with major government departments specifically excluded the formulation of priorities, responsibility for which remained within departments in keeping with Australia's decentralized and pluralist S&T system. Rather, the study was to be a demonstration exercise designed to increase the orientation of Australians toward managing the future and to show that there are robust mechanisms available to help achieve that goal. It set out to examine possible national and global changes over the next 15 years and to identify Australia's key future needs and opportunities which rely on, and could be affected by, scientific developments and the application of technology. The aim was to provide an information base that would enable government and industry to make better informed and longer-term decisions on the development and application of science and technology (S&T).

Special features of the ASTEC approach, developed to fit the Australian context, were:

- Adoption by ASTEC of a catalytic role emphasizing consultation and involvement;
- a multi-stream approach, with selective studies ("partnerships") complemented by a general overview and the use of multiple methodologies;
- a demand rather than supply-driven approach, with the emphasis on needs for S&T in achieving preferred futures; and
- a significant use of overseas studies to establish the general supply conditions for S&T.

ASTEC's approach was based on the assumption that building rich pictures of alternative futures, combining trends (expected futures), scenarios (possible futures), and visions (preferred futures) should provide a basis for assessing the ability of the current S&T system to meet future national needs in a variety of external circumstances. From this assessment, critical "levers" for change were identified.

A reference group of over 30 eminent Australians from industry, government, and the broader community formed the primary advisers for the study. Based on their views and on wider consultation, six Key Issues for Australia to 2010 were established: innovation and entrepreneurship, a technologically literate society, capturing opportunities from globalization, sustaining the natural environment, continuous improvements in community well-being, and building a forward-looking S&T system. Trend analysis and scenario construction were combined in a roundtable involving about 50 "stakeholders," broadly chosen, for each issue.

In addition, in-depth foresight studies were conducted through five partnerships, involving more than 20 major Australian organizations, on urban water life-cycles, broadband communication technology, neurodegenerative diseases in the aged, shipping, and youth. Each partnership selected and applied their own foresight methodology, under guidance from ASTEC, and produced a set of recommended actions.

To achieve maximum community involvement, some 20 detailed reports were released dealing with various components of the study [21] (all reports can be located at www.astec@gov.au), and scenarios and outcomes were tested through a range of sectoral, issue-based, and regional consultations. From an analysis of the outcomes of the roundtables, partnerships, and consultations, four "Key Forces for Change" which will profoundly influence Australia's future to 2010 were identified:

- Global integration;
- applying information and communications technologies;
- environmental sustainability; and
- advances in biological technologies.

New opportunities for industry are already emerging as a result of the Key Forces for Change. Opportunities were identified for adding an estimated $60 billion to national income over 10 years through increased and targeted R&D investment [22]. Future opportunities will require a strong knowledge base, including a skilled workforce, a good R&D infrastructure, and an enhanced capacity for technology transfer. Opportunities were highlighted for Australian businesses in developing information-based international services, applying sophisticated technology in new ways, and integrating business systems into global networks. As part of the study, ASTEC assessed Australia's performance in the six critical technology areas [23]. International comparisons revealed relative Australian strength in science related to biotechnology and genetics, and environment (including energy), niche strengths in information and communication technologies and transport, and a weak position in precision and control in manufacturing and new materials.

The ASTEC foresight project has demonstrated that foresight is a useful tool in helping to agree and move toward national goals for the future. Determining research priorities and improving the capacity for long-term planning are only two of these. Indeed, on several occasions, the process was presented as a pluralist alternative to the more top-down planning approaches of some industrializing Asian nations. As in other foresight programs, the ASTEC exercise has also shown that foresight can help to build consensus, assist communication between different groups, and act as a focus to developing a longer-term commitment and visions of the future. Indeed, a sixth "C" was added to the well-known 5Cs, namely comprehension—in other words, fostering an understanding of the changes occurring, and of the structural forces driving those changes.

Nevertheless, although the value of the ASTEC foresight process has been widely acknowledged, the direct outcomes have, to date, been somewhat limited. The priorities for action identified by ASTEC have largely been implemented or examined in a low-key manner within relevant government departments. An explicit commitment to continued foresight has not yet been forthcoming, although there has undoubtedly been a marked rise in the use of foresight processes, and in particular scenario planning at the meso- and micro-level, across a range of government departments and agencies, as well as in the private sector.

