Remaking National Science Policy and Public Sector Research for the 21st Century

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The Economists, not only in the west but also in the east, are essentially materialistic. We must say harshly of the “science” of economics that it is generally the skilled, exact, technological application of a totally false theory of human needs and values. A theory which recognises only the existence of lower needs or material needs. How could young people not be disappointed and disillusioned! What else could be the result of getting all the material and animal gratifications and then not being happy as they were led to expect, not only by the theorists, but also by the conventional wisdom of parents and teachers, and the insistent grey lies of advisors (Maslow, 1967).
THE NEED FOR A NEW PARADIGM IN SCIENCE POLICY

The Pressure for Change

For the past twenty years, there has been a fairly constant ‘fiddling with the research system’, driven by a view that not all is right, and that some improvement of its operation must be possible, even if a clear model of reform is not apparent. Thus, we have seen repeated attempts to restructure CSIRO in order to address one or other national issue. Indeed, restructuring CSIRO has achieved the status of a peculiar national past-time, carrying with it a powerful image of political frustration and failure.

The continuing nagging dissatisfaction on the part of politicians and officials, and consequent attempts to restructure or review the ‘science system’ to get it to work better, has led to regular calls, particularly from the scientists, for the formulation of a ‘national science and technology policy’ to sort out these problems and let them get on with their work.

“To me, the entire issue of the future directions of scientific research in general, and CSIRO in particular come back to the question of setting of priorities which reflect the needs of the customer (for applied research) and stakeholder (for public good research) and enables the provider (the scientist) to meet their requirements in the short, medium and long term’ — CSIRO commentator.

Such a centralised approach to the establishment of national objectives has, however, been something politicians have neither seen a need for, nor known how to construct. The rhetoric, and reality, of a pluralist science and technology system has been called on regularly to argue that there was little need for top-down consideration, or centralised leadership.

But now there are emerging signs that marginal structural adjustments to our research system are not only proving ineffective, but are to a large extent counter-productive. These structural modifications also signally fail to address the dramatically changed role of knowledge in shaping our economic, environmental and social future.

The conjunction of three significant and largely distinct influences suggest that now is the time for major reconsideration. The first of these is the growing, one might venture widespread, recognition of the dominant contribution of knowledge to economic competitiveness in this age of globalism.
'Knowledge in the form of technology and market information, is the principal resource in the world economy, especially knowledge in its dynamic form as the capacity to generate new technologies and to market new products' (Cox, 1987).

The emphasis of our current, but no longer appropriate science policy paradigm, has been almost exclusively on the generation of knowledge. The challenge now is to develop a model which can underpin understanding, and policy, across the full and much richer spectrum of knowledge activity.

The second force for change arises from advances, predominantly in the past ten years, in the theories, concepts and language to analyse and understand the basis of this economic activity, the centrality of innovation, and the characteristics of the knowledge system under these conditions.

The third force is more local, and relates to a number of government activities in Australia: firstly, the release of the Industry Commission draft report on Research and Development (1995); secondly the commitment of the Minister for Industry, Science and Technology, Senator Cook, to release an 'Innovation Statement' in August 1995; and thirdly, the continuing, public and divisive debate about the appropriate role, structure and management of CSIRO.

The Current Paradigm in Science and Technology Policy

The current paradigm in science and technology policy is composed essentially of two distinct elements: the economists’ view of scientific knowledge as a public good, and the scientists’ view of research as an endless source of knowledge upon which new activity can be built.

These two views are not necessarily coherent, though as we shall see they have provided implicit support for each other. It could even be argued that, on some issues, they are in conflict. The reality, however, is that together they have provided the rationale and supporting rhetoric which underpins modern (post-1945) science policy.

It is necessary to examine these arguments in a little detail in order to establish the extent to which they have provided, until recently, the largely unchallenged basis of science and technology policy. In this Chapter, we must grapple briefly with the arcane language of economics in order to expose its limitations in addressing the world of research and knowledge.
In doing so, it will be apparent that the neo-classical economic argument is conducted almost exclusively in terms of the direct economic returns from the research process. It does not take any explicit account of the role of knowledge in pursuing environmental, social, or cultural objectives.

The economist’s view of science is firmly established in the academic literature, policy analysis, and public discussion. Indeed:

Generations of students have learned that science is a public good. This principle has been embraced by economists of all shades. It has inspired science policymakers; it is supported by scientists themselves and even seems to fit in with the common-sense view (Callon, 1994:397).

Scientific knowledge is regarded as having a range of intrinsic characteristics that make it impossible for it to be treated, or managed as just another commodity; as a consequence there is an imperfect market for this knowledge, which causes business to under-invest; this market failure provides a justification, indeed a powerful reason, for governments to act to supplement and stimulate this investment.

