April 2004

53

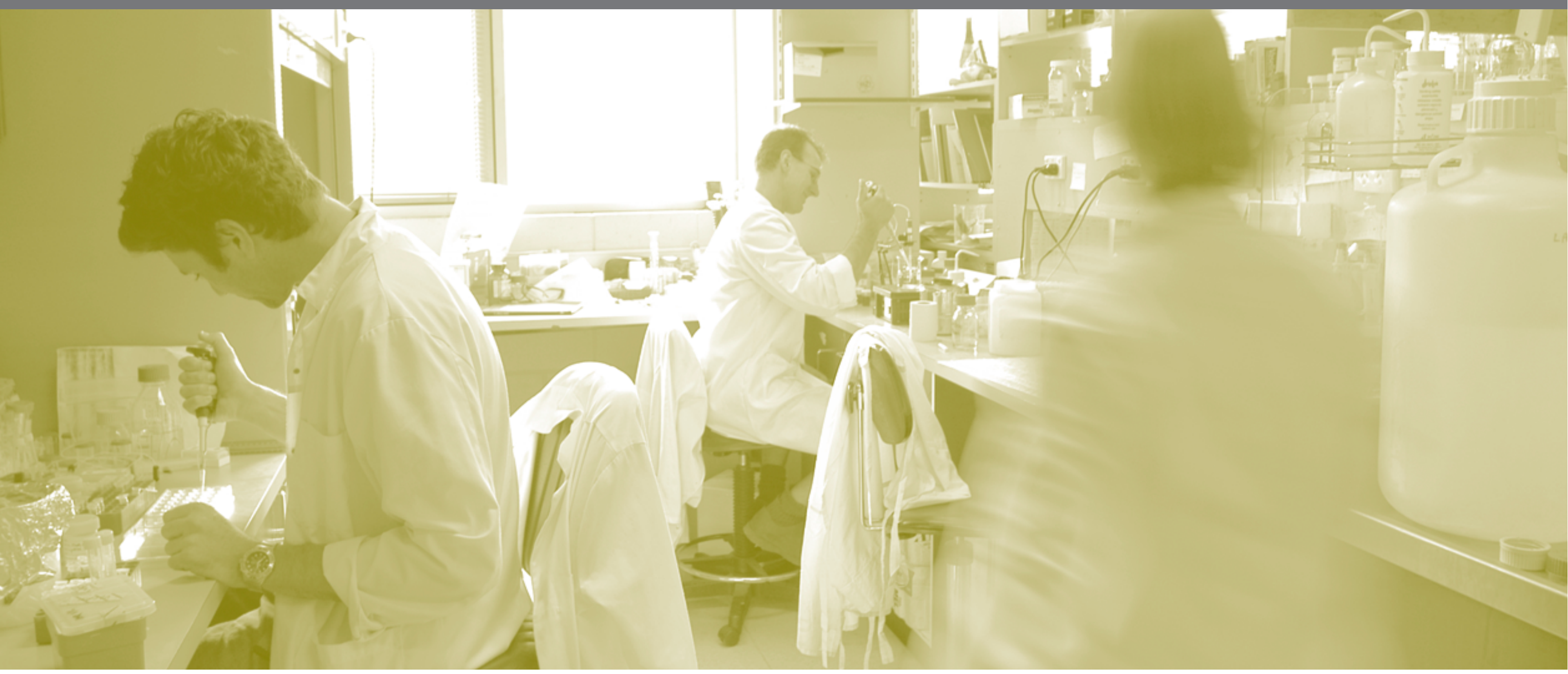
Growth

CEDA

Committee for Economic Development of Australia

Innovating Australia

Edited by Ian Marsh



Australian Business Foundation

State Government Victoria

MACQUARIE

The Committee for Economic Development of Australia (CEDA)

The Committee for Economic Development of Australia (CEDA) is an independent, apolitical organisation made up of business leaders, academics and others who have an interest in, and commitment to, Australia's economic and social development. CEDA aims to undertake objective discussion and research into issues affecting Australia's growth.

CEDA gratefully acknowledges the generous support of the Australian Business Foundation, the (Victorian) Department of Innovation, Industry and Regional Development and Macquarie Equities.

ISSN 0085-1280
ISBN 0-85801-263-4

Production coordination: Margaret Mead
Editing: Edward Caruso
Design: Origin Design
Photography: Ric Wallis

Committee for Economic Development of Australia
Level 5/136 Exhibition St
Melbourne 3000 Australia
Ph: (61 3) 9662 3544
Fax: (61 3) 9663 7271
E-mail: info@ceda.com.au
http://www.ceda.com.au

53

Growth

Innovating Australia

Contents

Tables, Figures and Boxes

Tables

Figures

Boxes

Contributors

Ian Marsh is Director of Research for CEDA and a Senior Fellow in the Research School of Social Sciences at the Australian National University.

His research interests include political futures for Australia, democratization and economic governance in Asia, and economic strategies more generally. With Brendan Shaw, he authored a study of the contribution of clustering to the success of the Australian wine industry. Other publications include *Beyond the Two Party System: Political Representation, Economic Competitiveness and Australian Politics* (Melbourne: Cambridge University Press). Prior to his ANU appointment, he was on the faculty of the Australian Graduate School of Management. He was educated at the University of Newcastle (BA) and Harvard (MPA, PhD).

Gavin Moodie is a graduate in law and philosophy of the University of Melbourne. He has published extensively in higher education policy, management and equity. Gavin has been a university administrator for over 25 years and is currently principal policy adviser for Griffith University. He is a regular columnist for the Australian's Higher Education Supplement.

Don Scott-Kemmis is the Director of the Innovation Management and Policy Program at the National Graduate School of Management, Australian National University. Previously he was a Program Director in the Centre for Technology and Social Change, University of Wollongong, and a Research Fellow at the Science Policy Research Unit, University of Sussex. He has also been a Ministerial Adviser and a program manager in the Department of Industry, Science and Technology.

