International Trends in Public Sector Support for Research and Experimental Development

A preliminary analysis

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Preface

The terms of reference for this study were as follows.

The consultant will provide a report that:

• Identifies those countries where significant and recent (five years or less) R&D initiatives have taken place. We expect such countries to include Japan, the UK, Germany, Canada, Finland, South Korea, Singapore, New Zealand and the United States;

• Examines initiatives in these countries that aim to increase public sector R&D spending and which have significant implications for the higher education sector;

• Examines private sector, private non-profit R&D spending or other R&D initiatives that have implications for higher education research, with particular emphasis on basic research; and

• Analyses these trends with possible implications for Australia’s own relative public sector R&D and basic research performance.

Acknowledgments

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## Abbreviations and acronyms

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<th>Description</th>
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<tbody>
<tr>
<td>APEC</td>
<td>Asia-Pacific Economic Co-operation</td>
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<td>ARC</td>
<td>Australian Research Council</td>
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<td>BERD</td>
<td>Business Enterprise R&amp;D</td>
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<td>CRADA</td>
<td>Co-operative Research and Development Agreement (US)</td>
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<tr>
<td>CRC</td>
<td>Co-operative Research Centre (Australia)</td>
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<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation (Australia)</td>
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<tr>
<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council (UK)</td>
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<tr>
<td>ERC</td>
<td>Engineering Research Centre (US)</td>
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<tr>
<td>G7</td>
<td>Group of 7 industrial nations</td>
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<td>GATT</td>
<td>General Agreement on Tariffs and Trade</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GERD</td>
<td>Gross Expenditure on R&amp;D</td>
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<td>GRO</td>
<td>Government Research Organisation</td>
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<tr>
<td>HERD</td>
<td>Higher Education R&amp;D</td>
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<td>IMI</td>
<td>Innovative Manufacturing Initiative (UK)</td>
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<tr>
<td>IURC</td>
<td>Industry/University Co-operative Research Centre (US)</td>
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<tr>
<td>MITI</td>
<td>Ministry of International Trade and Industry (Japan)</td>
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<td>MRC</td>
<td>Medical Research Council (Canada)</td>
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<tr>
<td>NCE</td>
<td>Network of Centres of Excellence (Canada)</td>
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<td>NSERC</td>
<td>National Science and Engineering Research Council (Canada)</td>
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<tr>
<td>NSF</td>
<td>National Science Foundation (US)</td>
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<td>NSTB</td>
<td>National Science and Technology Board (Singapore)</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
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<tr>
<td>PRI</td>
<td>Public Research Institutes</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Experimental Development</td>
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<tr>
<td>ROPA</td>
<td>Realising Our Potential Award (UK)</td>
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<td>RTO</td>
<td>Research and Training Organisation</td>
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International Trends in Public Sector Support for Research and Experimental Development: A Preliminary Analysis

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>SPEDE</td>
<td>Structured Process Elicitation and Demonstration Environment (UK)</td>
</tr>
<tr>
<td>SPIRT</td>
<td>Strategic Partnerships with Industry Research &amp; Training (Australia)</td>
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<tr>
<td>SSHRC</td>
<td>Social Science and Humanities Research Council (Canada)</td>
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<tr>
<td>TCS</td>
<td>Teaching Company Scheme (UK)</td>
</tr>
<tr>
<td>TC</td>
<td>Technology Centre (US)</td>
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<tr>
<td>TEKES</td>
<td>Technology Development Centre (Finland)</td>
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<tr>
<td>U3M</td>
<td>University of the Third Millennium (France)</td>
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<tr>
<td>UK</td>
<td>United Kingdom</td>
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<td>US</td>
<td>United States</td>
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<td>WMG</td>
<td>Warwick Manufacturing Group</td>
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<td>WTO</td>
<td>World Trade Organisation</td>
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Executive summary

Synopsis

This report discusses the findings from a preliminary study of international trends in public sector, and private non-profit sector, support for research and experimental development (R&D). The brief was to examine significant initiatives in a range of countries and to assess the implications of these trends and initiatives for Australian policy.

The study suggests that there is compelling evidence of convergence both in policies and in R&D expenditure profiles during the 1990s. This policy convergence involves moves towards a more balanced emphasis on supporting discovery and linkage-building. The Department of Education, Training and Youth Affair’s proposals to improve this balance are therefore in line with overseas trends.

The caveat is that the time-frame and budget for this preliminary study have not allowed a particularly extensive and detailed analysis to be carried out. The convergence finding should therefore be treated as a hypothesis to be tested via a more extensive and detailed study. Such a study should await the publication of updated R&D data by the OECD.

Context

The rationale and objectives for public sector support for research and development (R&D) are in the process of substantial transformation.

The emergence of the knowledge economy, reflected in the markedly accelerated supply of, and demand for, market-oriented knowledge, has placed knowledge and its creation even more clearly at the heart of the modern competitive economy.

At the same time, the general trend in Western nations away from government intervention in the market place, coupled with constraints on public expenditure, has increased the competition for the public purse from a range of worthy ‘public good’ causes.

These, and other, forces have led to the role of basic research being both questioned and, arguably, transformed.
Some have argued that the importance of knowledge production and interpretation in modern economies provides a clear and unchallengeable rationale for substantial public investment in basic research. An alternative argument is that within a national innovation system, performance in the knowledge economy is determined less by knowledge creation than the 'distribution power' of the system, to ensure timely access by innovators to relevant stocks of knowledge.

Traditional approaches, essentially based on the 'one-way' linear model of innovation, treat knowledge production and knowledge application as largely distinct activities. Both may be necessary to achieve the economic benefits of research, but their practice and their funding are separate endeavors. Indeed, the research community often sees investment in application and diffusion as being at the expense of research.

This traditional perspective, we would claim, is based upon an outdated view of both the knowledge production and knowledge application processes, and their interaction. Analysis of theoretical issues, international policies and actual patterns of investment indicate the emergence of a new model in which discovery and application are effectively fused, and linkages in both components are of crucial importance. This new model takes knowledge discovery and knowledge linkages as its central components.

**An appropriate policy framework for investment in discovery and linkages**

The discovery process is based, in part, upon feedback. Theory advances via empirical testing, not just in basic and applied research but also in experimental development and subsequent activities. Shortcomings in current theory are revealed by both deliberate experimentation and by the unanticipated outcomes in practical applications. The result is a two-way integrated process of knowledge advancement in which basic research, applied research and experimental development can be closely linked. Linkages are, in principle, an integral part of the overall discovery process, particularly when different types of research and their application are carried out in different sectors.

Under the competitive conditions in the knowledge economy, leading firms are seeking to reduce the large investments in experimental development that partly reflect weak predictive theoretical capability (ie building products and processes to see if they are safe and work effectively because theory cannot, yet, predict this with sufficient accuracy).
At the same time, there is a progressive strengthening of the linkages between the various components of the national innovation system resulting from a growing recognition of their interdependence. A variety of interface organisations have emerged to promote these linkages. Although the precise institutional form of these interface organisations varies internationally, the underlying capabilities are common.

The increasingly integrated nature of the discovery process is clearest in those countries in which both the research base and industry operate at, or near, their respective scientific and technological frontiers, most notably in the US. This integration can result in a virtuous circle in which intersectoral research collaboration and application via linkage-mechanisms improves linkage effectiveness via ‘de-bugging’ learning-by-doing, so lowering the risks and increasing the pay-offs associated with future collaboration.

This ‘learning-by-doing’ in linkage building often requires government support in order to overcome market failure in resource allocations and to obtain public good benefits. This is because cultural and legal impediments to linkage-building can limit what would otherwise be beneficial collaboration, yet these impediments can only be reduced via actual experience with linkage-building. In many cases this initial experience will need to be subsidised in order to offset the risks involved.

The greatest challenge to achieving this ‘virtuous circle’ of learning-by-doing in Australia is the low level of industry investment in R&D, and the underlying cultural perspective towards innovation this reflects. This results in a mismatch between public sector and private sector capabilities.

**International trends in investment in discovery and linkages**

A preliminary analysis of international trends in public sector support for R&D as expressed in policy and budget initiatives suggests that many countries have recently begun to converge in the emphasis placed upon discovery and linkages:

- Those countries that have traditionally placed a strong policy emphasis upon investment in discovery are now seeking to ‘re-balance’ this investment with more linkage-oriented investment and support mechanisms. Better industry-higher education and government research organisation linkages feature strongly in these older science powers. The United States, the United Kingdom, and Australia exemplify this trend.
• Those countries that have developed strong linkage capabilities (mainly within and between the business and government sectors) as part of their technology catch-up strategies are now attempting to develop better discovery capabilities. Japan, and Singapore are exemplars of this trend. However, industry-higher education linkages are not particularly well developed in these countries and they consequently face a problem in building discovery capabilities.

As a result, a new mode of converging public sector support for R&D appears to be emerging in which the overall capability of national science and innovation systems is seen as resting upon an appropriate balance between discovery and linkage investments.

An examination of readily available statistical data on the changes in each R&D performing sector’s share of national basic research and applied research expenditure (in the small sample of countries for which adequate data is available) indicates a similar process of convergence in the sectoral distribution of R&D activity during the 1990s. Over this period, the sectoral distribution of R&D activity exhibits a ‘regression to the mean’ with each performing sectors’ share of the different types of R&D converging upon apparent international norms.

Industry in the US is re-focussing R&D investment away from basic research and in favour of applied research and experimental development. Stronger research linkages with the higher education sector and government research organisations are being used to compensate for relative reductions in the business sector’s internal basic research effort.

The public sector R&D performers—higher education and government research organisations—appear to be settling upon norms for shares of basic and applied research expenditure which increasingly reflect their more integrated role in the R&D system. The result is more balanced basic and applied research activity with greater linkages to other R&D performing sectors.

The emerging R&D systems would seem, therefore, to be characterised by a more effective balance in:

• The distribution of investment between basic research, applied research and experimental development into the most appropriate performing sectors given existing linkage-capabilities and distinctive capabilities; and

• The relative emphasis placed upon linkage-building: within the R&D system; between the R&D system and the rest of a nation’s economic activity; and, internationally.
Conclusions

• Integrative capacity both within national science and innovation systems, and between different national systems (i.e., linkages), is likely to be a major determining factor in the future wealth of nations. There is evidence that policy priorities overseas are now focusing upon ‘balanced’ investments in discovery and linkages.