The list of these ‘intrinsic characteristics’ varies, but is generally considered to include:

- **limited appropriability** — this claim rests on the view that it is impossible to create a market for knowledge once it is produced, because others can access the knowledge at little or no cost, so producers have a limited ability to appropriate the benefits of their investment;
- **non-rivalry** — knowledge is a non-rival good, in that once produced, its use by one person does not preclude its availability and use to others; an important consequence is that ‘the good’s production costs are fixed: once the good has been produced, there is no need for continuing investment because there are no production costs in replicating it’ (Callon, 1994:400.);
- **uncertainty** or **risk** — knowledge outputs are not precisely predictable; it is necessary to invest in knowledge production without knowing the outcome with any accuracy;
- some commentators have added the quality of **durability**: the knowledge good is not destroyed or altered by its use; indeed increased use of a piece of knowledge can increases its value and applicability;
- a final characteristic commonly referred to is **indivisibility** — knowledge must be aggregated on a certain minimum scale to form a coherent picture before it can be applied.
Together, these characteristics provide the basis for scientific knowledge being treated, and supported, as a public good, the production of which is subject to market failure.

This market failure analysis has been widely accepted as providing a sound justification for government intervention to support research with public funds:

In this set-up, the basic policy task is to encourage discovery-oriented activities, and then to protect the use of the results. The problems of risk and indivisibility lead to straightforward under-provision of knowledge, and suggest that the public sector should either produce knowledge directly, or provide subsidies to knowledge-producing institutions. The appropriability problem implies the existence of a major positive externality, and suggests policies either of subsidy, or the creation of property rights (OECD, 1994a:8).

However, as some commentators have noted, this approach does not give any secure guide to how to identify areas of market failure, or the appropriate levels of public support which might follow from it. There appears to be a rationale for public provision, but where and how much? (Metcalf, 1994).

Indeed, it can be argued that market failure theory has been used primarily as a device to legitimate politically inspired policy (Joseph and Johnston, 1985). But demonstration of these limitations has done little to dent the command of the official paradigm.

Complementing this economic component of the current paradigm in science and technology policy are the political views which the scientific community managed to establish in the 1950s as the basis of the social contract between science, the community and government.

The exemplary author of the post-War contract between science, governments and the community was America’s Vannevar Bush (1947), in what is one of the most famous and oft-quoted government reports, ‘Science, the Endless Frontier’. His arguments rested on two assertions. The first of these was:

- basic research is performed without thought of practical ends.

In Bush’s view creativity is constrained by any thought of application, which implies that there is:

an inherent tension between the goals of understanding and use and, by extension, a radical separation between the derived categories of basic and applied research (Stokes, 1994:2).
Stokes goes further to argue that Bush implied that applied research inevitably drove out basic research if the two ever came into contact. Here is a clue to the origins of the linear model of innovation which has so dominated Western industrial society for the past fifty years.

The second claim, which at the time must have seemed somewhat paradoxical, provided the delivery end of the social contract between science and government:

- basic research is the pacemaker of technological development.

If basic science is not short-circuited by premature thought of practical use, it will prove to be a remote but powerful dynamo of the technological advances that will meet the full range of our society's needs, as the advances of basic science are converted into technological innovations by the processes of technology transfer (Stokes, 1994:2).

The power of these ideas has been quite remarkable. They spawned not only the modern form and extraordinary growth of science, setting its path irreconcilably from intellectual pursuit to industrialised manufacture. But they also very significantly contributed to the shaping of the modern industrial, and indeed, post-industrial, society. Their roots have penetrated so deeply that the majority of scientists, and many of the public, consider them to be a statement of the natural order, eternal, and unquestionable.

Yet it always was a dangerous bargain. In return for the unfettered funding of basic research, the commitment was implicitly made that all of society's needs, whether wealth, employment, health, security, or the good life, would be satisfied. But not only have 'old' problems such as starvation and conflict not been resolved; 'new' problems such as ecological sustainability have been added to the list. It was inevitable that a demand would emerge for a new 'social contract' between science and government.

It should be noted that this public good/market failure view of scientific knowledge was implicitly based upon, and has provided strong conceptual and rhetorical support for, the linear model of innovation. The central tenets of the linear model have been that technological advance and advantage depend on knowledge creation at the frontier; that science provides the prime knowledge base for industrial production; and that the translation of knowledge into commercial products is essentially sequential.

The most powerful implication of the linear model is the view that industrial innovation is primarily driven by the discovery processes
within science. As a consequence, public policy has emphasised government support for R&D, subsequent commercialisation, and technology transfer.

There have been many demonstrations of the conceptual and empirical inadequacies, indeed distortions, of the linear model (Gibbons and Johnston, 1974; Pavitt, 1991). However, these apparently well-argued cases have had relatively limited impact on the fundamental basis and practice of science policy. The linear model has resonated too strongly with deeply held views, and the nexus between the economists' public good and the scientists' view of the primacy of their knowledge has been too strong, to allow simple factual inadequacies to count for much.

It has become apparent that the overthrow of the linear model will require a much deeper, and concerted challenge to the set of ideas which constitute the dominant 'world view' of science and technology policy.