Professor Keith Smith works at the European Commission Joint Research Centre in Seville, Spain. He was previously at the Institute for New Technologies, United Nations University, and Professor at the Norwegian University of Science and Technology (NTNU). He trained at the Universities of Cambridge and Sussex. His academic background is economics and development studies. Following nine years as Lecturer in Economics at the University of Keele, he was appointed as Economic Adviser to the Science Policy Council of Norway in 1988. From 1990 to 2000 he was Research Director of the STEP Group in Oslo, carrying out a wide range of research on innovation issues for Ministries, Research Councils and the European Commission. His main fields of research are innovation and economic growth, the development of innovation statistics and indicators, the use of science in industry, innovation in 'low technology' industries, and knowledge studies. He has worked extensively as a consultant to policy agencies on innovation policy, both at a national and international level—he has recently been a member of the expert panel 'Innovation Policies in the Knowledge-Based Society', for the European Commission, and deputy chairman of the Norwegian Government Commission on Tax Incentives for Business-Financed Research and Development.

David Sparling is an Associate Professor at the University of Guelph, Ontario, Canada. His research and teaching are primarily in the areas of agribusiness and quantitative analysis. He is also the Managing Partner of FONA Technologies, a biotechnology startup commercialising a DNA identification technology. Earlier in his career, David was President of Canadian Millers' Mutual Insurance Company and of Janda Farms, a large producer of broiler chickens. He holds an MBA from Wilfred Laurier University and a PhD from McMaster University.

Michael Vitale is a Professor at the Australian Graduate School of Management in Sydney. His research, teaching and consulting activities span information technology, particularly IT governance and performance, and biotechnology. He was Dean of the AGSM in 2001 and 2002, and prior to coming to Sydney was a Professor at the Melbourne Business School and the University of Melbourne. He holds an MBA from Harvard Business School and a PhD from Dartmouth College.

Jonathan West is Associate Professor at the Harvard University Graduate School of Business Administration, where he teaches in the fields of innovation, operations, and business strategy. His doctorate and masters degrees are from Harvard University, and he holds a Bachelor of Arts majoring in the history and philosophy of science from the University of Sydney. West is the founder and faculty director of the Harvard Life Sciences Project, a multi-faculty university initiative to understand the creation and capture of value from the genomics revolution of the knowledge economy. His own research focuses on the development of national innovation systems, in particular, how cross-country variance in corporate governance approaches, knowledge creation, and risk management systems determines the environment for effective business strategy and technology development. He is currently investigating the sources of superior performance in biotechnology research and development, comparing the performance of companies in the US, Japan, Europe, Australia and China.

He is also the author of a detailed study of advanced development in US and Japanese semiconductor companies, and has studied the technology development strategies of leading semiconductor firms in Europe, Korea and Taiwan. He has served as a consultant to major corporations and several governments around the world. His research has appeared in many scholarly journals and several books.

1. Overview

Ian Marsh

Renewing Australia's Industry Development Strategy: Innovation and the 'Knowledge Economy'

This collection of papers explores aspects of Australia's emerging industry development strategy. Two structural developments affecting longer term industry performance warrant a fresh approach. First, science-based industries present a potential area of opportunity for Australia. These industries are of particular significance. The technologies that are involved create platforms that can transfigure established industrial activities. The development of ICT, in which Australia has no deep positions, illustrates this. In Chapter 2, Jonathan West argues that a deeper, more refined understanding of the importance of participation in these sectors, and of the distinctive risk-reward structure that drives successful innovation, is essential if Australia is to fully capitalise on emerging opportunities.

While science-based industries create technologies that have the potential to transform other industrial sectors, dissemination and adaptation requires attention to linkages and junctures that extend beyond those mediated by markets.

The second structural development concerns the challenge in disseminating productivity-enhancing technologies to established industries. While science-based industries create technologies that have the potential to transform other industrial sectors, dissemination and adaptation requires attention to linkages and junctures that extend beyond those mediated by markets. Markets are necessary but not sufficient agents in these processes. Upgrading poses special challenges, and countries are increasingly recognising that policy frameworks can stimulate and facilitate adaptive outcomes. Keith Smith argues that the distinctive policy tasks associated with the application and diffusion of knowledge have yet to be fully recognised in Australia. One legacy of tariff-based industry development is an industry structure based around a few large firms and a wide base of small and medium-sized enterprises (SMEs). The dissemination of technologies offers a bright future for these firms, but policy frameworks have yet to match the challenge.

A reassessment of industry strategies is timely for two additional reasons – one of which involves the current policy environment, and the other the scope of the recent national debate about industry strategy.

The Current Policy Framework

The current policy framework was fashioned in the early 1980s and involved a bipartisan reorientation of Australia's national economic strategy. Its purpose was to enhance the competitiveness of Australian firms by removing the tariff walls and other barriers that had hitherto sheltered Australia's manufacturing and service firms from international competition and engagement. Historically, industry development strategies had aimed to develop manufacturing firms to serve only or primarily domestic markets. Now the aim of policy was to leverage firm capabilities to facilitate their engagement with the expanding regional and global marketplace.

Specific policy changes included floating the Australian dollar, liberalising capital markets, labour market changes, reducing tariffs, privatising a wide range of public utilities and introducing market competition to a variety of regulated and administered sectors (for example, aspects of banking, airlines and public utilities). This program continues to unfold through national competition policy. Its central thesis is that economic welfare is maximised in an environment in which resources are priced and allocated according to the freest possible play of market forces. Markets evolve as entrepreneurs pursue profitable opportunities. In theory, and to a large degree in practice, through this process, the 'invisible hand' of markets attracts new entrants and bids down returns, prices and costs in ways that maximise social gain. However, a variety of considerations now suggest supplemental approaches which work with the grain of markets and augment their effectiveness might now be appropriate:

- First, save for aspects of labour market reform, the microeconomic reform agenda has now effectively been fully implemented. While various facets continue to unfold, the basic frameworks are all in place. This is evident in comparative assessments of international competitiveness, which rank Australia in the top five places in each indicator of market quality.
- Second, the development of the knowledge economy as a general concept, and of science-based industries and the national innovation system, introduces new perspectives and frameworks for thinking about the linkages between national institutions and the enhancement of firm-level capabilities. Key issues in innovation include the creation of capabilities, the abilities needed to respond to technological opportunities, incentive structures, and the management of risk and uncertainty. Success requires exceptional and differentiated returns: this is in contrast with the 'levelling' associated with microeconomic strategies.
- Third, a new array of institutional theories has emerged to 'model' the development of a knowledge economy in general and of science-based industries in particular. For example, systemic perspectives are required in evaluating the potential of particular technologies and designing programs to realise opportunities. In implementation, the developments of clusters and of public–private linkages are critical activities. Other theoretical perspectives (for example, Porter 2003; Hall and Soskice 2001) point to the key role of state-generated 'soft' and hard infrastructure in the development of economic capabilities.
- Fourth, globalisation poses new challenges to the Australian economy. Despite the financial crisis, Korea has experienced the highest growth rate of any state in the OCED. It has implemented a proactive industry strategy based on a facilitative and catalytic government role. On his recent visit to Korea, Prime Minister Howard praised this country for its record of policy adaptation:

  > *I make many speeches in Australia about globalisation. I extol its virtues and whenever I do, I almost invariably quote Korea as an example of a country, which has grabbed hold of the advantages of globalisation and through that, lifted in a quite short period of time and quite dramatically, the living standards of all its people. … in recent years, Korea's growth rate has been greater than any other member [of the OECD] (18 July 2003).*

- The current budget papers identify some of Australia's distinctive challenges in responding to a similar imperative:

  > *The costs of trading with key international markets remains a key barrier for Australia relative to other countries. For example, from the 1950s to the 1990s, the proportion of world GDP within a 10 000-kilometre circle from Sydney increased from some 16 per cent to 28 per cent. But*

Key issues in innovation include the creation of capabilities, the abilities needed to respond to technological opportunities, incentive structures, and the management of risk and uncertainty.

for London the same sized circle enclosed 94 per cent of world GDP… Distances among domestic markets continue to constitute an economic hurdle. Australia is the world's sixth largest country in area, yet has a relatively small population. No two cities in Australia with a population over 1 million are closer than 600 kilometres … California (which was once very similar to the Australian economy in size and affluence) now has a population of around 34 million in an area around one-twentieth of Australia's, with its population concentrated between San Diego and Sacramento – a distance of some 800 kilometres' (Budget Paper no. 4, pp. 20–1).

- Despite the various changes already introduced, the international orientation of Australian firms remains worryingly low in comparative perspective. For example, only 4 per cent of Australian firms are regular exporters, compared to the Canadian outcome of 16 per cent, which is the next lowest among OECD states. Recent economic achievements are widely recognised. Don Scott-Kemmis in Chapter 4 documents the longer term weaknesses that may ultimately inhibit performance.

The international orientation of Australian firms remains worryingly low in comparative perspective. For example, only 4 per cent of Australian firms are regular exporters, compared to the Canadian outcome of 16 per cent, which is the next lowest among OECD states.

Debating Long-term Industry Strategy

The past 20 years have been a period of momentous change in Australian politics and society. The policy frameworks that guided national industrial development broadly from the emergence of the party system in 1909 until the election of the Hawke government in 1983 have been repudiated. Tariff based industry development has ended. Centralised wage regulation is much less influential. Deregulation and competition policy have orientated Australia's economy to international engagement. In industry strategy, the Howard government has preserved and developed the approach of its predecessors.

Yet one issue that figured prominently in past debates about industry development has been missing from more recent bipartisan deliberations. This is the benefits and costs of national participation in 'platform' or transfiguring industrial sectors. Earlier political deliberation, from Alfred Deakin to Chiefley, Curtin and Menzies, focused on the national interest as a key consideration. Themes included the creation of jobs that would encourage Australia's best and brightest to remain at home or, when they had left, to return; national independence; defence capabilities; and our attractiveness to talented migrants and to international companies. In the former electro-mechanical age, this involved sectors that offered access to the most modern production techniques or technologies (for examples cars, steel, oil and shipping).

Protection as a means of securing a presence in such activities has long since been discredited. But the significance of our participation (or non-participation) in 'platform' sectors remains to be debated. The costs and benefits of our national failure to have a deeper commitment to the ICT sector is progressively unfolding. Some of these costs are detailed in Chapter 4. Biotechnology presents another opportunity. But, as Jonathan West argues, the bipartisan approach that has made possible rapid economic adaptation is ill-suited to drive a national effort in this emerging 'platform' sector. A new understanding of the special challenges of being a producer in this sector requires a new economic grammar and vocabulary. This is outlined in Chapter 2.

The need to reopen a debate about industry strategy is perhaps the central challenge arising from this collection. In the longer term, Australia can either stay in the mainstream of advanced industrial economies – or watch passively as her neighbours, for example Taiwan, Korea and Singapore, struggle with the challenge of preserving a presence in these 'platform' sectors. There is no fundamental reason disbarring Australia from participation in science-based sectors. In terms of technology, wealth, service sector sophistication, markets and entrepreneurs, Australia has the necessary capabilities. But motive and will remain to be mobilised, particularly at the national level. A first step is a debate that fully encompasses the challenges.

Some of the terms in which such a debate might be conducted are set out in this collection. Jonathan West discusses the imperative of accommodating the distinctive risk-reward characteristics of science-based industries. Keith Smith discusses the way linkages and knowledge in disseminating institutions augment the effectiveness of markets and enhance competitiveness.

A third structural development, not covered in this collection, deserves to be included in any review of industry strategy. This involves Australia's links to the global economy. Large multinational companies (MNCs) dominate world trade, investment and technology flows, but Australian policy is currently characterised by multinational myopia. MNCs dominate global supply chains, undertake two-thirds of world trade and the world's top 1000 companies direct some 90 per cent of foreign direct investment. The global markets served by MNCs are the primary driver of innovation; twenty large MNCs spend more on research and development individually than does Australian business in total. In the context of these developments, strategies for linking MNCs with Australia's SMEs and education, training and research institutions deserve to be at the forefront of national industrial policy. Indeed, for many firms, links to global supply chains could be critical for their longer term survival and growth. This is already occurring in Australia in, for example, the automotive sector. With intra-firm trade already equalling some 50 per cent of Australia's trade with the United States, attention to MNCs is an imperative for Australian government and business. Further, as Treasury has itself recognised (in the quote from last year's budget cited above), Australia's geographic distances from major trading centres creates particular challenges. In addressing these issues, MNCs need to be a central focus and policy frameworks need to play a wider facilitating or catalytic role. In sum, this collection surveys the case for a renewed debate about industry strategy. Political, bureaucratic and media elites will determine if this is to occur.