• Public sector support for R&D is increasingly reflecting attempts to integrate the different R&D performing sectors better than has been the case in the past. As a result, the sectoral distribution of national R&D efforts may be converging on new international norms.

• Sufficient linkage building will not necessarily occur without focused government support. This is because linkage building is affected by market failure. As a result, markets may not be efficient resource allocation mechanisms because past experience will ‘lock out’ potentially productive linkage-based investment options.

• Structural weaknesses in industry R&D in Australia will limit the pay-offs to more balanced investment in discovery and linkages.

• The best means of overcoming the industry R&D and innovation capability constraint is to facilitate stronger cross-border linkages between the Australian science-base and overseas industry. This will build the Australian science base’s capability to work closely with industry, which will in turn help to attract high-technology foreign direct investment into Australia in order to exploit this discovery capacity. A more balanced emphasis on discovery and linkages in Australian R&D policy should consequently emphasise international linkages as much as domestic linkages. This international focus is also in line with overseas approaches.
1 Introduction

1.1 The need for an improved framework for examining trends in public sector support for R&D

The terms of reference for this study set out an important empirical challenge: to assess overseas trends in public sector, and private non-profit sector, support for R&D and to draw conclusions as to the implications of these trends for Australia.

As the study progressed it became clear that this empirical challenge required an analytical policy-framework in order to attempt to make sense of the various overseas trends, but that no such framework could be readily found in the literature in an integrated form.

The policy literature identifies several key trends in the changing role of scientific knowledge in modern industrial economies, most notably:

- The increasingly systemic nature of knowledge flows within economies (national innovation and international innovation systems);
- Changing relationships between the sectors comprising these systems with respect to knowledge creation and diffusion (the new emerging division of labour sometimes called 'mode 2'); and
- The increasingly international nature of these knowledge flows, particularly in the private sector.

However, there appeared to be no generic framework able to translate these insights into an analytical framework suitable for practical use in informing policy. The next section (Section Two) addresses this issue and seeks to develop such a framework.

Section Three then applies this framework to the readily available quantitative and qualitative information on public sector support for R&D in different countries. Section four draws conclusions for Australia.

1 Gibbons, Limoges et al. (1994).
1.2 The evolving role of science in knowledge-based economies

The science system has traditionally been considered the primary producer of new knowledge, largely through basic research carried out in universities and government laboratories. This new knowledge, generally termed science, has traditionally been distinguished from technological knowledge generated by more applied or commercial research, which is closer to the market and/or practical application—such as in defence.

In the knowledge-based economy, the distinction between basic and applied research and between science and technology has become somewhat blurred. There is debate as to the exact line between science and technology and whether the public sector science system is the only or main producer of new knowledge. This debate is important because of different views on the appropriate role of government in funding the production and the diffusion of various types of knowledge.

This debate is part of a larger proposition that the very basis and structure for the production and application of knowledge is being transformed, or at least augmented. The traditional model of knowledge generation and application, labelled ‘Mode 1’ by Gibbons et al, has the following characteristics:

- Problems are set and solved in a context governed by the largely academic interests of the relevant research community;
- Problems, research agendas and accepted solutions are largely determined within a disciplinary framework;
- The community of discourse is homogeneous;
- Its form of organisation is hierarchical, and there is a tendency, if not an outright commitment, to preserve existing forms of organisation; and
- It maintains a high level of internal quality control.

This approach carries a clear distinction between what is disciplinary and internal—basic research, and what is shaped by external interests—applied research and technology development.

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2 See Dasqupta and David (1994), Brooks (1994) and Gibbons, Limoges et al. (1994) for discussions of these issues.

3 Gibbons, Limoges et al. (1994)
According to Gibbons et al, the expansion in both knowledge production and the demand for specialised knowledge has created the conditions for a new mode of knowledge production, called 'Mode 2', which is characterised by:

- Problems substantially set and solved in the context of application;
- A transdisciplinary approach;
- A heterogeneous set of skills directed to knowledge production;
- Weakly institutionalised, transient, and heterarchical organisational forms; and
- Quality control against a wider set of application criteria.

This provides a new basis for understanding the changing and more integrated role of knowledge production, its discovery, application and linkages, in producing a competitive knowledge economy.

1.3 Why the contemporary policy emphasis on linkages?

Over the last decade or so terms such as 'partnership', 'collaboration' and 'cooperation' have increased in prominence in policy statements relating to public sector support for research and experimental development (R&D).

For example, it is hard to find a United Kingdom science and innovation policy statement, under both the current and previous government that does not mention these policy objectives. Statements from the United States government place a similar emphasis on these issues.

Precisely why these 'linkage-focused' principles are important is less well articulated, aside from the general presumption that more partnerships and collaboration will improve innovation effectiveness via better communication over research requirements, capabilities, cost-sharing and the general advantages of a more effective division of labour. These improvements are usually couched in terms of market failure.

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4 Johnston (1998)
5 The incoming Clinton administration moved quickly to unveil a wide range of programs and initiatives that deliberately facilitated cross-sectoral partnership building. See Branscomb and Keller (1998) for a thorough analysis of the Clinton-Gore policy initiatives and their longer term implications.
6 See Cervantes (1998) and other contributions in a special issue of STI Review.
It is only recently that policy observers, reacting to actual policy initiatives, have started to develop and refine analytical tools that help to clarify why investment in linkage building is so important.

The linkage-focused policies have resulted in new initiatives and mechanisms aimed at facilitating partnerships, collaboration and cooperation—particularly between universities, business enterprises and government research organisations.

Examples include: Cooperative Research Centres (CRCs) in Australia; the US Cooperative Research and Development Agreements (CRADA’s); and, the UK’s range of partnership-focussed programs and initiatives, such as, the ‘University Challenge’ 7

These initiatives often challenge traditional ideas about the ‘fit and proper’ role of organisations in these sectors. Critics of the Clinton-Gore research and technology policy framework, for example, have stressed the ‘corporate welfare’ factor: the diversion of resources to subsidise what are seen by many as strictly private sector concerns.8

In a similar vein, a gradual move towards a higher level of prioritisation and emphasis on linkages in Sweden has produced a strong response from the scientific community, who have argued that all government research agencies and instrumentalities should be closed, and the resultant funds channelled to university researchers.

The new initiatives also require academics and business people to attempt to interact usefully and this is inevitably a difficult learning process. Of particular concern to some is the extent to which greater university-industry interaction is seen as potentially, or actually, diluting university researchers’ dominant focus upon basic research—to the eventual detriment of the economy as a whole.9

However, the new requirements of the knowledge economy, and the crucial role of the national innovation system, provide a new and far more...
valid justification of the role of basic research, within a quite different context and set of constraints and requirements.

1.4 Towards an appropriate model of research and innovation process

It is now common for policy reports to observe that ‘the traditional linear model linking basic research in the public sector and industry exploitation’ is defunct and to mention other more complex models of the innovation process.10 The problem is that these newer models tend to confuse senior policy makers, who in the end tend to fall back upon a simpler traditional perspective because it is readily understandable, and supported by standardised OECD data.11

This issue is examined in the next Section and based on the premise that policy is best informed by a simple model that helps to pick out key aspects of trends in public sector support for R&D in different countries. In other words, a model that is ‘vaguely right and usable for policy’ is more preferable than one which is ‘strictly correct but not usable for policy’. Indeed, the main problem with complex ‘non-linear’ models is that they require some form of simulation exercise to illustrate their behaviour and policy implications, or detailed case studies. Neither of these is necessarily a persuasive means of informing high-level policy-makers.

The framework we put forward has the advantage of simplicity and is based upon identifying the key processes involved in improving knowledge via theory and experimental testing rather than attempting to interpret an existing division of labour in the science and innovation system.

By starting at this level we are then able to demonstrate the importance of effective linkages between basic research, applied research, experimental development as well as subsequent product development and market introduction, using existing categories and data. Building inter-sectoral

10 Models include ‘chain-linked’ and ‘fifth generation’. See Dodgson (2000 forthcoming) for an up to date overview of models of the innovation process. In a sense these new models exemplify one of the problems in academic-industry-policy interaction. They are the product of ‘inward’ discourse within academia and consequently do not attempt to deliver the ‘operational capability’ required by policy-makers.

11 Although, as we will demonstrate in this paper, the OECD data can be interpreted in a rather different, and we would suggest, more useful way.
linkages is important because different sectors are responsible for different parts of this (in principle) integrated knowledge-improvement process.

The suggested framework allows policy issues relevant to optimising the relationships between ‘discovery’ oriented investment and ‘linkage’ oriented investment to be clearly identified.
2 A policy framework for examining trends in public sector support for research and experimental development

This section considers the linkages that can exist within the discovery process in addition to the linkages that can exist between the discovery process and the practical application of scientific knowledge. This discussion of the role of linkages within the discovery process moves beyond the widely accepted view that linkages are essentially a knowledge diffusion mechanism.\(^\text{12}\)

The latter perception is still dominant in policy circles and is clearly evident in the OECD-backed work on ‘national innovation systems’ in which linkages are explicitly treated as knowledge diffusion mechanisms.

Although the role of this type of ‘diffusion’ linkage is central to the role of universities in modern economies it is not an exclusive role. Universities, particularly those overseas, are enmeshed in a far more complex web of linkages with the private sector. If we want to understand what this role is and how it is changing, then we need an appropriate model for doing so—that is a model that does not start by assuming away the very thing that we are interested in, namely, linkages within the discovery process.\(^\text{13}\)

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\(^{12}\) The traditional ‘public good’ perspective towards basic research (the core discovery activity) is surveyed in Martin (1996). Arnold and Balazs (1998) and builds upon this approach. Other discussions of relevance are Steinmuller (1994) and Pavitt (1997).