Reassessing the Basis of the Current Paradigm in Science and Technology Policy

There are at least three major challenges to the current paradigm, and the views of research and industrial innovation upon which they are based.

The first of these is concerned with the supposed non-rivalry, and appropriability of scientific knowledge. The common emphasis is on the limited extent of control of new knowledge by the research performer. However, the fact that the producer of knowledge may have limited control over who can get access to it, (for example, anyone who can read the scientific literature) does not necessarily imply that such knowledge is freely available.

This argument can be countered from two perspectives. One is that the sociology of scientific knowledge has demonstrated that an isolated 'piece of knowledge', statement, or theory, is quite literally useless, indeed has no meaning, unless it is embedded in a supporting context of well developed theory, evidence, and argument.

You might print thousands of copies of an article or a book and air-drop copies in Lapland or in Bosnia-Herzegovina. You might similarly send well-trained students or well-calibrated instruments to the far corners of the earth. However if all these elements do not come together in a single place at the same time, then dissemination will have been a waste of time. Nobody will
adopt the statement; the skills will not have any object to which they can be applied; the instruments and the machines will remain in their boxes (Callon, 1994:402).

Making use of any piece of knowledge requires a considerable investment in establishing the necessary interpretive context of theory, concepts, data and tacit experience.

The other is that a scientific or technical resource has no intrinsic value or use. It is only when the necessary 'complementary assets' (Teece, 1988) of technological support systems, production capacities, and distribution networks are appropriately assembled that knowledge can be converted to profitable use: 'A veritable collective machinery is required to give knowledge a use or economic value' (Callon, 1994:409).

Thus, a public good is not necessarily a free good (Pavitt, 1991:117). The extent of the public or private nature of scientific knowledge is highly variable, and context-dependent, rather than an intrinsic property of the knowledge itself: 'Degrees of appropriability and of rivalry are the outcome of the strategic configurations of the relevant actors, of the investments that they have already made or are thinking of making' (Callon, 1994:407).

The second major challenge comes from the phenomenon variously referred to as irreversibility, increasing returns, or path dependency (Arthur, 1989; David, 1984). In order to limit the potentially infinite number of goods that could be offered on the market place, to allow the consumer the possibility of 'ordered, informed choice', and to ensure the possibility of a return on the investment in new technology and new products, what Callon aptly calls 'that strange conspiracy between technology and the marketplace' (Callon, 1994:408) occurs to develop a common techno-economic trajectory. Furthermore, it is the initial decisions concerning technology and design that commonly provide the powerful and self-reinforcing determinants of that trajectory.

The 'QWERTY' keyboard is the most familiar example of a technology that was shaped by a particular problem (the need to avoid mechanical keys sticking), which could be displaced by a far more efficient layout, but which is locked in by the variety of dependent and associated products and uses.

Under these conditions, the emergent trajectory acts as an active shaper of not only the value of knowledge items, but of the extent to
which they have any meaning. The overall process can be presented as the generation of knowledge which ‘fits’ within the system, and a large range of other knowledge candidates which do not fit, at least at that time, are left to pile up in storage, some to be used at a later date, and many never to see the light of day again.

Under these conditions, what is commonly called public good science, might be seen as a source of variety in knowledge, outside the confines of the accepted trajectories. It provides the mutations which are assessed via the selection criteria of the existing evolutionary systems, and which occasionally challenge successfully, and transform, the dominant paradigm, leading to the formation of completely new bodies of knowledge, new technologies, and new industries.

The third major challenge is presented by advances in the theoretical and practical understanding of the innovation process. The past decade has seen major changes in the understanding of the nature and characteristics of innovation processes, and their economic effects, through the application of ‘systems’ approaches (Nelson, 1987; Dosi et al, 1988; Scott-Kemmis and Johnston, 1988; Freeman and Soete, 1990; Dodgson and Rothwell, 1994).

Analyses of industrial clusters, as in the work of Michael Porter (1990), emphasise the creation of dynamic clusters of industries around key technologies, emphasising inter-industry interactions and the effects of the politico-economic environment.

An alternative approach is based on ‘national systems of innovation’, composed of ‘elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge’ (Lundvall, 1992; Nelson, 1993). This relies on analysis of innovative environments, processes of learning, and knowledge accumulation.

Yet another approach rests on the concept of the ‘knowledge system’ and focuses on learning systems for scientific and technological knowledge. David and Foray have developed the concept of:

“knowledge-product space”, which is essentially a way of categorising different forms of knowledge by placing them with respect to three different dimensions: from completely tacit to fully codifiable, from fully disclosed to fully restricted; from privately owned to publicly available (OECD, 1994b:13).

This differentiation of knowledge types provides a basis for analysing the characteristics of ‘effective’ knowledge, and the conditions for its effective application which is very different from the perspective offered by neo-classical economics:
within this complex structure of differentiated knowledges, what determines performance is not so much knowledge creation as the “distribution power” of the system: the system’s capability to ensure timely access by innovators to the relevant stocks of knowledge. The distribution power of the system affects risks in knowledge creation and use, speed of access to knowledge, the amount of socially wasteful duplication, and so on (OECD, 1994a:13).