The interest in priority setting has not disappeared, however. Partly in response to the ASTEC report, the Minister for Science and Technology commissioned the new Chief Scientist, Professor John Stocker (previously CEO of CSIRO), to report on gaps and overlaps in current publicly funded S&T and to recommend ways of identifying national priorities for science and technology [24]. The Chief Scientist has advocated a comprehensive approach to priority setting, starting with a clearly articulated preferred vision from the Commonwealth Government for Australia's development. In particular, "ASTEC should develop the priority identification framework and methods further" ([23], page 4). The process benefits of foresight, including learning, may be starting to yield new fruit.

Foresight in New Zealand

The major changes in structure and processes described earlier were associated with a government commitment to increase public investment in research, science, and technology (RS&T) toward a goal of 0.8% of GDP by the year 2010. This expansion raised the issue of where these extra funds should be directed. The principal vehicle was a major priority-setting exercise entitled "RS&T: 2010" conducted in 1994–95 [25] (see also [13]). The approach was based on a combination of detailed analysis of socio-economic sectors and the traditional framework of strategic planning, and was largely managed by the Foundation for Research, Science and Technology (FORST) with a key role being played by the Science Priorities Review Panel. The first step involved defining some 40 science "output classes," which were subsequently combined into 24 science "areas." Those involved in research projects supported by FORST were required to identify their appropriate output class and to specify their objectives.

In the second stage, expert panels were formed for each of the 24 science areas, (subsequently reduced to 17). They produced reports which identified the strengths and weaknesses, opportunities and threats for their area to 2010, and hence pinpointed where the knowledge base needed to be strengthened. For example, in the area of biological resources, the knowledge areas identified as being in need of development were native flora and fauna, micro-organisms, marine species, and introduced species. For manufacturing, the knowledge areas identified were flexible manufacturing systems, environmentally friendly technologies, new materials, fabrication methods, sensors, automation and control technologies, new design techniques, and human resource management.

The science area reports were aggregated to provide an overview of trends affecting New Zealand RS&T, along with the strengths, vulnerabilities and opportunities. Examples of such opportunities are international leadership in areas of New Zealand strength, advancing global ecological knowledge based on the country's unique geological, biological, and geographical situation, and "test-bedding" of new technologies given the characteristics of the population, the well developed infrastructure, and the deregulated economic environment.

In addition, a more quantitative analysis was made of each area in terms of its prospective contribution to the three broad areas targeted for government investment: supporting services for S&T, science and technology outputs for the nation, and assisting the application of the research results. On this basis, a detailed breakdown of the research funds allocated through the Public Good Science Fund was established. These ranged from (in cents per dollar) marine and climate, 15c; land and fresh water, 14c; through forestry industries and society and culture, 7c each; to energy, 4c; transport, 3c; and Antarctic, 1c. This allocation guideline was applied for the first time to the increased allocation of NZ$45 million for 1997/98.

Recently, the Ministry of Research, Science and Technology has announced a foresight project to establish "science and technology priorities for a knowledge society" [26]. The shift to foresight appears to have arisen from shortcomings identified in the previous approach—the restricted time available, the limited consultation with end-users of science and technology, the poor quality of data for determining priorities, and the weak linkage between strategic priorities and subsequent research strategies and implementation. This shift also reflects a much greater emphasis on the foresight process:

> Foresight is about changing mindsets. . . . Foresight is *not* centralised planning. Rather, it is a process where we generate, and keep generating, a shared sense of where we wish to go as a society. It is about being better prepared for the future, by understanding key trends, uncertainties and influences and drivers that will shape the way the future develops [26].

The target for a new set of priorities has been fixed as the budgetary allocation round for 2000–2002. A four-phase project has been designed to ensure the maximum involvement of stakeholders. The aim of the first stage is to develop a broadly shared view of the future through a series of virtual and face-to-face processes culminating in a think-tank overview. Phase two focuses on "knowledge foresight" (i.e., knowledge trends and capacities), "sector foresight" ("to encourage all sectors of society and the economy to develop their own foresight, to define challenges and opportunities" [26]), and an evaluation of previous "public good" science and technology investments. The third phase requires the formulation of a method for developing priorities and hence determining the allocation of future "public good" S&T investment—the area where foresight processes are perhaps least developed. Finally, implementation will occur through the new "purchase strategies."