> Large multinational companies dominate world trade, investment and technology flows, but Australian policy is currently characterised by multinational myopia … Strategies for linking MNCs with Australia's SMEs and education, training and research institutions should be at the forefront of policy.

Study Structure

Jonathan West introduces the collection with a review of the especial challenges associated with participation in science-based industries. As noted above, he emphasises the need to accommodate the risk-reward structure that characterises these industries and that distinguishes them from mainstream industrial activities. In the absence of a policy design that accommodates these factors, Australia's national innovation system will fall far short of its promise. Australia possesses all the requisite capabilities. But until the risk-reward structure is designed to create an appropriate alignment between the component parts of the overall system, the available synergies will not be realised.

Keith Smith explores the related issue of building the capabilities of established sectors through the application of transforming technologies. He cites European evidence concerning the impact of ICT on established industrial sectors. He also explores recent literature on the challenge of ensuring that appropriate linkages and knowledge systems are in place. Economies and sectors that have mastered these challenges suggest the varied ways such upgrading can be facilitated. They also indicate the rewards that can be derived from successful adaptation.

Don Scott-Kemmis reports on preliminary findings from a major review of the existing Australian innovation system. He surveys assessments of Australia's economic performance from both macroeconomic and structural perspectives. The former are generally positive in their findings, but the latter less sanguine about the presence of longer term growth platforms. No one assessment can be definitive or conclusive. He continues with a state-by-state survey of capabilities, patterns of specialisation and evolution. In general, Scott-Kemmis finds strong evidence of path dependence in Australian innovation; that is, Australia is specialised technologically towards agriculture, mining, and primary metals, but has recently increased its activities in biotechnology and pharmaceuticals. Apart from the latter areas, Australian inventions are focused in areas where technological change is relatively slow. In science, Australia's strengths are in geo-science, agricultural science, and animal and plant biology. More recently, biotechnology, engineering and commercial services have also emerged as significant R&D performers. Finally, the public sector dominates Australia's research and innovation system.

Australia is specialised technologically towards agriculture, mining, and primary metals, but has recently increased its activities in biotechnology and pharmaceuticals.

Michael Vitale and David Sparling explore the role of initial public offerings (IPOs) in the Australian biotechnology sector in the period 1998–2002. Their research found that Australia's young firms are almost entirely concentrated in human health. These firms have mostly been able to raise additional funds and stay on their original development path. The Australian sector has mostly outperformed its US counterpart. This has involved adding short-term sales of goods and services to supplement the longer term development plans.

Finally, Gavin Moodie explores strategies for the university sector that might best align its broader roles and purposes with the more focused requirements of innovation. There are two broad models on offer for the development of this relationship. One is the concentration of funding in a few specialised research universities. This is supported by most of the established major institutions. An alternative, proposed by Glynn Davis, Vice-Chancellor designate of Melbourne University, is to encourage the development of new institutional types through multiple contestable funding. This scheme envisages three contestable institutional performance funds, one focused on teaching, one on community service and equity, and a third on research performance. Particular institutions could compete for two but not three of these grants. This debate has yet to be finalised. Its resolution will have major implications for the future approach and capacities of all of Australia's universities.

The issues covered here have been the subject of recent reports for a number of governments, including New Zealand, Singapore and the United Kingdom (Singapore: *The Road Thus Far,* Ministry of Trade and Industry, February, 2003, available on the Ministry web site; New Zealand: *Building the Future,* Boston Consulting Group, 2001, report to Prime Minister Helen Clarke, available on her web site). In addition, Harvard's Michael Porter has prepared a discussion paper for the British government (UK Competitiveness: Moving to the Next Stage, May 2003, DTI Economics Paper No. 3, available on the DTI web site). As these varied reports illustrate, innovation, 'the knowledge economy' and globalisation pose a range of new challenges both for business and for states. This volume addresses these questions in the context of the specific circumstances of business and governments in Australia. Building on what has already been accomplished, they argue that, in Michael Porter's words, it is time to move discussion of competitiveness to the next stage.

References

Peter Hall and David Soskice, *Varieties of Capitalism,* Oxford University Press, 2001

Michael Porter, *U.K. Competitiveness: Moving to the Next Stage,* U.K. Dept of Trade and Industry, Economics Paper No. 3, 2003

2. Financing Innovation: Markets and the Structure of Risk

Jonathan West

1. Introduction

As the electro-mechanical industrial revolution unfolded in the early twentieth century, bringing with it the wonders of mass electrification, automobiles, telecommunications and air travel, Australia's business and political elite made sure that Australians could participate not only as consumers, but also as producers. Education and investment combined to guarantee that Australians could understand, develop and employ these technologies. In turn, mastery of these fields underpinned Australia's prosperity, and ensured that the nation continued to develop as a technologically sophisticated society, able to defend itself and provide challenging and satisfying work for its citizens.

As two successive technological and industrial revolutions have transformed the global economy, Australia has failed to build significant positions in either. In software and electronics, Australia has been left behind; in biotechnology it threatens to be.

In recent decades, however, as two successive technological and industrial revolutions have transformed the global economy, Australia has failed to build significant positions in either. In software and electronics, Australia has been left behind; in biotechnology it threatens to be. In all three, Australia now participates almost exclusively as a consumer and not as a producer. This weakness shows no signs of turning around, in spite of more than a decade of unprecedented prosperity. Nor has the contemporary Australian economy proven particularly successful at generating new approaches within its traditional industries. Why? This failure to innovate is all the more puzzling since it stands in sharp contrast to the nation's success in established industries over the same period. Why the difference? Why should Australia be apparently so good at 'routine' economic activity and yet so poor at innovation?

This chapter will argue that much of the explanation stems from Australia's failure to develop financial and organisational vehicles capable of managing the special forms of risk inherent in contemporary technological innovation. Australia's effort to build a 'market-oriented' innovation system, the very source of its success in routine economics, may be precisely the factor retarding the nation's innovation performance.