The common threads running through these ‘system’ approaches, with their emphasis on evolutionary systems of innovation, organisational learning, and a range of non-market transactions such as cooperation and collaboration, are a rejection of the assumptions underpinning the neo-classical model of economic activity. Instead, they emphasise interaction:

the overall innovation performance of an economy depends not so much on how specific formal institutions (firms, research institutes, universities, etc) perform, but on how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, and legal frameworks) (OECD, 1994b: 4).

These new analyses of innovation suggest a very different status of knowledge to that presented by the neo-classical model. Technological knowledge systems within industrial firms are characterised as:

- differentiated and multi-layered, ... involving the complementary development of very different types of knowledges: codified scientific results, tacit knowledges ...;
- highly specific, organised around a relatively limited set of functions which firms understand well;
- developed through costly processes of search, learning and adaptation, and are therefore cumulative;
- internally systemic, as part of an overall production and marketing system, including identifying and integrating technological and market opportunities, financing new product and process development, training, design, engineering and prototype developments; and
- interactive and externally systemic, based on structured interactions between institutions, involving processes of mutual learning and knowledge exchange (OECD, 1994a:11).

Hence, firms in general are severely constrained in their knowledge horizons and technological capacities. As a consequence, they are likely
to have great difficulty in identifying and accessing scientific or
technological information from outside their restricted environment.
They also rarely have costless access to a generic knowledge basis, and
therefore are required to invest in the location and 'purchase' of highly
specific knowledge to achieve their innovative goals. A great deal of
knowledge is not available as a commodity for purchase, and must be
obtained through investing in the establishment of non-market
relationships.

This provides a much broader justification for government support
for public sector knowledge organisations than that of spillovers from
public good research afforded by the neo-classical view. Such
organisations are not simply engaged in the uncertain practice of
research in support of national objectives. Rather, they provide the
central core of the knowledge infrastructure of the nation, assembling
and disseminating relevant knowledge throughout the economy and
social structure. Parts of this infrastructure exist within, and can be
provided by, the private sector. But the non-market nature of many of
the transactions indicates the importance of a continuing role for
public sector involvement.

This raises, however, a significant challenge for public sector
research organisations like CSIRO. By objective, by ethos, and by
recruitment, their emphasis has been on the performance of quality
research — a very demanding requirement in itself. However in
practice, in some Divisions there has been a considerable effort in the
assembly, interpretation and communication of relevant knowledge to
identified groups of potential users, precisely through the formation of
long-term, non-market relationships. Under a new policy model, it
would be necessary for a CSIRO to reconstitute itself as a knowledge
management organisation, rather than just as a research organisation.

Some Components of the New Framework for Science
and Technology Policy

The evolutionary/systems view of innovation and the roles of
technological knowledge outlined above provide the basis for a quite
different view of the appropriate form of government intervention in
the world of research and knowledge transfer. Whereas current neo-
classical-based policies place all their emphasis on support for
knowledge creation, the evolutionary model points to coordination
across all components of the knowledge system. The most appropriate
place for public support may be in providing mechanisms to assist in
knowledge identification, location, and distribution, as well as
knowledge generation.
As a consequence, it is:

knowledge of how to develop new knowledge, how to locate and acquire rapidly knowledge generated elsewhere, how to diffuse knowledge throughout an organisation, how to recognise possible inter-connections between two distinct pieces of knowledge, how to embody knowledge in products and services, how to obtain access to the learning experiences of customers — all of these are the challenge for the modern manager, and for those who would make science policy (OECD, 1994a:14).

In summary, the new paradigm for science and technology policy will:

- focus on interaction as much as on institutional performance;
- characterise knowledge and its value in accord with the categories of knowledge-product space, rather than in terms of the traditional distinction between basic and applied research;
- emphasise knowledge distribution and access as a coherent continuum with knowledge generation;
- take full account of the non-traded nature of knowledge interaction;
- comprehend the tacit nature of much knowledge, and its important role in framing questions and possibilities as much as in solving problems;
- acknowledge the necessarily limited technology horizons of industrial firms, and the need for knowledge workers (the researchers in this new model) to find ways to interface with those horizons.

**KEY ELEMENTS OF A NATIONAL SCIENCE POLICY FOR THE 21ST CENTURY**

One way of examining the requirements of a national science policy is in terms of the key elements to be delivered by it. These can be considered as: the generation of new knowledge; access to the world's knowledge base; capturing the benefits of knowledge; and the provision of informed input into decision-making at all levels and sectors.

The **generation of new knowledge** is a continuing requirement of a research system, to address new problems, to open up new opportunities, to conduct the new generation of researchers to the frontiers of knowledge, to maintain and develop new contacts with the international research community, and to have the basis of accessing and interpreting knowledge generated elsewhere.