\(^{13}\) Indeed, it is worth pointing out that most of the studies of the ‘importance of basic research’ and the role of universities in ‘national innovation systems’ have been carried out by academics. Academics will naturally tend to justify both the role of universities and the importance of basic research in ways that suits their own interests. Unfortunately, industry’s reluctance to open its doors to detailed research on what industrial R&D actually consists of helps to re-enforce what is arguably a distorted view of the reality of R&D and innovation investment.
2.1 **Linkages within the discovery process: R&D as an integrated theory—refinement and exploratory process**

This sub-section attempts to define the dynamic knowledge-generating processes that link basic research, applied research and experimental development, and also subsequent non-R&D activities. We argue that understanding this knowledge-generating dynamic is the key to understanding the importance of linkages.

This perspective builds on consulting studies carried out as part of efforts to define the ways in which academic research and industrial R&D can be more closely linked. The perspective is new because it ‘unpacks’ what actually goes on within the R&D process per se, and between R&D and other processes, using what amounts to a philosophy of science perspective. In other words, it asks how, and in what ways, the different activities comprising R&D actually develop the theoretical understanding of phenomena. It recognises that researchers in universities and government research organisations are not the only people for whom theoretical capabilities are an explicit research objective.

All countries exhibit an overall generic division of labour in the various sectors that comprise the national science and innovation system. In this division of labour:

- Universities concentrate on basic research, research training and teaching, with a subsidiary emphasis on applied research;
- Government laboratories/research organisations concentrate on applied research with a subsidiary emphasis on supporting basic research and

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14 The analysis draws heavily upon a recently completed study for the Australian Research Council Howard and Matthews (1999 Forthcoming) and a previous study for the UK Engineering and Physical Sciences Research Council (EPSRC) Broughton, Deasley et al. (1995). The latter study, which reported on consultations with industrialists over the forms of research collaboration with universities which they would like to engage in, highlighted the fact that advanced theoretical capability aimed at reducing current levels of experimental development investment levels is a major objective for leading firms.

15 Although elements of this (applicable) theory-based perspective can be found in the literature, see for example Vincenti (1990) and Brooks (1994) it has yet to be given the prominence that it deserves—particularly given the emphasis put on this theoretical capability in leading firms’ (proprietary) technology strategies. Although ‘feed-back’ processes within the R&D process are noted in passing, see for example Australian National University (1999), and explicitly recognised in the guidelines for collection official statistics on R&D, the wider implications of this feed-back is not given the prominence in deserves.
experimental development (the exception being some of the major basic-research focussed defence-research laboratories in the US—these have a larger, but declining, emphasis on basic research);

- The private non-profit sector has a similar activity focus to government laboratories often with rather more emphasis on basic research, and is often highly focussed on medical research; and

- Industry concentrates on experimental development with supporting investment in applied research, and a relatively low level of ‘gap filling’ basic research (focusing on theoretical capabilities and exploratory investigation not provided by the science base and/or viewed as too valuable to be carried out beyond the firm, or by trusted contractors).16

The following two graphs illustrate the key features of this division of labour using US R&D data.

Figure 1: Distribution of R&D types across performing sectors, US 1996.

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Whilst some commentators have expressed reservations about the adequacy of these R&D expenditure categories for policy analysis, often suggesting alternative and more complex approaches, one fundamental point is often overlooked.\(^{17}\) This is that research and experimental development do not share the same underlying rationale for investment.

Research, in general, generates knowledge that creates options for doing things in the future. These options are often based upon the development of fundamental theoretical understanding and can be commercial, military, health-oriented and social in nature. The option-generation characteristic of research applies both in the public and private sectors.\(^{18}\)

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\(^{17}\) The basic argument against using this breakdown of R&D is that decisions made about how to classify different R&D projects can be rather arbitrary. These inaccuracies are therefore reflected in the expenditure data collected from each R&D performing organisation. For example, an R&D project may start out being defined as a basic research project and end up 3 years later as an applied research project. Also, particularly at the interface between the three main types of R&D, the need to 'force' a project into one or other category can lead to over and under-estimates of the different types of R&D expenditure. It is also the case that many respondents to R&D surveys have difficulty in understanding the rationale for drawing these distinctions. This results in the somewhat paradoxical situation that policy discussions over the relative importance of investment in basic research are not backed up by comparative statistical examinations of the relative importance of basic research vis-a-vis applied research and experimental development even though many countries collect these data.
Experimental development involves investigations into the viability of these options. In other words, it generates information on the actual behaviour of mechanisms and systems and in turn, informs decision-making over how much further to pursue a set of options. Information derived from experimental development is characteristically expensive to obtain.

Having a large number of technology options and the capacity to evaluate, select and develop these options quickly and cheaply is an important determinant of competitive success. Leading firms adopt a form of 'mutation-selection' process designed to generate a wide range of technology options (at low cost—on paper/computer simulation if possible) and then apply successive, and increasingly expensive, selection processes in order to identify the most suitable options for full scale development and production. It is recognised in industry that one key determinant of commercial success in using the R&D process is management’s capacity to stop experimental development projects even when they have built up considerable momentum.

The key distinction between generating options via (often basic) research and investing in getting more information about the viability of these options is that you can never have enough options, yet the determining their potential is simply a cost to be reduced.

The theoretical understanding produced by research provides a capability to be able to model and predict the behaviour of real mechanisms and processes. The better this predictive capability the lower the requirement to actually construct and test real mechanisms and processes.

This results in a close, and very important, relationship between basic research and experimental development, a relationship in which applied research plays a key role. A virtuous circle can therefore be created by a close coupling of basic research and experimental development. This circle is based upon feedback between the findings obtained in experimental development and improvements to theory.

When there is a close correlation between theory and actual behaviour, ie the theory ‘works’, then many, commonly expensive aspects of experimental development can be reduced or even eliminated. Often, experimental development precedes and drives the ‘upstream’ theoretical

18 It is a documented fact that business firms explore a wider range of technologies in their R&D activities than are actually used in commercial operations—this reflects the option-generation aspect of R&D. However, most of this option-generating activity is concentrated in the ‘R’ rather than the ‘D’.

research that may eventually allow whole areas of experimental
development to be eliminated.

The history of engineering science shows a strong focus on building this
virtuous circle between theory and experimentation with the objective of
improving the theoretical capacity to predict real behaviours.20 Hypothesis
testing and more 'inductive' investigations in basic research tend to involve
experiments to develop and test theories. Likewise, the linkage between
research and experimental development involves the same two-way
theory-experiment relationship. Improvements to theory frequently involve
identifying and explaining anomalies and other differences between actual
and predicted behaviour.

Experimental development is therefore a mix of activities that are
necessary in order to compensate for inadequate theoretical/modelling
capability relative to the world science and technology frontier and other,
more exploratory, investigations that are way beyond state-of-the art
theoretical/modelling capability.

A key policy issue in every nation is therefore: what is this mix of state-of-
the-art and 'poor relative capability' in experimental development in each
industry sector and what are the implications of these capability mixes for
linkages to university and GRO research?

Illustration: The links between experimental development and theoretical capacity in the aerospace industry

The demanding product performance parameters for modern aircraft have driven attempts to closely couple the process of experimental development to improvements in the fundamental understanding of such things as:

- aerodynamic behaviour in the complex non-linear environments exemplified by turbulent air flow;
- the behaviour of complex structures under dynamic loads; and
- complex thermodynamic behaviour within aero-engines.

Aerospace engineers devote considerable effort to examining the correlations between the actual behaviour of different aircraft structures and systems and the behaviour predicted by computer models. These models are based upon state-of-the-art theoretical understanding, e.g. highly sophisticated computational fluid dynamics equations.\(^{21}\) When predicted behaviour does not correlate with actual behaviour during applied research and experimental development efforts are made to improve both the fundamental theoretical equations and the simulation models that execute these equations. Experimental development is, literally, the experimental testing of advanced theory for commercial and military ends.

Civil aircraft ‘air worthiness’ certification authorities are willing to accept simulation model results for modified systems and structures when a close correlation between theory and actual behaviour in the ‘parent’ systems and structures can be demonstrated. This can dramatically reduce development times and costs, particularly for model variants, in which small modifications can be shown to be within the predictive ‘envelope’ of existing simulation models—reducing the need to physically demonstrate compliance with operational standards. This close coupling of theoretical research and experimental development activity is not unique to the aerospace industry, however the massive cold-war defence research budgets in this area have helped to put the aerospace industry at the scientific/technological frontier in this respect.

\(^{21}\) Interestingly, some aerodynamicists contend that the basic theory of aerodynamic behaviour has been worked out and is mbust, whilst others contend that it is far weaker and requires a considerable effort in order to explain all observed behaviour.
2.2 **The special role of basic research in identifying ‘blind alleys’ in industrial technology**

The role played by basic research that identifies 'blind alleys' in the technology-based competitive process is particularly important—as long as such research results are proprietary.

An industry-funded basic research project that concludes that a particular technological avenue is highly unlikely to prove to be is of great value when the results are kept secret. This is because it increases the probability that competitors may pursue this technological avenue and thus waste money.

The weaker the competitors' theoretical research capabilities the larger the value of the investment they are likely to waste (the cost of R&D escalates as one moves from basic research to experimental development). In other words, the scientifically ‘unsuccessful’ research project has a high economic value to the private investor provided that this failure is kept secret.

This produces an interesting difference between public sector and private sector investment in basic research. The scientifically unsuccessful public sector research project will be more likely to disseminate the fact that a particular technological avenue is highly likely to be a blind alley—thus avoiding wasteful investigations in the future. The public good value of the ‘unsuccessful’ investigation is therefore the value of future research expenditure that would otherwise be wasted (both in the public and private sectors).

However, the incentive structure in the public sector research system (publication of successful research findings) may severely limit this pay-off to the public investment in research. Policy towards public sector research should therefore ensure that sufficient mechanisms and incentives exist to communicate unsuccessful research findings.

Policy should also recognise that a large incentive for business investment in basic research is the ability to keep such results secret. It follows that collaborative industry-academic research and the basic research end of the spectrum will be severely constrained, unless public sector researchers accept stringent restrictions on their ability to publish.

We can observe this syndrome emerging in economies in which there is a critical mass of R&D intensive firms. These firms tend to focus their collaborative research with the public sector research system on applied research.