No successful innovating country today relies on free markets alone to finance innovation. There are good reasons for this. While markets are undoubtedly powerful and effective resource allocators, better than any known alternative for most transactions, they fail in the face of certain types of economic challenge because they can't manage the form of information involved – in the case of innovation, they can't manage information asymmetry, moral hazard and adverse selection (these terms will be explained below). As a result of these weaknesses, markets alone neither enable innovators to capture sufficient returns, nor to insure adequately against the consequences of failure.

An effective national innovation system must therefore comprise both market and non-market resource-allocation systems, for different economic and technical tasks. And all effective systems do. But Australia has recently tended not to. An unsought consequence of over-reliance on the very factors that make Australia so good at routine economic activity may actually retard its ability to cope with the particular challenges inherent in contemporary innovation.

This need not be so. Nothing intrinsic to Australian society, geography or demographics says it cannot develop world-class technology companies. It is not 'too small', 'too isolated' or 'too conservative'. It is not less entrepreneurial than other developed countries, or less scientifically creative. In aggregate, it has the human and financial resources. To understand what might be done to build upon Australia's free-market system – which this writer wholeheartedly supports and wishes to extend – and to facilitate innovation, it will be useful, first, to provide an overview of the special characteristics of risk in innovation, then to survey the range of economic vehicles available to manage economic risk of different kinds, before finally examining the set of institutions currently employed in Australia. This will provide a platform for discussing initiatives that might improve Australia's innovation performance without sacrificing the fundamental national institutions that have made the core of its economy so strong.

2. The Nature of Innovation Risk

Risk is the defining challenge of innovation. By comparison with day-to-day economic activity, innovation risk is present on more fronts and in greater intensity. While risk-taking has always been central to value creation in capitalism – indeed, markets themselves have been described as processes that resolve uncertainty about human needs and the means to satisfy them[1] – innovation poses the issue of risk in more forms, and especially bluntly.

Any economic activity, no matter how routine, necessarily calls forth at least some risk. Neither the actual desires of customers, nor the behaviour of competitors can be predicted precisely in advance of production. Markets help resolve this uncertainty. But attempts to innovate induce a far greater level of risk than is present in routine production. Innovation necessarily implies grappling with the unknown, not only because prices and quantities of given commodities cannot be predicted in advance, but also because the technical qualities and very feasibility of yet-to-be-created products or processes cannot be known or even described with confidence. Markets that don't yet exist cannot be analysed. The parameters of risk-taking in innovation are therefore both more numerous and more severe than those of regular economic activity.

Risk is the defining challenge of innovation. By comparison with day-to-day economic activity, innovation risk is present on more fronts and in greater intensity. While risk-taking has always been central to value creation in capitalism … innovation poses the issue of risk in more forms, and especially bluntly.

These considerations are vital for understanding the problem economic institutions must confront as they attempt to innovate. If the nature of technical problems shifts, so too must the social and organisational vehicles needed to undertake them. And indeed, the economic and organisational dimensions of innovation have been changed notably over the last century. Contemporary technological innovation is enormously more complex and uncertain than it was a century ago. This has fundamentally altered the character of the organisational task facing innovators.

Complexity can be defined as the number of elements, and element interactions, a technical system requires to deliver its intended functionality; and uncertainty of the degree of perceived inability to predict the future state of these elements accurately, either because of a lack of information or an inability to discriminate between relevant and irrelevant data. Both these parameters have risen substantially over the last century, especially in the technical systems at the centre of innovation. As the functionality of technology has grown, so too has the number of components in the technical systems required to deliver that functionality. In turn, as the number of system elements has increased, so too has the range and depth of technological knowledge needed to master these systems, and individuals have been forced to become increasingly specialised. Any individual can now master only a smaller and smaller proportion of the total. Finally, because all the elements must be integrated to form a coherent whole, the number of elements in the *organisational* systems required to undertake innovation has expanded, sometimes exponentially. A few examples will suffice to illustrate:

- components in a typical automobile: 1920 – 1500; 2003 – 30 000
- components in an aircraft: 1945 – 20 000; 2003 – 3 500 000
- components in a handgun: 51 (musket); 140 (riffle)
- transistors on a typical chip:1970 – 1000; 1980 – 100 000; 2003 –100 000 000.
    - ines of code in a software operating system: 1980 – 10 000; 2003 – 80 000 000.
    - Interconnects in a Private Branch Exchange (PBX), telephone switching system: 1950 – 1000; 1990 – 100 000 000.

The size and intensity of risk inherent in any innovation project depends on the structure of the technology itself. Innovation risk can be measured along three dimensions: scale, duration and intensity.

The phenomenon is general; the world really is getting more complex. This rise in technological complexity and uncertainty, and accordingly in the complexity of the social systems required to develop technology, has heightened the inherent risk of innovation. The parameters of risk are multiplied by complexity and intensified by uncertainty. Complexity magnifies both the real difficulty of uncertainty management, and its perceived difficulty. By multiplying the number of variables in which unpredictable variation is possible, additional complexity increases the possibility of technical failure. But, in addition, by multiplying the number of variables of which human managers must take account, complexity increases the social and cognitive challenge of innovation, and hence its human-derived risk.

Thus the size and intensity of risk inherent in any innovation project depends in the first instance on the structure of the technology itself. Innovation risk can be measured along three dimensions: scale, duration and intensity. Scale refers to the minimum necessary investment needed to bring an individual innovation to market. *Duration* refers to the minimum period required before an outcome is known. *Intensity* refers to the likelihood that the product will make it to market. The greater the first two factors, and less the third, the greater the project's overall risk.

The innovation scale of a technology depends upon the minimum resource commitment that must be made to an individual project within it. This is sometimes referred to as it 'lumpiness'. Lumpiness will be determined by the minimum efficient scale of the proposed technology, and, again, by its complexity. Complexity is also a factor in determining the minimum duration required to complete an innovation project. The more variables that must be tested, and the more variable interactions that might be important to the technology's functioning, the longer the time needed to determine its feasibility. Also important in determining time-commitment is the number of environmental variables with which the technology must interact, and their criticality.[2] A new drug, for example, might not only itself be molecularly complex, but will also be the product of a complex production system. It will then interact with an even more complex system – the human body – and be subject to severe demands of criticality, such as an exceedingly low rate of side-effects. A company attempting to bring it to market will also be required to test the molecule, and to document that it has been tested, under a wide range of potential failure modes. Under such circumstances, the period required to perform all these tests may extend to many years; in the case of drug development, to more than 10 years. Because science is pushing ever faster against its frontiers, and business has moved closer to those frontiers, the uncertainty inherent in contemporary innovation has escalated.