There are a number of crucial elements of a national capability to generate new knowledge. The first of these might be the provision of
an appropriately trained and experienced labour force of researchers. This issue provides a good illustration of the complexities and interactivities of the research system.

Initially, talented students must be attracted to study science and mathematics subjects at school. This requires, as a minimum, well-trained and enthusiastic students, a challenging curriculum, adequate infrastructure, equipment and materials to support both the directed and discovery learning processes, a widespread perception of the social and financial value of a career in science, and a school and community culture that values education and achievement.

Then there is the requirement for universities with adequate resources, a commitment to excellence in undergraduate and postgraduate learning, a strong research ethos, adequate facilities, well-developed connections into the international scientific community, and an ability to communicate the challenge and excitement of the research process, and the extreme self-discipline required to be successful.

There is a further need for a strong labour market for researchers, with provision for an attractive career, the possibility of moving freely between a range of employers, financial and social status, a significant level of autonomy and responsibility associated with a professional, and the opportunity to work towards challenging objectives.

A second requirement is infrastructure to support the generation of knowledge. This includes not only laboratories, equipment, information resources, funds to attend meetings and conferences, etc, but the organisations to provide the necessary general support structures. A significant level of generation of new knowledge will occur in the private sector, or be supported by it. But the analysis presented previously also indicates the need for a continuing and substantial public investment in knowledge generation.

While the obvious infrastructure is material, the research process also relies intensely on more intangible infrastructure: for example, the ability to test new ideas with trusted colleagues, to exchange the results of experiments, and experimental material, to ‘pick up’ on the tacit elements of a new experimental procedure, to access results long before formal publication. Access to this infrastructure is available only to those who have established themselves as accredited and reliable researchers, and who have demonstrated their commitment to the sharing ethos of science. Hence there is a continuing requirement for a system of apprenticeships to transmit to new practitioners the technical, social and ethical requirements of their profession.

A third component of the research infrastructure is the ethos, and culture, which supports the highly uncertain nature of the research
process, that allows failure, as long as it leads to learning, and which recognises the necessarily long time horizon of research. After all, with an apprenticeship of 10-15 years, there has to be the promise of an opportunity to make a powerful use of the hard-won skills, to make great achievements.

**Access to the world's knowledge** is as important as the generation of new knowledge, if not more so. Often quoted statistics indicate that Australia produces approximately 2 per cent of the world's research output, as measured by publications in international journals. Access to the other 98 per cent, no matter how notional that figure, is obviously imperative. 'Our' 2 per cent will not provide the basis for addressing our problems, for keeping up with major advances in new fields, for identifying new techniques, for understanding the technology employed by our competitors, or for being part of the international research community.

How have we managed this process up to now? Not, to be sure, in a highly coordinated and centrally directed way. But, as with the Internet, it appears that central direction may not be the key to networking. Rather a low control, low reliability, low cost approach may turn out to be the most effective, at least in developing networks in the world of research. Thus our 'knowledge intelligence system' has consisted essentially of the international connections of scientists, through the scientific literature, conferences, and specific collaboration, and the intelligence efforts of companies, which are focussed on overseas parent firms, trade fairs, and conferences.

There is room for the development of a much more explicit 'knowledge intelligence capability' than we have had in the past. The Japanese have pioneered the intelligent analysis, on a global scale, of recorded information of all kinds, in order to identify technological trends and scientific breakthroughs. Alternatively, the Swedish have placed great emphasis on using doctoral and post-doctoral training as an explicit tool to build international connections, and research intelligence networks.

Here is a role for public sector research organisations like CSIRO, and the universities. By the nature of their activities, research staff of these organisations invest considerable energy in establishing effective links with their overseas counterparts, and in ensuring they are up to date with the latest advances. However, this intelligence has largely been confined to the immediate research group. There is a challenge to develop means to make this intelligence more widely available.

**Capturing** (or 'exploiting') the **benefits of knowledge** has been an important motive for the development of the ethos of managerialism
in research. The glittering prizes of the stockmarket and control over market share in the new technologically-driven industries have placed a dramatic new premium on reaping the benefits of investment in the generation of or access to knowledge.

At a national level the question of the return on the investment in research has been brought strongly into focus by the pressures of global economic competition. In some countries, particularly the US, there has been a great deal of concern, and some legislative action by government, to restrict those ‘free-loading’ countries and companies taking ‘unfair’ advantage of their investment in research. While some knowledge can undoubtedly be privatised, much of it cannot easily be captured through exclusive ownership. Are there ways of ensuring that the payoff of taxpayers’ funds for research flows predominantly into the national economy? The globalisation of industry, so aptly captured in Reich (1990) suggests such an approach may be largely unproductive.