Comparison and Assessment of the Three National Foresight Exercises

Elsewhere, one of the authors (BM) and John Irvine have set out a conceptual framework for analysing the foresight process along a number of dimensions [7]. We can use this typology to compare the foresight exercises described above (see Table 1). The first set of distinguishing characteristics relate to the performing organization. In the British, Australian, and New Zealand cases, though the "performing organization" cannot be identified with the same precision in each case, primary responsibility lay with the government agency or advisory board concerned with the coordination of national science and technology policy (as opposed to some lower-level body with more limited responsibilities). In terms of specificity, all three exercises were holistic, although in the Australian case there were selected foci such as health, information and communication technologies, and shipping. The three exercises differed somewhat in relation to their aims; in the UK case, the main emphasis was on the determination of priorities, while the Australian exercise was more concerned with broad direction-setting, anticipatory intelligence, and communication and education (although all of these were certainly subsidiary aims of the British program). The RST: 2010 exercise in New Zealand was directed to priority setting, but the new foresight project announced in 1997 has a much greater emphasis on broader objectives.

TABLE 1
Comparison and Assessment of the Three National Foresight Exercises

Characteristic	UK	Australia	New Zealand
Performing organization	Office for coordinating national S&T policy (OST)	Advisory council on S&T (ASTEC)	Agency for funding S&T (FORST)
Specificity	Holistic	Holistic + selected foci	Holistic
Main aims	Determining priorities	Direction-setting, anticipatory intelligence, communication and education	Determining priorities
Balance between			
S&T push vs demand pull	Balanced	More emphasis on demand pull	Slightly more emphasis on S&T push
Top down vs bottom up	Balanced	Balanced	Balanced
Interested vs 3rd party	Interested party + consultants	Interested party + consultants	Interested party + consultants
Time horizon	Up to 30 years	15 years	15 years
Methodological approach	Informal + semiformal + Delphi	Informal + semiformal + scenarios (+ some Delphi)	More formal (including some quantitative)
Successes	Learned from overseas experiences but tailored to national circumstances	Learned from overseas experiences but tailored to national circumstances	Learned from overseas experiences but tailored to national circumstances
	Pre-foresight phase—developing enthusiasm	Involvement of stakeholders	Identification of NZ strengths
	Process benefits	Process benefits	Relating priorities to current spending
Weaknesses	Too rushed	Limited data/research	Limited research
	Limited data/research	Limited influence of ASTEC	Limited process benefits and involvement of users
	Limited influence of OST post-1995		Implementation of priorities

Foresight exercises can also be categorized in terms of the balance struck in relation to a number of "intrinsic tensions" [7]. One of these is the balance between science/technology push and demand pull. In the Australian case, the latter was given rather more emphasis, while in the British program the balance was more even (it has been criticized by industrialists for being too technology-driven, and by academics for being too user-dominated!). In New Zealand, the strategic planning approach emphasized both supply and demand, although in practice there was more input from researchers and scientific organizations such as the Royal Society of New Zealand than from industry and other users.

A second intrinsic tension is the balance between top-down and bottom-up pressures, and in this respect there is little difference between the various exercises with all of them having a fairly equal balance between the two types of pressure. Likewise, there is a similar balance between using an interested party or a more independent "third party" to carry out the work, with an interested party (OST, ASTEC, and FORST) working in conjunction with independent consultants in all three cases.

As regards time horizon, the Australian and New Zealand exercises focused on the next 15 years, while the UK program was looking up to 30 years ahead, although the emphasis was on the next 10 to 20 years. Finally, in terms of methodological approach, the British and Australian (and the latest New Zealand) exercises relied mainly on informal or, at most, semi-formal methods, mostly of a qualitative rather than a quantitative nature. The UK program did include a Delphi survey which yielded a large amount of data, but this was just one of several inputs (and, in most cases, by no means the most important input) considered by each sector panel. The Australian study also used a Delphi survey in some aspects.