Risk intensity, or (inversely) success probability, is influenced by the maturity of the science base upon which a new technology relies. Where the science and the engineering knowledge associated with the technology is mature, the character of physical elements will be well established, as will the systemic interactions of those elements. Most electronic projects, for example, rely upon a well-characterised base of solid-state physics and materials science, and the probability of their technical feasibility can be predicted with some accuracy. Projects that rely on the much-less mature biological science base are inherently less certain, and any individual project is less likely ultimately to succeed.

Innovations closest to the scientific and technological frontier will pose the most extreme risk: the lowest probability of success, the largest minimum resource commitment, and the longest time frames to bring them to fruition.

But success probability for most innovation projects depends on more than just technical feasibility. Just as important, and often more important, are two other dimensions of risk: market size and managerial capability. Will the product appeal to consumers, and to how many? Does the management team and organisation attempting to devise and perform all the tests required to bring the product to market possess the required capability? These considerations are often just as important as whether the device actuality works.

The intensity and location of risk thus varies by industry and technology. In some sectors, the technology itself is likely to be feasible – to function as anticipated – but identifying a market sufficiently large to justify the investment required to introduce the technology may be problematic. Many innovation projects in information technology will be of this type. In other technology types, a market will probably be available, but whether the technology will operate as anticipated, or can feasibly be scaled from laboratory bench top to production facility, will be more uncertain. Drug development, and especially biotechnological projects, are often of this type.

In general, innovations closest to the scientific and technological frontier will pose the most extreme risk: the lowest probability of success, the largest minimum resource commitment, and the longest time frames to bring them to fruition. These considerations help us understand the appropriate risk management vehicle for each risk type. Not all vehicles are appropriate for all types of risk.

3. How Innovation Risk is Managed

To induce individuals and firms to attempt to create new technologies in the face of such risks, two factors must be present. First, profits substantially greater than those to be won from 'normal' economic activity must be on offer. Second, potential innovators must also be assured at least some degree of protection from the consequences of failure. The bigger the innovation – that is, the greater the complexity and the more the uncertainty that must be overcome relative to the innovator's resources – the greater is the need for such super profits and protection from catastrophe.

Successful innovation offers some above-normal profits more or less 'naturally'. Being first to market with a new product that buyers want provides an opportunity for (at least temporary) monopoly pricing power. Such super profits will not always, however, provide sufficient incentive to confront the risk to innovate. An efficiently functioning market, with technically capable firms, will soon allocate resources to compete away such profits. Indeed, the more efficient the market, the less incentive firms face to innovate. One of the simple ways governments encourage innovation is by blocking the natural action of the market to compete away such super profits, by extending this period of monopoly through the creation of intellectual property rights, such as through copyright and patents. Without such market-blocking, the drug industry, for example, would swiftly implode.

Protection from the downside, however, does not come naturally. Downside risk must be managed deliberately, by organisational vehicles designed specifically for this purpose. Such vehicles can employ one or more of only three potential tools. They can attempt to *reduce* risk (by, for example, changing behaviour); they can *hedge* it (shift it from the principal innovators to a different group more able or willing to bear it); or they can *diversify* it (spread it across a wider base). The latter two can be seen as forms of risk reallocation.

To induce individuals and firms to attempt to create new technologies in the face of such risks, two factors must be present. First, profits substantially greater than those to be won from 'normal' economic activity must be on offer. Second, potential innovators must also be assured at least some degree of protection from the consequences of failure.

Risk reduction is always difficult in innovation, and usually impossible. For other types of risk, such as personal injury, the government can prevent exposure. It can, for example, outlaw dangerous activity. The risk of driving a car can be reduced by mandating speed limits, imposing quality controls on automobiles, and even forbidding distractions such as the use of mobile phones while driving. But such measures are rarely feasible when risk derives from innovation. The risk in innovation, particularly technical risk, is frequently irreducible, at least at the outset. Government can, however, reduce market risk by, for example, guaranteeing to prefer local suppliers over foreign rivals, or granting tax concessions. It can also attempt to reduce managerial risk by supporting management training, or encouraging technically skilled personnel to move from academia.

More commonly, however, institutions must manage innovation risk by hedging or diversification. Hedging attempts to move risk from the originating party, in this case the innovator, to another who is more able or willing to bear it. It is thus a form of risk redistribution. Such movement of the burden of risk is usually accompanied by payment for risk bearing; that is, others are paid to expose themselves to the risk the originator is not willing to bear. A market for risk, or more precisely for the time-, intensity- and lumpiness-adjusted rewards of risk, can thus develop.

Most of those willing to bear such risk, in turn, employ diversification to make the risk from any specific enterprise tolerable. Diversification works on the principle that the *per-party* burden of any given risk declines as more instances are pooled in a portfolio, and then shared among more risk-bearers. Note that the *aggregate* amount of risk in the pool does not change – risk itself has not been reduced, and the same number of innovation projects will fail as before they were pooled – only the impact of any losses suffered on particular individuals is reduced by sharing. By the same token, the per-party opportunity for windfall has been reduced, also by sharing.

The magic of diversification for innovation is that by pooling resources and risks it makes feasible projects of much greater scale, complexity and uncertainty than would be possible for any individual. How many individuals could bear the risk of a space program, for example, even if they could raise the necessary finance? The drawback, however, is that as the complexity and uncertainty inherent in technological projects mounts, so too the scale and breadth of risk-bearing entities must escalate. Such risk-managing bodies then become difficult to manage, and at the extreme, exceedingly so. In contemporary society, and for some aspects of science-based industry, the scale required to assume the risk inherent in some projects has grown from individuals, to partnerships, to organisations, to governments, and even to multi-government or global bodies.