In Australia, the emphasis on capturing the benefits of science has been about the commercialisation of research, reflecting the Bush model of technology transfer. This focus on commercialisation, which assumes that economic returns are largely obtained by the transformation of a set of knowledge into a product or service, commonly through a start-up company, can be considered as a first generation response to the recognition of the central role of knowledge in economic activity. The record in both CSIRO and the universities, is of very limited success, and many failures. In most cases there was a failure, or an inability, to assemble the complementary assets necessary to achieve commercial success.

However, with the much richer picture of the interaction between knowledge and economic activity outlined above, commercialisation of research outputs is but one, modest, and very special form of interaction. The second generation, more mature approach, recognises that the majority of the commercial, and social, returns from knowledge generation and management will arise from the effects of knowledge on the performance of existing enterprises. Promotion of a rich pattern of interaction and relationship building, backed up where required by appropriate intellectual property protection, is likely to produce a much larger return on the investment in knowledge generation and access.

The fourth key element of a national science policy is in providing an appropriate input of knowledge to decision-making.

The economic pay-off from an effective system of knowledge generation and supply is much more than that realised from new products, and even new industries. It is in providing an informed network for the multiplicity of decisions made by politicians,
bureaucrats, industrialists, workers of all kinds, community groups, families, and individuals, which collectively reinforce the shared values, the common purpose, and the belief in the possible, which underpin so much economic activity.

Such a system also provides, not entirely by coincidence, a necessary input into the wide range of crucial decisions about national security interests (whether geo-political, technological, trade, biological, etc), diplomatic relations, treaty negotiation, regulation, health care, environmental conservation, industrial competitiveness, and so on. The list is virtually endless. A characteristic of the modern democratic state is its ability, in the face of all the competing pressures, and the realities of political compromise, to identify and bring to bear knowledge which can directly shape the decision to be made. In the face of the opportunities and challenges of globalism, national sovereignty will rest crucially on our ability to be effective players in the international knowledge economy, for our own purposes.

In addition to the key elements to be delivered by it, there is the issue of how an effective national science policy is to be formulated and implemented. The interest here is not on the detailed mechanics, but on the general principles that are appropriate to shape the formulation of national science policy for Australia for the 21st century.

Assuming the continuing central role of the knowledge economy, the importance of interaction, and the maintenance and refinement of a decentralised, pluralistic system of decision-making, what might these general principles look like?

1. The process of formulation of science and technology policy should be continuous, but with a regular summation and presentation to stakeholders; this might take the form of a considerable expansion of either the current ‘Science and Technology Budget Statement’, or the Science (or Innovation) Statement.

2. The process should be open and transparent, with opportunity for input and debate from all stakeholders — knowledge producers, knowledge managers, knowledge users, knowledge analysts and strategists, and knowledge investors.

3. Connections between the elements of the process should be maintained predominantly by the building of strong networks and encouraging communication flows between the stakeholders, rather than by centralised planning.

4. Groups of stakeholders across this pluralist system should be brought together on a regular basis to consider the medium- and long-term challenges and opportunities for the knowledge
economy in their area of expertise or interest, and to develop and disseminate a collective foresight on potential developments.

5. Organisations charged with knowledge generation and access should have clearly established objectives, and appropriate accountability processes; beyond these, they should be free from external interference to pursue their objectives, and to be judged, in an orderly process, at appropriate (3-5 year) intervals in the market place they are committed to serve.

DESIGNING THE NATIONAL RESEARCH AND INNOVATION SYSTEM

What would a national research and innovation system designed to meet the requirements of the knowledge economy look like? In some ways it might not look very different, given that much practice, if not structure and objectives, already reflects this new reality. In other aspects it might be quite different. We will examine this issue through two aspects: mechanisms for the allocation of resources, and institutional structure, objectives and responsibilities.

Mechanisms for the Allocation of Resources

An array of principles for the effective allocation of resources to research derived from neo-classical economic theory has emerged over the past decade. These include the notions of ‘purchase’ of research outcomes, particularly by government departments on behalf of the public, separation of purchaser and performer, and ‘contestability’ in resource allocation. Each of these is derived from a flawed model of the research process, and the operations of the knowledge economy.

The interactive nature of understanding and use, of knowledge and action, places issues such as the need for clear articulation of government research needs, a major role for contestability, and the separation of government roles of policy-maker, purchaser, and performer, in a very different light.

Leaving aside the important issue of the competence of government departments to identify their research needs in principle, the underlying model of the ‘purchase’ of research outputs is of a clearly articulated problem, for which the best knowledge to achieve resolution can be sought.

In reality, knowledge is needed to articulate a problem, and the clarification of the precise nature of the problem commonly emerges through the research process, in interaction with the ‘purchaser’. In the same way, the ‘resolution’ of the problem is likely to require a
continuing knowledge input, as the purchaser's view of what counts as adequate resolution is changed by the availability of knowledge. The purchase model is based on the totally inaccurate and counter-productive separation of use and understanding rooted in the Vannevar Bush model.