How successful have the foresight efforts in the three countries proved? Among the strengths of all three is that systematic efforts were made to learn from overseas experiences but at the same time an approach to foresight was developed that was specifically suited to the country concerned. In the case of the UK program, which adopted the three-phase model of foresight put forward by Martin and Irvine ([7], page 30), the pre-foresight phase was particularly successful in developing interest and indeed enthusiasm for foresight in the industrial and scientific communities. Another key element of that phase was the co-nomination process which involved new people (and not just those already on government advisory bodies) in the exercise. In all three countries, foresight has generated an impressive amount of longer-term information. Lastly, in Australia and Britain the process benefits have proved substantial [27, 28]. (In the case of New Zealand, by contrast, it is the lack of process benefits that has been a major criticism of its formal, strategic-planning approach.) These process benefits are captured in the 5Cs identified previously by one of the authors [4, 7]:

- Foresight has enhanced Communication (among companies and among researchers and between researchers, users, and funders);
- it has resulted in greater Concentration on the longer-term future;
- it has provided a means of Coordination (again among researchers and between researchers, users, and funders);
- it has helped create a level of Consensus on desirable futures over the next 10–20 years;
- it has generated Commitment to turning the ideas emerging from the foresight programme into action.

These 5Cs correspond to areas where all three countries—with their emphasis on the "Anglo-phone" form of capitalism in which governments have tended to leave responsibility for industry, innovation, and even technology to "the market"—were previously perhaps rather weak in comparison with countries such as France, Germany, and Japan. Technology foresight provides a mechanism for considering and developing strategies without engaging in top-down planning—that *bête noire* of non-interventionist governments.

However, the foresight activities in the three countries have also had various weaknesses. In the UK case, the time-scale for completing the main phase of the program (which was determined politically) was too tight with the result that certain elements had to be rushed or omitted. In addition, the British co-nomination process should probably have been repeated for one further iteration. As it was, the lists of experts it generated reflected the composition of the starting list of experts, leaving some areas still unrepresented. In all three countries, constraints of time and resources meant that only a limited amount of data could be collected and used. Yet at this stage in their development, national foresight exercises undoubtedly require a significant level of direct and indirect resources. This, in turn, means that some will question whether the benefits outweigh the considerable costs (especially the time costs of those who participate). This will be a continuing challenge for proponents of foresight. Nevertheless, the evidence is clear that technology foresight is providing a new mechanism for directing public resources toward science and technology.

In both Australia and Britain, the foresight efforts have suffered because of the somewhat limited influence of the organization responsible (ASTEC and OST, respectively) in relation to other government departments and agencies. ASTEC was only able to provide advice to a junior, if enthusiastic, minister. In the UK, the transfer in 1995 of OST from the UK Cabinet Office to the Department of Trade and Industry complicated arrangements for implementing the program's findings with regard to the R&D programs of other departments. Similarly, because OST only has direct responsibility for the budgets of the six UK Research Councils, there has (in the view of many in the scientific community) been a tendency to over-emphasize imposing the foresight findings on the Research Councils' spending as opposed to the R&D budgets of government departments (where the results arguably have more relevance). Related to this is another criticism of the UK program, namely that it has perhaps been too closely linked to setting specific budgetary priorities as opposed to other functions of foresight such as anticipatory intelligence, determining broad directions, and communication and education [7]. These weaknesses are being taken into account in preparing plans for the next UK foresight program in 1999/2000.

Toward a New Rationale for Foresight?

Much of the recent analytical work on the relationship between technological development, innovation, and economic performance has focused on the concept of the "national innovation system." In this, the emphasis is not just on the constituent actors within that system—firms, universities, government research laboratories, and so on—but more importantly on the relationships and linkages between them. The notion of a national innovation system was first described by Freeman in relation to Japan; he defined it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" [29]. The concept has since been developed by others and fleshed out with various empirical studies [30–33]. (A useful summary of the concept and these empirical studies can be found in a recent OECD report [34].)

The concept of the national innovation system has come to prominence for several reasons. One is the growing economic importance of knowledge, with many economic activities becoming increasingly knowledge-intensive. A second and closely related reason is the widening range of institutions involved in knowledge generation [2]. Another reason is the emerging interest in systems approaches to the study of technological development, not least because of widely recognised limitations of the traditional linear model of innovation ([34], page 11).

As the foresight exercises in the three countries described here (and indeed foresight activities more globally) have all demonstrated, many important potential innovations and the emerging generic technologies likely to underpin them are characterized by the confluence of a number of component technologies [4, 5]. This creates the need for multidisciplinary, multiinstitutional and even, in a number of cases, multinational effort, and hence for networks, cooperation and partnerships. Furthermore, many of the policy issues thus raised, such as intellectual property rights and the commercialization of new ideas, require the development of effective links between science and technology, on the one hand, and the financial and legal systems, on the other. The development of such links is becoming more crucial.