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22 This sub-section draws upon an argument put forward in Matthews (1998)
2.3 Understanding industry-academic research linkages

The following diagram expresses something of the complexity of the R&D linkages that can exist between academic research and industry R&D. At the top we can see the sequence of activities that translate market intelligence into the definitions of products and processes that will actually enter detailed design, development and full scale production.

The set of industry R&D activities below these commercial activities are driven by, and in turn inform, the firm’s technology strategy. The role of academic research, from an industrial perspective, is to interface mainly with the firms’ applied research and experimental development activity. The in-house basic research is more likely to be ‘off limits’ to academic research collaborators unless specific, confidential, consultancy arrangements are made.

This ‘mapping’ of the R&D and commercial processes (which is highly simplified) does illustrate some of the difficulties that are encountered with ‘commercialising’ public sector research. As can be seen, industry’s investments are related to a set of inter-related market-driven strategies (in the upper diagonal set of activities) and the investment options originating in universities, for example, will need to ‘mesh’ with existing strategies and capabilities. The fact that many inventions do not ‘mesh’ is what drives the high rate of small technology start-up companies in the US ‘spawned’ from larger companies.

23 This perspective towards basic research was identified via a series of interviews and focus groups with industrialists in the UK aerospace industry, see Broughton, Deasley et al. (1995) for a report on these consultations.

24 This ‘spawning’ process means that the individuals in the small start-up companies are reacting against commercial strategies and capabilities that they are familiar with as compared to entering the commercial domain for the first time. The lack of large and medium sized technology-based companies in Australia dramatically reduces the incidence of this spawning process and results in severe managerial capacity problems in the research commercialisation process, see Matthews and Johnston (1998).
2.4 The linkages between discovery and the practical application of scientific knowledge

The above argument suggests that linkages can play an important role within the discovery process by coupling theory testing in the experimental development stage with theory-development in the basic and applied research stages.

There are, however, other types of linkages that are more concerned with knowledge-dissemination than with discovery processes per se, which are examined here.

National economies are characterised by different degrees of ‘distribution power’ in their ability to transfer knowledge within and across networks of knowledge production and application institutions. The distribution power of an economy depends partly on the existence of institutions, such as those of higher education, which have a responsibility for distributing knowledge. It also depends upon investing in the skills for finding and adapting knowledge for use, and in developing bridging units or centres.

In Australia, as in many other countries, government research organisations, notably the CSIRO, focus on applied research supported by basic research and experimental development. Part of the mission of these
research organisations is to provide this integrating capability by focusing R&D upon specific socio-economic objectives.

Because there is this sectoral division of labour in terms of the emphasis placed upon basic research, applied research and experimental development (and product development) these ‘knowledge-distribution’ inter-sectoral linkages are crucial for the effective functioning of the overall system. This point is already well captured in the literature and in policy perspectives and there is therefore no need to repeat it here.

2.5 A taxonomy of linkages

We have proposed a model of the discovery process in which linkages are a central capability because of the need to operate with a division of labour within R&D and between R&D and other activities that cross sectoral boundaries.

It is helpful to use a simple taxonomy of linkages in order to be clear about the different types of linkage that can exist.

There are four fundamental characteristics of linkages:
• Intra-sectoral: linkages that do not cross sectoral boundaries;
• Inter-sectoral: linkages that cross sectoral boundaries;
• Intra-R&D: linkages that do not transcend the R&D process; and
• R&D to non-R&D: linkages that transcend the R&D process.

The combination of these fundamental characteristics generates the following taxonomy of linkages:
International Trends in Public Sector Support for Research and Experimental Development: A Preliminary Analysis

Table 1: Taxonomy of linkages

<table>
<thead>
<tr>
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<th>Intra-sectoral</th>
<th>Inter-sectoral</th>
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<tbody>
<tr>
<td>Intra-R&amp;D</td>
<td>Linkages between organisations in the same R&amp;D performing sector which do not transcend the R&amp;D process.</td>
<td>Linkages between organisations in different R&amp;D performing sectors which do not transcend the R&amp;D process.</td>
</tr>
<tr>
<td></td>
<td>eg. university-university research collaboration</td>
<td>eg. university-G RO research collaboration</td>
</tr>
<tr>
<td>R&amp;D to non-R&amp;D</td>
<td>Linkages between organisations in the same R&amp;D performing sector that extend beyond the R&amp;D process.</td>
<td>Linkages between organisations in different R&amp;D performing sectors that extend beyond the R&amp;D process.</td>
</tr>
<tr>
<td></td>
<td>eg. business-business research commercialisation consortia</td>
<td>eg. university-business research commercialisation partnerships</td>
</tr>
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International linkages introduce a further dimension. Thus, each of the four types of linkage can also be national, bilateral or multinational in extent.

We suggest that this taxonomy provides a useful policy tool for dealing with linkages. In particular, for assessing any gap between existing linkage-building priorities and target priorities.

The Australian Cooperative Research Centre (CRC) program, for example, involves support for inter-sectoral—intra-R&D linkages, as do the SPIRT and Key Centre programs. Linkage-building programs that target the R&D to non-R&D dimension are rarer in Australia—yet, in many respects, the translation of research options into market introduction is the most pressing policy challenge.
2.6 The role of interface organisations in linkage-building

In some countries, such as the UK, industry/trade associations have been closely involved in the establishment and operation of interface organisations and capabilities. The extent to which industry associations seek to play an active role in national innovation systems varies markedly between countries.

The UK industry research and training organisations (RTOs) provide an important interface between industry and the university sector. This role goes back to the 1920s and 1930s period in which university-industry interactions were far lower than today. These organisations exhibit a wide variation in their genesis, longevity, modes of governance, and sources of finance.

There is now a substantial body of academic research that highlights the key role played by interface organisations that mediate university-industry interactions.25

As Dodgson and Bessant observe:

“…research and technology organisations (RTOs) working on a sectoral basis are playing an increasingly important role, not just in generating technology or providing technical services to members but also in identifying, understanding and articulating user needs, and tailoring suitable solutions to these needs.”26

These interface, or buffer, organisations have evolved as a means of reconciling the incompatibilities between universities (and other essentially academic organisations) and profit-driven industry. Some RTOs have their roots in professional and trade associations, others in regional economic development initiatives, others stem from central government initiatives. Indeed, some of these interface capabilities are provided by universities themselves.27

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25 See Dodgson and Bessant (1996) for a discussion of the role played by this type of organisation.
26 Ibid, p183
27 For example, the Warwick Manufacturing Group (WMG) part of the University of Warwick is a very large and financially successful interface organization that receives large amounts of industry funding, partly to act as this sort of buffer. The WMG provides executive short courses, MSc level teaching in engineering management etc and acts as an infrastructure for collaborative research both between universities and industry and intra-industry.
RTOs help to absorb the stresses and strains that inevitably occur in university-industry interactions given the different objectives of each type of organisation.

Although there is this wide diversity in the type of organisation involved, they share the characteristic that they inter-mediate between the distinctive objectives of universities and industry. They often have a sectoral focus.

Given the importance of these RTOs any analysis of public support for R&D must consider policies that impact upon these RTOs, and international differences in this ‘interface’ capability between nations.

2.7 Linkage-building as investment in ‘social capital’

Social capital ‘refers to features of social organisation, such as networks, norms, and trust, that facilitate co-ordination and co-operation for mutual benefit’. Social capital can be thought of as the ‘glue’ that allows physical capital and human capital to work together effectively. Without adequate investment in social capital existing physical capital and human capital can be insufficiently exploited because there is insufficient trust and shared expectations to overcome the inherent risks in knowledge-based interactions.

Co-operative and collaborative research provides a good example of this. Such interactions will tend to fail irrespective of the scope and severity of the contractual and institutional mechanisms used if there is insufficient trust between the partners. Trust and shared expectations overcomes the inevitable problems that will be encountered in such collaboration.

The concept of social capital is being explored in the United States by researchers and policy-makers because it helps to explain the pervasive trend towards greater inter-organisational linkages in R&D and innovation via partnerships and consortia of various kinds. The social capital concept provides policy-makers with a means of explaining why collaborative networks are playing an increasingly important role in university-industry interactions (and in the economy in general). It also highlights the importance of modernising those aspects of government policy that can act as impediments to network-evolution.

In particular, the encouragement of punitive sanctions for contractual failure, mandatory regulations that limit trust-building and rigid eligibility criteria for government support that limit network-building constitute potentially severe impediments.

28 See Serageldin (1996) for a discussion of the social capital concept originating in the World Bank
29 Fountain (1998)
Government policy in a number of countries currently expresses a tension between an emphasis on formal support for collaborative/interactive networks (e.g. SEMATECH, CRADA's etc in the US\textsuperscript{30}, Faraday Centres in the UK and CRCs, SPIRT, Key Centres for Teaching and Research in Australia), and the need to give more recognition to the beneficial effects of the informal linkages that also build up social capital. This tension is inevitable given the need for accountability in the use of government funds and how it can be resolved more effectively is still an open question.

### 2.8 Linkages and market failure

An adequate level of linkage-building is not necessarily achieved without focused government support. This is because it is subject to market failure.\textsuperscript{31}

Linkages involve building relationships between organisations. These relationships are inherently of a cooperative or collaborative nature in the sense that the participants expect mutually beneficial payoffs in some form or other.

There is no direct ‘market’ for these relationships and there are consequently no relative prices upon which to base resource allocations concerning linkage-building investments. Knowledge of the pay-offs to linkage-building investment is primarily acquired through learning-by-doing.

When no linkages of a particular type have been developed there will tend to be a high level of uncertainty over the possible outcomes. Under these circumstances, the unknown risk will tend to mitigate against such an investment. These risks are reduced only through cumulative experience.

It follows that there is a role for government assistance for linkage-building akin to ‘launch aid’—pushing linkage participants along the learning curve to the point at which the risks become sufficiently low to break what would otherwise be a vicious circle. The interesting feature of this risk-based vicious circle that limits linkage-building is that it limits the public and private pay-offs to public sector R&D investment in ways that cannot be readily appreciated until ‘learning-by-doing’ experience has actually been gained.

\textsuperscript{30} The US also has an Industry/University Co-operative Research Centers (IUCRC) program run by the National Science Foundation, Engineering Research Centres, Science and Technology Centers and a number of other cooperation/collaboration facilitating initiatives.