Fortunately, per-party risk declines sharply with each pooled project and incremental risk-bearer, even for the out-sized risks stemming from innovation. A simple example will illustrate the power of large numbers in risk bearing. Consider a hypothetical gold prospector. Searching for gold is risky, with a low success probability, let's say, for the sake of an example, 1 per cent in any given year; but it's profitable if successful, let's say $100 000 for the average strike. The expected value of such an undertaking is therefore $1000 (1 per cent probability of $100 000, plus 99 per cent probability of nothing). While the expected value of this undertaking is positive, few citizens in fact turn to gold prospecting because the risk is too high. A 1 per cent chance of finding gold means it is overwhelmingly likely that in any given year the prospector will not realize even $1000, and will waste his or her time. Indeed, it is likely he or she will derive no income 99 per cent of the time.

As the complexity and uncertainty inherent in technological projects mounts, so too the scale and breadth of risk-bearing entities must escalate. Such risk-managing bodies then become difficult to manage, and at the extreme, exceedingly so.

As if by magic, however, a little diversification can substantially improve the odds of gaining at least the $1000 sum for the individual and more diversification can virtually guarantee it. With two prospectors agreeing to pool their searches and divide their finds equally, three outcomes are possible: (1) neither finds any gold (98 per cent); (2) one finds gold worth $100 000, the other nothing, giving each $50 000 (1.98 per cent); (3) both find gold, giving each $100 000 (0.01 per cent). Note that the expected value remains $1000 per prospector. With only two risk-poolers, prospecting is still not particularly attractive. With 100 prospectors pooling, however, the odds that one will find gold, bringing the gain of each to at least $1000, grow to a comfortable 63 per cent; with 1000 prospectors, the odds of at least one finding gold grow to an overwhelming 99.99 per cent (implying the per-prospector gain is $100). The problem, of course, is that it is exceptionally difficult to organise and sustain pooling among 1000 grizzled gold prospectors.

The same logic holds for innovation, and also from the opposite direction: the probability of successfully bringing a particular innovation to market. Diversification increases the aggregate probability of solving a particular problem. Consider a hypothetical city facing an innovation problem: a plague of mice and no effective mousetrap. Let's assume, for the sake of the example, that the probability any single new trap design will succeed is one in 10, the cost of developing a trap design is $1000, and the reward of success is $100 000 to the inventor and to the city a mouse-free environment. The individual inventor thus faces a 90 per cent probability of losing the $1000 investment in developing the trap, and a 10 per cent probability of gaining $100 000. The inventor's project thus has an expected value of $9100 (10 per cent probability of $100 000 plus 90 per cent of minus $1000), and would make sense for the individual to try. But the city would face a 90 per cent probability of not solving its mouse problem, even if it could persuade the inventor to proceed.

Now consider a circumstance in which the city commissions more inventors to try their hand at designing a mouse trap. Under the same assumptions as before (10 per cent success probability per project), the city now has more attractive alternatives. With two inventors working on the problem, it has a 19 per cent chance of someone building an effective trap; with 10 a 65 per cent chance, and with a 100 a 99.99 per cent chance. The problem is, of course, that the market for mousetraps is still only estimated at $100 000. With 100 projects underway, the city makes no profit, but its mouse problem is solved. Interestingly, halving the number of inventors at work, to 50, reduces the probability of success only to 99.5 per cent; dropping the number to 30 reduces the probability to 95.8 per cent. Thus, by diversifying even modestly, the city enjoys an overwhelming likelihood of both solving its mouse problem, and of making a profit of doing so.

The fact that risk can be managed in these ways, that some economic actors are better than others at bearing risk, and that profit can be made from managing risk, implies that a market for risk services will develop.

What is the price of this strategy? One trade-off is already apparent in our gold prospector example. Along with the reduction in risk of failure, diversification shrinks the probability of gaining a more desirable outcome than the expected value. Already with only two prospectors, the probability of gaining $100 000 per prospector had been reduced by 100 times (from 1 per cent to 0.01 per cent). This explains why gamblers, who play for the love of risk-taking, rarely pool their activities. It also goes a long way towards explaining why gold prospectors don't either. For prospectors, the lure of the big pay-off, however remote a likelihood, provides much of the inducement.

The strategy also requires certain preconditions to have been met. The most important is that the risks being pooled are truly independent of each other. If all our prospectors are looking in the same place, or all have been supplied with similarly rusty prospecting pans, then all are affected by the same factor, and the actual risk has not been diversified. The 'pooled' risk under these circumstances is essentially the same as that of the individual. Similarly, if all mouse trap designers were trained in the same school, and therefore all take a similar approach to a mouse plague, the real probability of finding a solution will not be increased by pooling. The need to meet such preconditions points to the difficulties economic institutions face in coping with innovation risk.

4. Markets as Risk Managers for Innovation

The fact that risk can be managed in these ways, that some economic actors are better than others at bearing risk, and that profit can be made from managing risk, implies that a market for risk services will develop. This is as true for innovation as for other forms of risk. Some economic actors can potentially be better risk managers than others for two reasons. The first is that they might be better able to diversify. They may be larger, or have access to a wider range of independent projects than others. Banks and insurance companies, for example, rely on this advantage to enable them to assume risk from individuals. Larger companies can spread the risk across a greater number of bets. Venture capitalists also rely on size to share risk with entrepreneurs. Second, some economic actors may be better than others at choosing projects for inclusion in a risk-management portfolio. Specialist risk managers cultivate expertise and experience at judging and balancing the multi-sided risk inherent in innovation projects. Venture capitalists are (or should be) much better at assessing the market and managerial risk in new ventures than are individual entrepreneurs themselves.

In addition, however, some may actually be able to reduce the risk in a particular innovation project. How might this be achieved? For a firm with deeper scientific, technical, or managerial capabilities, the risk inherent in a particular project might be substantially lower than for another lacking those capabilities. When a pharmaceutical company buys the rights to a candidate drug from a biotech start-up, for example, it can actually reduce the risk that the product will fail to reach the market by combining its own capabilities with those of the project team or initial sponsoring company. The chance that a start-up biotech company can not only invent a potential new drug, but also successfully manage the complex process of clinical trials, interact effectively with regulatory agencies, scale up manufacturing processes, and distribute the product through a nationwide or global distribution channel, are much less than those of an established pharmaceutical company. By taking over the project, and plugging it into its own development portfolio, the company has effectively reduced the project's risk.