A 'purchaser' would almost never call up CSIRO and request a particular bit of information. The more common approach is along the lines of 'I'm having a problem with our whatsit; we've tried this and this but they don't help. Do you think you could sort out what is going on?' or 'I have an idea for a product that the market is screaming for, and I need a technology that can help me deliver these capabilities. Do you have any ideas of what might work?'

Thus, the need is for high levels of interaction between the purchaser and those, wherever they are located, who may possess knowledge which can assist in illuminating, identifying, characterising and resolving potential problems. Closeness, rather than arms-length relationships, is what is called for.

With regard to the separation of the roles of purchaser and performer, it is undoubtedly important to ensure that monopoly conditions are not established by a research performer. But the operation of the highly competitive 'knowledge market', where the emphasis is on competition of ideas, and priority of discovery, has in practice ensured that a monopoly research performer is strictly a theoretical concept. For example, the provision of a block grant to CSIRO in no way confers a monopoly status.

Moreover, with the highly pluralist science and technology systems common today, with a wide range of both 'purchasers' and 'sellers', the danger seems less one of monopoly, than of the policy-makers, 'purchasers' and performers all operating in isolation of one another. Promotion of more effective dialogue between the players, and significantly improved coordination mechanisms, seem to be the more pressing requirement.

Finally, with regard to contestability, economic theory suggests that its application should ensure all the virtues of competition. However, despite its widespread rhetorical use in New Zealand, there is doubt about its applicability to research.
The technical conditions of contestability do not apply in the case of research funding. There is no direct market test permitting competition to sort out good research from bad, and hence no sense in which the removal of barriers to entry will automatically lead to improved outcomes.

Rather the choice is between alternative mechanisms of funding and alternative funding bodies. Both mechanisms are contestable in the ordinary language sense of being open to competition. The first mechanism is one in which funding is given to institutions which appoint individual researchers, selected on the basis of their research record, with a degree of freedom as to the research program pursued after appointment. The second is one in which funding is allocated on a project basis, on the basis of proposals submitted by individuals and research organisation.

In fact, the distinctions are perhaps not quite so clear-cut. As time progresses, systems of project funding move towards a situation in which, in effect, researchers are rewarded for past research efforts. On the other hand, appointments to research groups are usually based, at least in part, on the fit between the research interest of the appointee and those of the existing group.

There is no general consensus on which of these funding mechanisms has produced superior output (Professor John Quiggin, correspondence).

Moreover, if in practice contestability prevents the development of long-term capabilities, and relationships, such competition may only ensure a continuing waste of research funds, as substantial energy is directed to beating the competitors. In this sort of environment, the competition for excellence may be a far more effective driver than the only lever available to the economist — the competition for resources.

In a pervasive knowledge economy, it is interactivity, rather than isolated organisational performance, which is all important. The important measures are those of the density, the quality, and the consequences of knowledge flows, as well as of the quality and relatedness of the knowledge itself, rather than the dollar and body input, and papers and patents output, of traditional research performance indicators.

In this model, the requirements for effectively directing the resources are twofold: first an intensely collaborative and continuous process to identify ‘knowledge-product spaces’ — those possibilities for combining knowledge as yet unavailable, with markets as yet unimagined, or environmental and social challenges as yet not fully articulated. The second component is marked by intense competition,
as knowledge producers and suppliers struggle to win backing for their approach, and to be the first to deliver the knowledge which allows all the other elements of the creative jigsaw to reveal their emergent shape, and fall into place.

The effectiveness of a collaborative research agenda rests firstly on being able to develop a strong knowledge capability. Such a capability will only be generated by a sufficient and steady investment in its development. Hence the need for national research resources maintained in the universities and public sector organisations like CSIRO.

The second determinant of research effectiveness is the strength of productive capacity, whether in business to generate economic growth, or in those organisations charged with responsibility for environmental, social or cultural matters. As we have experienced only too painfully in past eras of ‘science push’ in Australia, research cannot propel an unwilling or incapable industry into internationally competitive performance.

The third determinant of effectiveness in this type of research is the vitality of the collaborative processes themselves. Until recently, we had very little experience of, or success with, such collaborative agenda setting at a sufficiently strategic or long-term level. However, this is changing. The approaches adopted by a number of the rural R&D corporations, with their role as managers of the knowledge delivery process for their sectoral clients, and their involvement of researchers, users (direct and indirect), regulators, and relevant government officials provide one example. Another is the Cooperative Research Centre Program, with their structural integration of universities, public sector research organisations (predominantly CSIRO), and industry.

The collaborative processes, which subsequently become expressed through competitive activity, provide the major means for priority setting within sectors or disciplines. In many cases they will also cross these boundaries in pursuit of opportunities. However, the setting of boundaries at a broader level, as between agriculture, mining and manufacturing, or between, say the biological and the information sciences, will remain within the province of politics. However, in keeping with the principles for science policy outlined in the previous section, the political process can be considerably strengthened and enriched by bringing together groups of stakeholders to develop and disseminate a collective foresight on potential developments.