At the heart of the concept of the national innovation system is a belief that a better understanding of the linkages between the component actors in the system is the key to improved technological performance:

> The national innovation systems approach stresses that the *flows of technology and information* among people, enterprises and institutions are key to the innovative process. Innovation and technology development are the result of a complex set of relationships among actors in the system. . . . For policy-makers, an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness. . . . Policies which seek to improve networking among actors and institutions in the system . . . are most valuable in this context (original emphasis) ([34], page 7).

The policy implications of the national innovation system concept are far-reaching. As OECD has argued, it suggests a new rationale for government funding of research and technology based on correcting systemic failures - in other words, the lack of effective interactions between the actors in the system. It also points to the need for new types of policies to address those systemic failures, policies that develop, extend and strengthen the communication and the flows of information, and the networking, cooperation and linkages between the component organizations that make up the national innovation system ([34], pages 41–42).

On the basis of the exercises analyzed here, we would contend that technology foresight offers a fruitful mechanism for pursuing such policies. As was noted in the earlier discussion of the 5Cs, the process benefits associated with foresight are very much concerned with fostering productive long-term partnerships—among researchers and among firms, across industrial sectors, and between industry, universities, government, and society at large. Technology foresight offers a means of "wiring up" and strengthening the connections within the national innovation system so that knowledge can flow more freely among the constituent actors, and the system as a whole can become more effective at learning and innovating.

There is a close link here with the new rationale for public funding of science put forward by Callon. In place of the traditional "public good" (or "market failure") rationale, he proposes that public support for basic research be considered as an investment in network reconfiguration and renewal. Public funding for science generates new combinations of organizational and individual relations, encouraging new mechanisms for interaction and collaboration, out of which may then be created new scientific and technological options [35].

The above arguments are also related to notions of organizational learning (within an organization) and system-wide learning (in this case, in the national innovation system). Such learning requires a process for stimulating, nurturing, encouraging, and strengthening interactions between the actors so that the linkages between them become more permanent. In the case of system-wide learning, we need a process capable of wiring up the national innovation system so that it too becomes more effective at learning. The more this wiring up takes place, the more effective the national innovation system should become in terms of learning and hence innovating. Foresight is a process for achieving this goal.

Mathews has made a similar point in relation to “high technology” industrialization in East Asia, arguing that such industrialization depends on the level of interdependence between the players involved. “The more sophisticated this network of institutions, the faster the economic learning, and the more secure the process of high technology industrialization” [37]. From this, he develops the concept of the “national system of economic learning.” Whereas organizational learning is concerned with each organization learning individually, economic learning involves learning in the wider industrial system comprising the interactions between firms, the market and the state more generally [37].

Technology foresight offers a means to facilitate such economic learning. With this should come an increase in the “knowledge distribution power” of the national innovation system [38–40] and hence in its capacity for innovating. Effective knowledge distribution and learning are becoming ever more important as we move toward the knowledge-based economy, and technology foresight constitutes a promising tool for helping to achieve these.

Before we consider the conclusions to emerge from this analysis, there is one further issue that we should mention in passing. This is the apparent contradiction between the growing emphasis on national systems of innovation at a time when the trend toward globalization seems to be growing more marked. Certainly, science and technology systems, like innovation systems, are becoming more integrated across national boundaries, raising questions about how an individual country can best benefit from the changing situation. For example, as we noted earlier, Australia is part of a dynamic region which has been rapidly expanding its scientific and technological efforts. There are many complementarities between Australia’s S&T system and that of the region as a whole. In particular, Australia’s strengths in biotechnology and environment could enhance the country’s long-term future through mutually beneficial collaborations with its Asian neighbors.

Until now, virtually all technology foresight has been confined within the nation state. However, there is no reason in principle why, in due course, it cannot be extended to look more widely at regions—at their economic and social needs, and at the scientific and technological opportunities for helping to meet those needs. Indeed, discussions and planning during 1996–97 have led to the formation of a fledgling APEC (Asia Pacific Economic Forum) Technology Foresight Centre (the feasibility study is presented in [13], pages 1–20), with its headquarters in Bangkok but with nodes proposed to be established elsewhere. The objectives of this center include acting as a focus for the development of technology foresight across APEC, the conduct of APEC-wide technology foresight exercises, and providing a means for comparison of national studies (it has been suggested that OECD might perform a similar role in relation to its member states, see [40]).