\textsuperscript{31} The market-failure aspect of government linkage-building support is touched upon in Cervantes (1998) and the various contributions in that issue of STI Review, however the argument is not put as strongly as it might be—particularly in relation to the learning-by-doing/’launch aid’ concept.
This linkage-building ‘launch-aid’ approach has been a clear feature of a number of government policies towards inter-sectoral R&D linkages. It is sometimes recognised that the initially high risks associated with such linkage-building mean that project outcomes should not be measured against the apparent short-term success of the collaborative ventures. Instead, the linkage-building investment is treated as a capability-building exercise—improving organisations’ capability to handle linkages in the future, thus reducing the risk profile for the future. However, this recognition is not universal in policy circles. Serious problems can occur when linkage-building programs are assessed too strictly on the basis of short term ‘within project’ achievements as against long-term capability building.

The interesting policy question is: to what extent has linkage-building passed from the ‘launch aid’ phase aimed at capability-building into a more self-sustaining process?

The US experience seems to suggest that this transition has been made after more than a decade of business R&D consortia-building (eg. SEMATEC) and industry-academic—Government Research Organisation linkage-building.

As with all learning curve situations, however, there is comparatively little ‘leakage’ from being the first to start up the learning curve because the capabilities developed are highly tacit and not easily imitated. The policy implication is therefore that delays in linkage-building may be very costly.

Given that Australia has an emerging network of inter-sectoral R&D linkages in its Cooperative Research Centres, the country should be relatively well placed to exploit the pay-offs to linkage building. This is provided that the constraints of the relatively low business R&D capability are not too limiting.

### 2.9 The long-term implications for industrial R&D and R&D linkages

The two-way integrated model of the R&D process we have advocated highlights the pervasive ‘search for applicable theory’ that links academic research and industrial R&D. Consideration of the role of applicable theory in industrial practice leads to the remarkable conclusion that leading technology-based firms are seeking to significantly reduce their experimental development expenditure by substituting theoretical simulation for actual ‘experimental’ development. This substitution of (in effect) applied
research for experimental development is based upon the fundamental ‘enabling’ role of advanced computing power that allows complex, non-linear, physical phenomena to be simulation modeled.

The heavy demands upon computing power and mathematical sophistication in dealing with complex processes traditionally associated with basic research are increasingly finding application in industrial research. This promises to bring industrial research closer to public sector basic research. It is almost as if the two ends of the traditional linear sequence relating basic research to industrial application is becoming a circle in which theoretically-driven linkages are the ‘attractors’ causing the line to become a circle.

This theory-based convergence also applies to the R&D and innovation processes themselves. A number of overseas university, GRO and industrial research projects are focused upon gaining a better analytical understanding of R&D and innovation processes in order to simulate and re-design them. 32

The overall implication is that the increased capacity to model complex phenomena enabled by information technology will eventually result in a paradigm shift in R&D expenditure. The current paradigm involves a positive relationship between expenditure on research (basic and applied) and expenditure on experimental development. This is because the process of attaining the very advanced theoretical capacity to substitute applied research for experimental development involves a closer coupling of these two activities. In other words, more expenditure on generating feedback R&D from experimental development to applied and basic research.

The new paradigm that is likely to emerge following success in improved feedback R&D will, conversely, involve a changed relationship between expenditure on research and on experimental development. Experimental development expenditure will decline as costly activities are replaced by simulation modeling, however, industrial research expenditure will probably stabilise at levels thought appropriate by financial and equity markets—the fundamental determinants of corporate R&D budgets. This implies that changes in industrial research expenditure and industrial

32 For example, the UK multi-industry-academic ‘SPede’ project (Structured Process Elicitation and Demonstration Environment) funded by the Innovative Manufacturing Initiative (IMI) seeks to develop software tools for trying out different ways of designing complex products and processes by simulating how they would function ‘off-line’. This will eventually allow better design processes to produce better designs without costly and risky modifications. US defence R&D has been focused on developing this engineering process optimisation capability for some time. See Howard and Matthews (1999 Forthcoming) for a more detailed discussion of this.
experimental development expenditure should cease to be correlated as much as they are at present. 33

33 In technical terms, this means that any paradigm shift can be assessed econometrically by analysing the behaviour of ‘first differences’ in de-composed R&D expenditure data. The breakdown of the ‘co-integration’ between these time series will indicate the arrival of the new paradigm. At present, increases and decreases in ‘R’ and ‘D’ over the business cycle tend to move together. Certain industries like aerospace, advanced civil engineering and the automobile industry are likely to be the first to exhibit this change in the cyclical behaviour of first differences in the various components of R&D expenditure.
3 International trends in public sector support for research and experimental development

3.1 The general trends

At the most general level, the 1990s have witnessed a strong process of convergence among national policies for the public funding of R&D.\(^{34}\)

In the USA the accepted policy position allows the only appropriate explicit role for the Federal Government to be the funding of basic, and defence-related, research. In Europe, government intervention was seen as justifiable also for selective support for industrial R&D, and in the pursuit of valid national objectives such as independence, the need to 'catch up' technologically, or to defend domestic markets. In Japan, the validity of Government intervention to directly influence the setting of industrial targets was unquestioned.

However, during the 1990s, there has been a marked process of apparent convergence. The role and function of MITI were remodelled by the Japanese. The US Federal Government initiated research programs that sought the participation and cooperation of private firms. European countries withdrew, somewhat, from direct support for industrial development, and placed a greater emphasis on pre-competitiveness and generic technologies.

As a consequence an apparent consensus has emerged which recognises the need for governments to fund more than academic research, and to assist collaborative aspects of industrial R&D, while at the same time avoiding the introduction of distortions which might prejudice healthy competition.

This consensus was enshrined in the latest GATT (now WTO) Agreements, with place aid to R&D on the 'Green List' of permitted actions. No limitation has been placed on support for academic research or basic industrial research. However, limits of 75 per cent for structured industrial research designed to yield know-how on new products and processes, and 50 per cent for pre-competitive development have been established.

\(^{34}\) Caracostas and Muldur (1998).
This policy convergence is also being reflected in patterns of R&D expenditure, as we shall develop below.

Examination of the changes in public sector support for R&D needs to be conducted against a background of two general structural trends that have dominated most of the 1990s:

- First, a reduction in the growth of the total R&D effort in absolute terms, or as a percentage of GDP, in almost all major OECD nations; and
- Second, a general reduction in government budgets for all activities, including R&D.

Thus, in the OECD countries, growth in national R&D spending has been on a slight downward trend since the late 1980s through to recent times, and it fell in absolute terms in the early 1990s. R&D expenditures have now leveled off to account for, on average, about 2.3 per cent of GDP in the OECD area.

Figure 4 shows the trends in total R&D investment as a percentage of gross domestic product for the G7 countries. Figure 5 shows G7 R&D investment in real terms.

The general decline is most clearly seen in the data for R&D as a per cent of GDP in Figure 4. However, there is evidence that 1995 may have been a watershed year, with an evident change in the trend in the US and Japan. Hence, we will examine policy and performance developments in the 1990s in terms of two phases: the period of declining resources, 1990–1994 in the US and Japan, but much longer in other countries, and the period of renewed growth.
Another general trend is that the proportion of total R&D financed by industry has increased relative to the government share in almost all OECD countries. Industry now funds almost 60 per cent of OECD R&D activities and carries out about 67 per cent of total research.

Figure 5: Total R&D investment in constant 1992 US dollars

US data in particular show a very strong long-term growth in privately funded R&D (see Fig. 6).

Figure 6: US trends in privately and publicly funded R&D
The research effort in the higher education sector (HERD) across the OECD represents 15–30 per cent of total R&D expenditures, with an average of 17 per cent. In most countries, after a steady increase in the relative importance of HERD in the overall R&D effort (GERD) throughout the 1980s, there has been a stabilisation followed by a slight decrease in the 1990s. Up to the early 1990s, R&D in the higher education sector had grown at a higher rate than the overall R&D effort. Since then higher education researchers' shares of national totals show trends relatively similar to those concerning financial resources.35

Government support to university research has been maintained in absolute terms and as a share of government R&D expenditures in most countries. However, compound annual growth rates are declining and even becoming negative in some countries (Canada and Italy, for instance). The bulk of basic research (50 per cent or more) is performed by the higher education sector. The relative government contribution tends to have diminished slightly in the 1990s.

This pattern is exemplified by US data (Figure 7), where the significant decline in Federal Government Funding is evident.

Figure 7: Percentage breakdown of funding sources for US basic research

The most significant replacement for this declining Government funding, at least in the US universities and colleges, is internal funds. There is a clear trend towards financing an increasing proportion of their basic research from internal funds.36 Internal funds now account for over 17 per cent of university sector basic research expenditure ($2.747bn at constant 1992

35 See for example, OECD (1997).
dollars). The other funding sources (state and local government, industry and private non-profit organisations) have converged at something over 6 per cent of basic research funding each.37

The US trends suggest an evolving funding mode for basic research in which universities’ internal funding from such sources as non-specific donations, commercial investments and teaching revenue pick up the shortfalls caused by cut-backs in Federal funding for basic research.

This change in the funding of basic research parallels industrial experience, in which firms tend to invest in the more risky aspects of R&D using retained profits in order to avoid the (heavy) ‘risk premium’ associated with obtaining external funding.38 The trend offers further support for the argument that universities are converging in key respects with businesses, in, for example, increasingly competing with business enterprises for government and business consulting contracts.

An important trend noted in a significant number of countries is the relative reduction of the core funding resources for university research compared to contract-based resources.39 There are several concurring factors that explain this trend. Firstly, core resources are generally obtained from general allocations given to universities for both research and education. The overall amount has often not been raised despite the increase in the numbers of students enrolled by universities as a result of the widespread process of democratisation and ’massification’ of higher education. A second factor is the growth of contract-based allocations for specific missions.