**Institutional Structure**

A modern knowledge-based economy involves a variety of organisations in the generation, exploitation and delivery of knowledge. Such
knowledge is necessary and central to problem solving, opportunity identification, driving future markets and securing a base for national sovereignty in a globally competitive economy. The case for a strong national research infrastructure is paramount in this context.

Moreover, as indicated previously, knowledge and research are themselves becoming increasingly global. The potential for CSIRO to build on its present research strengths and networks to develop as an international research organisation, networked with top research organisations elsewhere in the world, is very considerable.

In addition to this role, CSIRO already makes a vital contribution to the national innovation effort, including its ‘public good’ research. CSIRO is thus forced to juggle a number of quite separate roles and functions. In certain circumstances, there can be considerable tension, and even conflict, over the pursuit of different objectives. This will require the establishment and maintenance of appropriate systems to ensure these are clearly separated. However, the advantages to be gained from having a single ‘premier’ research organisation capable of responding to all these challenges are considerable, particularly because of the benefits of interaction from meeting these various requirements.

The universities will continue to play an important role in the knowledge economy also. Their educational responsibilities will become even more significant, but the delivery of learning will take many new forms. In this respect, their ability to access the global knowledge databases, and to assist in bringing knowledge to bear on action, will be a crucial infrastructural capability of the knowledge economy.

RESEARCH STRATEGY AND MANAGEMENT

A range of mechanisms, including priority setting, planning by objectives, contestability, selectivity, evaluation, application of performance indicators and requirements for accountability have been widely introduced into research organisation and management in recent years in countries around the world.

These have been interpreted as a structural response to resource limitations for research (Ziman, 1994). More broadly, they can be attributed to the emergence of ‘industrialised science’, resulting from the increasingly valuable contribution of research to economic growth, and hence the need to maximise the return on investment in research (Johnston, 1990).

Other causes appear to be the general movement towards fiscal constraint in the public sector, and a particular concern that publicly
supported research should not only meet the requirements of increased productivity being applied to other sectors, but also be appropriately directed towards 'national needs'.

There can be little argument against the need for improving the accountability and transparency of government research agencies' investment decisions, or for raising the efficiency of research.

But the ways in which this accountability and efficiency are achieved, and their contribution to the overall effectiveness of the research effort certainly deserve scrutiny. Thus far, the benefits of the introduction of a range of research management tools appear to be twofold. Firstly, they have provided a bureaucratic accountability which was previously absent, and which is widely regarded as being the appropriate way to guard the public purse. Secondly, in an era of strong competition for resources, they have provided what, while not universally accepted, has nevertheless been regarded as a neutral, rationing device.

There is also an emerging body of evidence suggesting that excessive attention to the new requirements of research management, and in particular, frequent changes of structure or management requirements, can lead to a reduction in the quality of the research activity itself.

Leading scientists such as Sir Gustav Nossal (1995) have sounded a warning that the expectation of scientists in CSIRO and the universities to 'do their bit for the nation's economic and social development' may be achieved at the expense of the excellence of their research.

Ziman (1994:251) has challenged the effectiveness, at least in their current manifestation, of some elements of the new research management repertoire, and questioned the impact of rapid refashioning of research systems which have evolved over many years. Thus,

The scientific enterprise is much too complex, interactive, diverse, inconsistent, self-actuating and contextually unpredictable to be represented by a working model and then redesigned to a new set of blueprints ...

Realistically, the most that we can usually do is to try to understand how an effective research system actually functions, so as to make sure that essential functions are not impeded as a result of seemingly harmless organizational change ...

The various practices through which the essential functions for 'good science' were traditionally performed have been melded with or replaced by a whole host of new practices and procedures ... In many cases, it is not even clear whether these functions are being carried out at all, even though they are vital to the long-term health of the enterprise.
In the United States, there have been warnings that:

short-run policies aiming to shift resources towards commercial applications of scientific knowledge (by dismantling bits of the distinctive institutional infrastructures of Science, or by weakening its ability to hold talented researchers in the face of competition from business) may seriously jeopardize a nation's capacity to benefit from a sustained flow of innovations based upon advances in scientific and technological knowledge (Dasgupta and David, 1994:493).

The institutional machinery and social dynamics of research are characterised as both intricate, and 'jerry-built' (perhaps rather like the Internet), and as such they may be less robust, and more sensitive to structural and managerial changes, than is commonly supposed.

It is also worth reflecting on the increasing imposition of bureaucratic decision-making and reporting requirements on researchers at the very time when command-control management systems are being rejected in private sector management as cumbersome and ineffective, and replaced by an emphasis on reduced levels of management, decentralised decision-making, and work group autonomy.

In summary, the special demands of knowledge work have never lent themselves well to excessive bureaucracy. The quite appropriate requirements of efficiency, accountability, and a focus on national needs cannot, however, be achieved through command-control management. The effective linkage of the knowledge worker to national priorities is more likely to be achieved through partnership, and a management style of directed autonomy.

It is these issues which form the subject matter of Chapter 4.