However, the demand for further development of the procedures of technology foresight and their appropriate mode of application, the need to examine and share the tacit learning which currently underpins so much of the foresight process, to translate tacit into codified knowledge, and to develop effective interfaces with the public and private resource allocation systems—all of these present sufficient challenges for now! As a consequence, foresight should probably first become firmly established on a national basis before more ambitious multinational foresight exercises are attempted.

Conclusions

We have argued that three main trends have been driving the spread of technology foresight. The first derives from the increase in the number of “players” in market economies which, together with the enormous variations in salary differentials and the trend toward globalization, has accentuated the pressures of economic competition. As a result, innovation is becoming ever more important along with the development of knowledge-based industry and services. Science and technology have an increasingly influential role to play in responding to these competitive pressures. Second, government spending in most industrialized countries is coming under growing strain, leading to demands for more accountability and value for money. Science and technology, with their inevitable demands upon the public purse, have not been immune from such pressures. Since no country, however rich, can afford to pursue all the possible opportunities in science and technology, we need better mechanisms for choosing between competing alternatives, and for linking science and technology more closely to economic and social needs. Third, we are witnessing changes in the nature of the knowledge production process as a result of which we need better interactions among researchers, and between researchers and research users. Technology foresight offers a means to meet some of the needs created by these global driving forces.

Prior to 1990, the use of technology foresight was relatively limited. It was most widely used in Japan from around 1970 onward. Elsewhere, there was only limited experimental use of foresight—for example, in France in the early 1980s (see [4] and [7] for a description of the use of foresight in science and technologies in the period up to 1989). Since 1990, foresight has spread rapidly, as other articles in this special issue describe. This is also true with respect to Britain, Australia, and New Zealand where, as we have seen, technology foresight has been adopted on a large scale for reasons similar to those pertaining more globally.

Comparisons of the experiences with foresight in the three countries point to a number of lessons. First, technology foresight can be used for different aims, reflecting the economic, political, and cultural circumstances of the country concerned. Second, considerable benefits can be derived by learning from the experiences of other countries with foresight, at the very least reducing the risk of failure. At the same time, however, it is essential to tailor the foresight process to local circumstances and needs. Third, if the foresight process is well designed, it can result in considerable process benefits, in particular in relation to the 5Cs of better communication, greater concentration on the longer term, more effective coordination, the development of a level of consensus on desirable futures, and the generation of the commitment necessary to translate the results of foresight into action. Fourth, it is virtually impossible to get foresight right the first time; indeed, at this stage of its development, there are few reliable guides as to just what constitutes success in relation to foresight. In the case of the three countries analyzed here, the initial attempts at foresight have suffered from several shortcomings. Given the complexity of the process and what it is trying to achieve, one must accept this as inevitable and concentrate on evaluating the process, identifying the problems, learning the lessons, and doing better in second and subsequent attempts.

Linking this experience with foresight in the three countries with the wider literature on technology and innovation policy, we have argued that technology foresight has a potentially important role to play in relation to national innovation systems, strengthening them in terms of the capacity to learn and innovate. We examined why the concept of the national innovation system has become more important as a result of such factors as the transition toward the knowledge economy, and the increasing range of institutions involved in research, technological development, and innovation—institutions which need to exchange information, learn from one another, form partnerships, and so on. Central to the concept of the national innovation system is the vital importance of the interactions between the actors making up the system. To strengthen the national innovation system, we need to stimulate, extend, and deepen those interactions if the system is to learn and innovate more effectively. Technology foresight, we contend, offers a fruitful mechanism to help achieve this.

In conclusion, experience with foresight in the countries reviewed here suggests that government, industry, research and educational organizations, professional societies, and community groups should all be encouraged to undertake, or to be involved in, foresight exercises. Such exercises develop a better informed forum and a participatory and transparent process for decision making on science and technology, allowing us to anticipate the potential consequences of current decisions. In short, technology foresight can enable us to shape the future so that it better meets our longer-term economic and social needs.

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