One consequence of these trends is a significant increase in the uncertainty of employment and career for university researchers—a source of concern in more than one country (eg Belgium, France, UK). The OECD has argued that serious problems appear when the ratio of core to contract base funding falls below 50 per cent, and that between “sure resources and precarious resources” falls below a 70/30 ratio.40

36 This trend reflects, in part, assumptions made in the OECD Frascati R&D accounting framework that assumes that a given proportion of tenured academics time is spent on basic research. This assumption, combined with a trend for universities to rely upon their own investments as a source of operating revenue results in this trend. Although the accuracy of the assumptions made about the use of academics’ time can be questioned, particularly in the light of increased teaching loads, the underlying validity of allocating a proportion of academics time to basic research activity is valid.

37 It should, however, be noted that this 17 per cent includes non-specific funding from the business sector that the university decides to allocate to research.

38 See Fazzari, Hubbard et al. (1988) for an influential discussion of this issue.


40 Ibid, p26
Government laboratories have, in general, been more affected than universities by the reduction of government support. This has been accompanied by a trend towards privatisation in some countries and/or a strong push to make such laboratories largely self-financing through becoming a source of service for industry, government and the community. Indeed, US observers have raised concerns about 'mission creep' in Federal laboratories seeking to move outside of their main areas of research capability in response to these new financial pressures.41

With regard to industry, and notably in the large scientific powers, the effort of industry in favour of basic research seems to have been roughly maintained, though it remains modest (less than 5 per cent of the overall industry R&D effort) in most OECD countries. Likewise, the support of industry for university research has been maintained in most countries, with nevertheless important differences between countries (it is particularly significant in Germany, Canada, and the US).

This is apparently consistent with a general trend of industry outsourcing some of its non-core basic research work while reducing inner capacities in the enterprises themselves. At the same time, enterprises are involved in an increasing number of joint R&D centres within universities set up with government incentives.

3.2 The period of declining support

Within the general trends, and with varying budget pressures, different countries have produced different responses. The first pattern, characteristic of the Anglo-Saxon countries, has been to sharpen significantly the allocation resources process in a number of ways. These include reinforcing selectivity, drastically reducing support to non-priority areas, linking government support to matching business funding, and increasing evaluation efforts to ensure that governments get the best value for money.

New Zealand has shifted strongly towards contract-based funding of the science base through application of the principles of the market economy. A bold restructuring of its policy has been implemented, completely separating the policy from the funding function.

Perhaps the most extreme example of reductions in government support for R&D occurred in Canada, where the continuing fiscal crisis led to cuts in government expenditure across the board during most of the 1990s. In 1980, the Government funded 50 per cent of national R&D; by 1995, this share had fallen to 26 per cent. The base budgets of the Research Councils

were reduced by 17 per cent (NSERC and SSHRC) and 13 per cent (MRC) over the period 1995–2000; federal government laboratories have been closed or trimmed; and private sponsorship of university research has increased from 18 per cent to 31 per cent of the total.

The UK suffered similar cuts, extending well beyond the first half of the decade. Thus, the Conservative Government announced major cuts to the funding of science in 1995, as part of a general cost-cutting approach. Capital funding was cut by 30 per cent in 1996, and the overall science budget was to decline by 5 per cent over 1997-98.

The second main behavioural pattern, observed in most countries of continental Europe, has been characterised by the maintaining, up until recently, of the overall support to the science base, but with the persistence of serious rigidities preventing significant re-allocations between departments, disciplines and institutions.

Some governments have reacted to this problem. Germany has recently decided to introduce more competition and selectivity in resource allocations to public laboratories, operating in fundamental as well as in more applied or technical research. The Netherlands has also increased the relative importance of the second money flow (contract-based finance) in the university system, while the government laboratory network, and notably the major body constituted by the TNO, has been obliged to increase its self-financing.

A third response in the UK, France and most notably the US, has been the drastic reduction of large-scale programs in major strategic areas—defence, space and energy. In the US there is evidence that the reduction in large government contracts has had a negative impact on support for fundamental research in universities.42

Public sector support for R&D takes place within the context of the overall national R&D effort. In other words, the national composition of public sector R&D is, in part, geared towards supporting the strengths of, and addressing weaknesses in, the private sector R&D effort.

### 3.3 Changes in the division of labour in national R&D efforts

One key aspect of the structure of national R&D efforts is the division of labour between the four different R&D performing sectors in the type of R&D undertaken. Comprehensive data on this subject would allow a very

detailed comparison of changing policies and performance in public sector support for R&D.

Although some data on the type of R&D performed in different sectors is available for some 20 countries it is rather patchy. This is because:

• Some of the older ‘science powers’, such as the UK, have ceased to either collect or publish these figures during the 1990s (reflecting public sector cut-backs and a withdrawal from close monitoring of the national R&D effort); and

• Some of the recent ‘post cold war’ entrants into the OECD R&D statistics system only provide data for the late 1990s.

As a result, it is only possible to provide a detailed assessment the structure of national R&D efforts using readily available data with respect to the type of R&D and sector of performance for the following five countries:

• Australia
• France
• Japan
• Portugal
• United States

Although this is a small sample of countries it is a diverse sample. By implication, any converging trends observed in this sample would suggest that convergence may be taking place in a larger sample of countries.

We have assessed the extent of convergence in the structure of national R&D efforts in this sample of countries by examining each performing sector’s (business enterprise, higher education, government research organisations, and private non-profit) share of national basic research, applied research and experimental development expenditure considered separately. Some care should be taken in interpreting these figures because they relate to the sector of performance of R&D not to overall R&D funding.

Figure 8 shows how the business enterprise sector’s share of national basic research expenditures has changed between the early 1990s and the most recent years for which figures are available (1994–95).

43 These calculations have used nominal expenditure estimates rather than constant price or purchasing power parity estimates in order to avoid any distortions caused by the use of these indices for international comparisons.
We can clearly see indications of a convergence between these countries in the share of national basic research expenditure performed in the business enterprise sector. In other words, those countries, such as Japan, in which the business enterprise sector performs a high proportion of the national basic research effort, exhibit a declining sectoral share. On the other hand, those countries, such as Australia and France, in which the business enterprise sector performs a low proportion of the national basic research effort exhibit an increasing sectoral share over this time period.\(^4\)

\(^{45}\) There have, of course, been important changes in the behaviour of business enterprise R&D expenditure (BERD) in Australia in subsequent years. However, the reductions in BERD, in more recent years may well be concentrated in experimental development rather than in basic and applied research. We will have to wait for as yet unpublished BERD data in order to determine whether or not this is the case because the type of R&D performed is only surveyed in Australia every two years. It is worth noting that the previous increases in BERD in Australia appear to have been due to increases in experimental development rather than basic and applied research. Experimental development expenditure is particularly sensitive to the state of the business cycle and changes in BERD (which is dominated by experimental development) should therefore always be analysed against the state of the business cycle.
Figure 9 shows the business enterprise sectors' share of national applied research expenditure in these countries.

Figure 9: Business enterprise sector's share of total national applied research expenditure

Again, there are indications of convergence, mainly caused by reductions in the business enterprise sector's share of the national applied research effort in Japan and the US.

The reduction in the US business enterprise sector's share of both basic and applied research during the 1990s has been attributed to market pressures in equity markets. Many large corporations have been forced to cut back on industrial research (as opposed to experimental development) because Wall Street analysts view the previously higher levels of industrial research as not having generated appropriate returns for investors.

US business enterprise experimental development has, however, increased both in absolute terms and in terms of that sector's share of the national experimental development effort over this period (from 84.8 per cent to 87.34 per cent over that period). This resulted in the business enterprise sector's share of total US R&D expenditure remaining at 72 per cent over this period.

Turning to the higher education sector we find similar evidence of a convergence in the sectoral division of labour among these countries. Figure 10 shows the higher education sector's share of national basic research expenditure and Figure 11 its share of national applied research expenditure.
We can see that although there are indications of convergence here as well, Australia stands out in its higher education sector’s declining share of national basic research expenditure. However, subsequent R&D expenditure data indicate a ‘re-alignment’ of the Australian trajectory with the international trends exhibited here. On the other hand, the sector’s share of national applied research expenditure has increased, along with all the other countries in the sample except for Portugal.

Government research organisations in all the countries in this sample exhibit a declining share of national basic research expenditure—see Figure 12. This can be attributed to the combined effect of the ‘peace-
dividend’ in weapons laboratories and a general policy move during this part of the 1990s to increase applied research in preference to basic research in government research laboratories. Thus we find GROs in the US and in Japan increasing their share of the national applied research effort over this period (Figure 13). Australia stands out only in the fact that the GRO’s share of the national applied research effort declined when it was stable or increasing in the other countries in this sample.

Figure 12: Government research organisation sector shares of total national basic research expenditure

![Graph showing government research organisations' share of total national basic research expenditure from 1989/90 to 1994/95.]

Figure 13: Government research organisation sector shares of total national applied research expenditure

![Graph showing government research organisations' share of total national applied research expenditure from 1989/90 to 1994/95.]

Source: Calculated using OECD data
Turning finally to the private non-profit sector (Figures 14-15) we find a more mixed set of trends. Australia stands out in exhibiting the second largest increase in the PNP sector’s share of the national basic research effort whilst having the lowest share of the national applied research effort—which changes little over this time period.

Figure 14: Private non-profit sector shares of total national basic research expenditure

![Graph showing private non-profit sector shares of total national basic research expenditure.]

Source: Calculated using OECD data

Figure 15: Private non-profit sector shares of total national applied research expenditure

![Graph showing private non-profit sector shares of total national applied research expenditure.]

Source: Calculated using OECD data
The overall picture given by these figures is that the sectoral division of labour in the R&D effort in the countries in this sample is converging over this time period. If this trend continues it may provide evidence of a growing ‘maturity’ in national science and innovation systems as countries converge upon a more comparable R&D structure.

This convergence reflects the combined impact of several factors, namely:

- Changes in each R&D performing sector’s basic research expenditure;
- Changes in each R&D performing sector’s applied research expenditure;
- Changes in each R&D performing sector’s experimental development expenditure; and
- Changes in inter-sectoral funding flows for ‘outsourced/contracted’ basic, applied research and experimental development.

Some possible implications are that:

- The business enterprise sector in economies with a high-R&D intensity in that sector will shift its emphasis away from basic research and towards applied research. This is in order to provide more effective support for experimental development investment, whilst still accounting for a major share of the nation’s overall basic research effort. Stronger research linkages with the higher education sector and government research organisations will be used to compensate for the relative reductions in the business sector’s internal basic research effort.

- The business enterprise sector in economies with a low-R&D intensity in that sector (such as Australia) will increase its share of the national basic and applied research effort in order to provide more effective support for experimental development. Similarly, improved research linkages with the higher education sector and government research organisations will be used to help to achieve this objective as internal research capabilities are unlikely to be adequate.

- Government research organisations will eventually settle on a fairly balanced level of basic and applied research. Too little investment in basic research risks the well known problems caused by insufficient fundamental discovery and theoretical capacity-building, whilst too great an emphasis on basic research relative to applied research will reduce the public and private yield on public sector investment in basic research both in GROs and in the higher education sector.

- The private non-profit sector will play a more idiosyncratic ‘gap filling’ role in national R&D investment, reflecting cultural norms, public interest and fiscal regimes.
The higher education sector, the traditional host of a nation’s basic research investment will need to pick up much of the slack provided by any shifts away from basic research in the business enterprise sector and in government research organisations. This may well mean an increased emphasis on basic research. By its very nature this (mainly) public sector investment will require strong linkage-building in order to generate both private and public benefits.

The emerging R&D systems would seem, therefore, to be characterised by a process of searching for a more effective balance in:

- The distribution of investment into basic research, applied research and experimental development;
- The distribution of these investments into the most appropriate performing sectors given existing linkage-capabilities; and
- The relative emphasis placed upon linkage-building both within the R&D system and between the R&D system and the rest of a nation’s economic activity.

The overall conclusion is that ‘balanced’ public sector R&D support in terms of these three dimensions may be becoming an international norm.

Given Australia’s structural weakness in business enterprise R&D investment, this implies that Australia will become increasingly ‘out-of step’ in the structure of its R&D investments unless business enterprise R&D investment can be increased. This, in turn, will cause inter-sectoral R&D linkages in Australia to face different, and arguably more severe, challenges than are faced in other developed economies.

### 3.4 The period of renewed growth

First, it should be made clear that the renewed growth in public sector support for R&D has by no means been universal across all OECD nations. What we are reflecting here is evidence of renewed growth, or commitment to growth, in public sector support for R&D in a number of leading countries. In addition, growing awareness of the implications of the knowledge economy among policy-makers e.g. the British White Paper on Competitiveness⁴⁶, is producing a climate in which the level and form of public sector support for R&D is under active scrutiny.

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In particular there was clear evidence in 1998, strengthened in 1999, that a number of national governments had achieved the budgeting surpluses that were the objective of previous cuts, and were now able to translate their rhetoric of commitment to science and technology into action. Alternatively, with the emergence of the global knowledge economy and an improved understanding of the operation of their National Innovation System, they were prepared to invest in science and technology at the expense of other priorities.

Thus, in the US, there has been a substantial and continuing growth in all categories of R&D (Figure 16).

Figure 16: Historical trends in US basic research, applied research and experimental development expenditure

This growing commitment was reflected in the Clinton Administration's budget for 2000 (see the following Box).
R&D in the US FY 2000 budget

- The Clinton Administration’s goal of non-defence R&D funding exceeding defence R&D funding will be met for the first time:
  - non-defence is expected to increase by 3.6 per cent to $39.4 billion (50.6 per cent total R&D); and
  - defence R&D is expected to decrease by 6.6 per cent to $2.7 billion.
- Basic research is a priority and is expected to increase by 4.7 per cent ($816 million) to $18.1 billion total.
- The National Science Foundation (NSF) and Department of Energy (DOE) are favoured agencies due to their support for priority areas of basic R&D, general science and energy related R&D, and the IT2 initiative.

In the UK in 1998, the new Labour Government announced an increase in funding of the science base by £0.7 billion. As a result, by 2001–2 the science budget is projected to be 15 per cent above its 1998–9 value in real terms.

In Germany, there was an 11 per cent rise in the 1999 science budget to total nearly DM 15 billion or US$8.2 billion. The Budget of the Federal Ministry of Education and Research was increased by 6.4 per cent to DM900 million. A further DM3 billion was directed towards existing and new strategic research projects in a number of targeted areas: health, employment, work and technology design, biotechnology, IT, environment and transport.

At the end of the financial crisis in 1996, the Finnish Government committed to raise GERD/GDP from 2.4 per cent to 2.9 per cent by 1999—the highest planned increase in Europe, and public R&D expenditure was committed to rise to Mk 78.5 billion.

Nearly one-quarter of Finnish R&D is carried out in universities. Some 60 per cent of research in universities is financed from State budget allocations. Competitive project grants from the Academy of Finland provide the largest ‘external’ source of funds for basic research, (Mk 375 million) and nearly 20 per cent of research financing of the Technology Development Centre (TEKES) is also delivered to universities.

The overall government effort was planned to increase by 25 per cent over the period 1997–99. A large part of these funds were earmarked for technology programs and basic research in universities on a competitive basis. Some reallocation of resources among sectors also took place.
through an incentive mechanism stimulating the different government departments to fund R&D by matching funds from a central R&D budget.

In Japan, despite the slowdown of economic growth and the severe budget problems faced by the government, support to R&D has remained a clear priority. Government expenditures are planned to increase at significant rates (5 per cent per year) in the context of long-term ‘visions’.

The contribution of public sector funding to national R&D in Japan, averaging 20 per cent over the past twenty years, has traditionally been well below that of the US (50 per cent) and Europe (40 per cent). The 1996 five-year ‘science and technology basic plan’, included a pledge to double spending on research between 1996 and 2001. This was driven, at least in part, by recognition that the internationally low level of basic research was becoming a constraint on future international industrial competitiveness.

Japan’s 1999 budget (beginning 1 April) is designed to revive the nation’s economy with an injection of public spending and includes an 8.1 per cent increase (US$8.5 billion total) in general science related expenditure—in particular, to basic research.

Singapore’s gross expenditure on R&D (GERD) increased sixfold between 1987 and 1998, reaching S$2.33 billion in 1998, or 1.65 per cent of GDP. Both the public and private sector had contributed to the growth in R&D investment in Singapore. BERD rose from 53 per cent to 64 per cent of GERD. More than 60 per cent of this is performed by MNCs. However both HERD (from 21 per cent to 13 per cent), and Government R&D (from 17 per cent to 10 per cent) declined relatively, though not absolutely.

Funding for the Public Research Institutes (PRIs), established at the end of the 1980s, increased to 14 per cent of GERD. Over 1990–97, R&D spending by PRIs grew nearly sevenfold, faster than the fourfold increase experienced by private R&D. By 1997, the 15 PRIs accounted for close to S$300 million of R&D spending. Throughout the period of fiscal restraint, and longer, there has been a widespread concern that the infrastructure to support research in universities and other research institutions is undergoing a severe decline.47

Two recent initiatives may reflect a new type of response to the challenge of increasing support for basic research (see the following Box).

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47 For example, in Australia see the Ross Report.
Recent research infrastructure funding initiatives

In Canada, the 1997 Federal budget announced the formation of the Canada Foundation for Innovation, to be set up as an independent entity with an endowment of C$800 million (the largest foundation in Canada) to invest in research infrastructure in universities and research hospitals. It is intended to invest C$180 million per year, at least matched from other sources.

In the UK, the Wellcome Trust offered £300 million to support infrastructure in universities in biological and medical fields, conditional on the government matching that fund; with other contributions, the Joint Infrastructure Fund now stands at £700 million. In the first round of the scheme, 37 British research groups will share £150 million.

3.5 Linkage investments

All OECD countries are placing an emphasis on developing and enhancing linkages between their knowledge production and the knowledge application systems. A number of initiatives are common across a range of countries. These include centres of excellence, cooperative R&D centres, science parks, and 'link' programs.48

Centres of excellence are becoming more widespread in a number of countries initiated by significant government funding. These funds are generally given for a period of three to five years with some matching funds required from industry, while using academic premises and personnel. More frequently, these centres take a virtual form, associating several teams located at a distance from each other. The centres are generally focussed on interdisciplinary fields that respond to generic technology needs and train doctorate and post-doctoral researchers.

Co-operative R&D centres are generally set up for research of a more strategic or applied nature. Industry is required to match funding on at least a one-to-one basis. These centres have been particularly promoted in the English-speaking (Anglo-Saxon) countries where they fulfil a gap which would appear to be less felt for instance in the German-speaking ones, where there is a long tradition of such co-operation, the model being the Fraunhofer system. The joint industrial and academic work developed in these centres has the objective of developing a shared culture and contributing to the establishment of a fruitful and durable climate of collaboration.

Science or technology parks have been established in many countries, and were inspired by the famous US examples. Finland, with its nine science parks, each located near a university provides a series of successful examples worth examination. There have been approximately 1 000 jobs created per 100 000 inhabitants for the most dynamic parks.

Finally, there are programs specifically designed to encourage cooperation and collaboration between universities and industry:

- There are four major linkage schemes in the UK. The LINK program supports long-term, collaborative, enabling and generic research in areas of strategic importance to the national economy. Each LINK programme is made up of a number of projects lasting 1–5 years. By 1997 there had been 57 LINK programs, 24 of which are still in progress. To date, the Government has spent £183M and committed another £344M to ongoing projects; there has been similar matching expenditure by industry.

- The Teaching Company Scheme (TCS) operates through programs in which academics in universities work with companies to contribute to the implementation of strategies for technical or managerial change. Each TCS program involves academic participation with company managers in the joint supervision and direction of the work of a group of young graduates. The TCS expanded rapidly in the early 1990s, establishing its 1500th programme in 1994–95. In 1995–96, Government Departments and Research Councils committed over £21.3M to 253 new TCS programs, complementing about £10M of direct funding committed by participating companies.

- A third example are the ‘Realising Our Potential Awards’. These are intended to reward academic researchers who receive financial support from UK private sector industry and commerce for basic or strategic research through the award of grants with which researchers can carry out curiosity-driven, speculative research of their own choosing.

- Cooperative Awards in Science supports doctoral research on projects jointly devised and supervised by an academic department and a company.

In the 1999 UK budget, linkage funds have also been increased, through the £50 million University Challenge Fund and the £25 million Science Enterprise Challenge. In addition the Department of Trade and Industry’s innovation budget, has increased over three years by 20 per cent to £220 million, to re-focus resources on innovation, technology access, and partnership between UK industry and the science base.

The UK has also developed the ‘Innovative Manufacturing Initiative’ (IMI) which is a multi-research council funded, and industry sector focused
collaborative research initiative focusing mainly on applied research. The IMI’s research is explicitly aimed at improving the competitiveness of firms and involves establishing strategic plans for this research via consultation with industrialists and academics.

In Japan, following the passage of legislation promoting collaboration between universities and industry, funding for the creation of new businesses through ‘commercially applicable research’ and university-industry collaborative research has been increased.

Thus, MITI received a 44.6 per cent increase to Y44.3 billion for ‘New Industry R&D’ and a 3.6 per cent increase to Y3.6 billion for ‘joint research with universities’. The Ministry of Education, Science, Sports and Culture had a 11.1 per cent increase to Y117.8 billion for ‘joint research with industry’ and a 9.7 per cent increase to Y17.6 billion for post doctoral fellowships.

In 1998, the French government allocated FF1 billion to create a ‘national technology network’, bringing together private and public laboratories in key sectors. In addition, the ‘University of the Third Millennium’ (U3M) initiative is a multi-billion dollar, regional development scheme for higher education and for the creation of regional networks of research excellence. The nodes of such networks are proposed to be regional universities and are planned to run from 2006 onwards.

In Canada, the network of Centres of excellence program, which facilitates knowledge transfer between universities and the private sector, will receive an extra Can$90 million (see the following Box for details). Other spending initiatives include: Can$60 million for improving researcher’s access to computers, Can$150 million for companies to market innovative products, and Can$50 million for the Business Development Bank to assist and finance knowledge-based and export-oriented companies.

The Canadian ‘Networks of Centres of Excellence’ (NCE) program

The NCE program is jointly administered by four research councils in partnership with Industry Canada. It provides an exemplar of network-focused support. The NCE aims to focus Canada’s research talent specifically via network-based funding spread over two seven year funding cycles. The NCE’s multi-agency ‘ownership’ is at attempt to cut across portfolio-driven concerns and to create coherent research and innovation networks.
The Singapore Government’s decision to establish the National Science and Technology Board (NSTB) in 1991 within MTI reflected the strategic intent of the government to make R&D policies industrially driven. Its mandate is to plan and manage the development of PRIs, to promote private sector R&D, to promote R&D manpower development, and to plan and manage the development of S&T infrastructures such as science parks and incubators.

In its first five years of operation (1991–95), NSTB had a $2 billion R&D fund to promote R&D in Singapore, which was doubled to $4 billion for the second period (1996–2000). It was only in this second phase that the importance of science was acknowledged, though the key focus still remains one of promoting short to medium term technological development. Funding for longer-term R&D has to be justified on the ground of strategic economic relevance.

Both the Japanese and Singaporean governments have focussed for many years on building a very strong industrial R&D capability. In contrast, public sector support for research, particularly in universities, was relatively weak.

With an understanding of the new requirements of the knowledge economy outlined in Section 1, these countries have moved to complement their already strong linkage infrastructure with a greater commitment to basic research.

For the OECD nations with a much longer history of public sector investment in research, the greater weakness, and hence the increased focuses of public sector investment, appears to be in linkage mechanisms and performance.

49 Facilities that assist start-up businesses in the first few years of their life via specialised officespace and managerial expertise.
4 Summary and conclusions

4.1 Conclusions

There is sufficient evidence to specify a new and more appropriate policy model of the inter-relationships between investment in discovery and in linkages. This model treats linkages as an inherent part of the discovery process not as an adjunct to it. The new policy model is based upon a more accurate conceptualisation of the fundamental knowledge-creating dynamics within the R&D process.

There is compelling evidence that policy priorities overseas are now focusing upon ‘balanced’ investments in discovery and linkages even though the policy-model that explains these trends ‘lags behind’ actual policy implementation.

This converging trend is illustrated in the following diagram.

In region ‘A’ we find the established ‘science powers’ who have traditionally prioritised discovery investment and are now seeking to ‘re-balance’ this emphasis on discovery with a greater emphasis on linkage-building. This includes both linkages within the discovery process and linkages between discovery processes and the practical application of this knowledge. The diagram expresses the ‘wavering’ in commitment to discovery exhibited by some countries as a dashed trajectory in which support for discovery initially declines before increasing as linkage-building efforts grow.

In region ‘B’ we find the ‘technology catch-up’ economies who have prioritised linkage-building, primarily inter-firm linkage building, and are now seeking to increase the emphasis placed upon discovery.
The possibility of the two groups starting to converge via a more balanced emphasis placed upon discovery and linkage-building is highly significant for policy-makers.

Key aspects of DETYA’s current Green Paper on Higher Education reform are therefore in-line with actual overseas trends in seeking to provide a better balance between investment in discovery and linkages.  

The policy challenge faced by Australia is both substantial and challenging because structural weaknesses in industry R&D in Australia will limit the pay-offs to more balanced investment in discovery and linkages.

One way of overcoming the industry R&D and innovation capability constraint may be to facilitate stronger cross-border linkages between the Australian science-base and overseas industry. This will build the Australian science base’s capability to work closely with industry, which will in turn help to attract high-technology foreign direct investment into Australia in order to exploit this discovery capacity. Such a strategy would avoid the constraint placed upon developing more balanced discovery and linkages activity caused by weaknesses in business R&D in Australia.

A more balanced emphasis on discovery and linkages in Australian R&D policy should consequently prioritise international linkages as much as domestic linkages. This international focus is also in line with overseas approaches.

4.2 Final remarks

This paper has sought to improve our understanding of the relationship between discovery and linkages, and in doing so has moved beyond conventional assumptions about these activities.

There is consequently a need to develop, further substantiate and publicise the policy convergence trend and integrated discovery-linkages model that may explain this trend. A more substantial study of the detailed nature of industry-public sector research linkages in selected sectors and countries with a particular emphasis on unpacking the R&D ‘black box’ would accomplish this. In particular, there is a serious lack of information in Australia on what both leading and other firms actually do in experimental development and how this relates to applied and basic research. Such a study would provide suitable information for an ‘innovation awareness campaign’ aimed at disseminating this information to the research community and industry in Australia.

50 DETYA (1999)
Appendix A

Towards an adequate analytical base

This study has identified a range of substantial weaknesses in the ability to provide a sound empirical analysis of trends in dis-aggregated R&D by sector of performance. The most prominent shortcomings are:

- In the treatment of existing data on R&D expenditure collected by national statistical agencies; and
- In the capacity to track and analyse actual government policies towards R&D support against appropriate analytical categories.

These two shortcomings are related because they appear to be a consequence of a distrust of the OECD’s ‘Frascati’ definitions of what R&D expenditure consists of.

This distrust is reflected in:

- The ‘unitary’ treatment of R&D expenditure as a single category (in preference to de-composing these data into the constituent basic research, applied research and experimental development categories); and
- The consequent difficulties that policy analysts have in relating government policies towards R&D support to existing official statistics.

Guidance for this study’s approach was provided by an examination of current US science and technology policy analyses. On the basis of the evidence collected in this study, the United States now stands out amongst OECD nations in the policy-relevance of its statistical data and analyses relating to R&D expenditure.

The US advantage in policy analysis is the result of the combined effect of:

- ‘Open government’ policies with respect to data provision and disseminating analyses of R&D data;
- The National Science Foundation’s mission in tracking and analysing the nation’s R&D expenditure as a ‘customer’ to the various ‘contractor’ agencies charged with collecting the data according to the NSF’s policy analysis driven requirements; and
• An explicit acceptance by the NSF and Federal and State-government agencies that de-composing R&D into basic research, applied research and experimental development is useful for policy analysis—even though it is difficult to achieve and interpret.

An examination of the NSF's work suggested that particular attention should be paid in this study to:

• Integrating the existing ‘building blocks’ for an appropriate policy framework for examining international trends in public sector support for R&D; and

• Making a clear attempt to ‘rehabilitate’ the three-part decomposition of R&D into basic research, applied research and experimental development in order to understand both public policies and the resultant expenditure patterns.

It makes little sense to attempt to articulate policy in the R&D area without recourse to detailed statistical and other data on the mix of R&D activities in different sectors and how these mixes are changing.

The current US dominance in the statistical coverage of R&D expenditure

Over recent years the quality and coverage of R&D statistics in the US has far outstripped the quality of data available in other countries. This reflects, in part, a concerted effort by the National Science Foundation (NSF) to provide analysts and policy-makers with as comprehensive a set of data as possible. As a result, highly detailed data is now readily available via the Internet together with comprehensive discussions of estimating methodologies and the results obtained.

Given that resource allocation decisions are based, in part, upon analyses of current R&D trends the superior quality of the US R&D statistics can be expected to give US policy-makers an additional advantage over their foreign counterparts.

The fact that the NSF acts as a direct customer for US R&D statistics, and commissions the various R&D surveys and analyses carried out by other agencies has a major impact upon the utility of the R&D data thus produced. In other countries, where there is not this form of customer-contractor relationship between government agencies R&D data tend to reflect the concerns and constraints of the collecting agencies.
Put bluntly, most governments accept the need to support basic research and research training as a public good investment yet the OECD (the major provider of comparative R&D data) chooses not to analyse the breakdown of R&D expenditure highlighting basic research expenditure on a regular and comprehensive basis.

This selective publication may be due to the need to avoid highlighting the fact that many OECD countries choose not to collect data in the different types of R&D carried out, thus producing a 'lowest common denominator' in the collated data published. It may also reflect a fundamental distrust in the definition of the three types of R&D.

Whatever the causes, the current position results in a situation in which a policy debate over the relative importance of investment in basic research, and by implication the role of universities in national economies, is hampered a policy perspective that denies the relevance of 'de-composed' data on R&D expenditure.

This situation is not tenable, particularly in a study aimed at identifying key trends in public sector support for R&D. Accordingly, efforts have been made in this study to identify a 'road map' for moving beyond the current impasse.
References