Other reasons why markets develop for innovation risk include differential risk aversion levels, including those due to differential risk *impact* levels, and portfolio balancing. Risk aversion levels vary either simply because some parties are less fearful of risk – a few actually enjoy risk – or because some (for example, the rich) are more capable of withstanding the impact of losses, especially at the margins. Those with greater fear of risk can then attempt to 'sell' the risk to others who are more comfortable with it. In innovation, this might take the form of partnering, outsourcing certain activities, or pre-selling the yet-to-be-realised product to a major customer.

Other reasons why markets develop for innovation risk include differential risk aversion levels, including those due to differential risk impact levels, and portfolio balancing.

But parties might agree to exchange risks simply in order to re-weight their portfolios, and align time periods. Firms processing raw materials for which year-round capacity utilisation is important, for example, seek to balance the price they pay for inputs, so as not to face price spikes in non-harvest periods. They do this by buying and selling futures contracts from others, including farmers, who may seek to 'lock in' stable prices for their products in advance of harvests.

All these are powerful reasons why different economic actors will seek to trade and exchange risk. And indeed, this desire has generated a wide variety of tools, techniques and vehicles for buying and selling risk: bank loan portfolios, put and call contracts, a dazzling array of derivative contracts, insurance contracts and so on. In turn, the creation and spectacular growth in recent times of these instruments has spawned a wide variety of markets for trading risk. These include the Chicago Board of Trade Futures Exchange, and many markets for options and other derivatives of stocks, loans and currencies.

Some economists have been led by this proliferation of instruments and exchanges to hope that all risk, including risk in innovation, can be managed through market exchange. It is a laudable hope, since indeed if all risk could be managed through markets, the organisational and managerial overhead would be much lower, and the results would be more available to entrepreneurs. Life for innovators would be much simpler. The only role for other institutions, and policymakers, would be to support markets, and to help them be as liquid, transparent and flexible as possible.

But in order that markets for risk come into being, several conditions must be met. Of central importance are conditions relating to the availability of information. In essence, the same information must be accessible to all actors. If this condition is breached, buyers and sellers cannot reliably estimate the degree of risk inherent in any position, and cannot establish a real value for the risk management instrument. Similarly, for markets to establish a price for the instruments, these instruments must be made sufficiently similar in key respects that they can be compared effectively.

Unfortunately, in markets for risk, and as we will see, especially markets for innovation risk, such conditions are frequently *not* met, and cannot be met. Several factors combine to inhibit the growth of markets for risk, particularly of certain types and under certain conditions. Two widely observed defects in the information surrounding risk available to market participants undermine the action of markets. These are commonly termed *adverse selection* and *moral hazard*. Both are virulently present around innovation, and lead to severe information asymmetries in the markets for knowledge and technology risk.

Several factors combine to inhibit the growth of markets for risk. Two widely observed defects in the information surrounding risk available to market participants — adverse selection and moral hazard — undermine the action of markets.

Adverse selection occurs when the sellers of risk know more about the degree of jeopardy involved in a particular transaction than do buyers. The result may be that the most risky projects are sold too cheaply; the worst risks 'select themselves' for inclusion in the sale portfolio (hence, the term 'adverse selection,' from the point of view of the risk buyer) – this is to the disadvantage of risk managers. Sellers keep the best, least risky, projects to themselves. Frequently, adverse selection results in risk managers discovering that rather than managing an unbiased portfolio of independent risks, which is, as we have noted, a necessary condition for enabling diversification to function effectively, they have accumulated a group biased towards the most risky. When buyers fear adverse selection, they retreat, and the market for the type of risk subject to this defect crumbles.

Whether a problem of this type might exist in markets for knowledge was tested by Harvard Professor Gary Pisano in the arena of biotechnology.[3] Pisano found it did exist. He took a 1970 article by Berkeley economist George Akerlof,[4] in which Akerlof framed what has become known as the 'lemons' problem, and used data from R&D alliances in biotechnology to test for evidence of the problem Akerlof postulated. Akerlof's argument was that in transactions in which the parties could access differing levels of information – that is, in which information was 'asymmetric' (Akerlof's example was used cars) – buyers could not tell the difference between a good product and a defective one. Only the seller of a used car, and not the buyer, really knows whether the shine of the hood conceals unrevealed defects. In this circumstance, Akerlof argued, even if the car was in fact good, buyers would discount *all* cars in the used market, compensating for the risk that the particular one they were buying concealed unsuspected defects.

The size of the discount would be derived from the expected probability that the particular car the buyer gets will be a 'lemon'. If the expected probability of unwittingly purchasing a lemon is 50 per cent, the buyer will discount the purchase price by 50 per cent of the difference in value between a 'good' car and a 'lemon'. The result of such (rational) behaviour is a severe distortion of the market. If the seller of a good car knows that his or her offering will sell for 50 per cent less than its true value, due to the presence of lemons elsewhere in the market, he or she will be less likely to sell it at all. Conversely, potential sellers of 'lemons' can be confident that their offerings will go for 50 per cent more than true value, and they will have a greater incentive to sell 'lemons'. Eventually, only 'lemons' will be available on the used car market, and the market will collapse.

Pisano argued that in licensing deals among biotechnology companies, the prospective licensee does not know the true quality of the project on offer. He or she may have difficulty in finding out. While the licensee can conduct extensive due diligence, inevitably some critical information will not be passed across to buyers, either because the seller is unwilling to do so or because they are unable to. The seller clearly wants to present the project in as favourable a light as possible. Indeed, were the seller to hand over all information, the licensee would have little need to pay anything for the license, having already obtained the needed information.

Under such circumstances, licensees must discount how much they are willing to pay for licenses, and the 'lemons' dynamic potentially kicks in. To test whether it in fact did kick in, Pisano analysed data on 260 biotechnology projects. He asked whether licensed projects suffered a statistically significant lower success rate than non-licensed projects, all other factors being taken into account. He found that partnered projects were only 46 per cent as likely to succeed as non-partnered. This is a large difference. It implies that eliminating the 'lemons' effect could effectively double the success rate in partnered projects. The implication was clear: the market for knowledge is likely to be inhibited as more firms experience the 'lemons' problems with projects they in-license. Innovation risk is thus more difficult to manage through intellectual property markets.

The second major problem of asymmetric information, moral hazard, results from the creation of an incentive to undertake more risky behaviour, or even to cheat, once the risk of doing so has been sold to another party. The classic example given by economists is fire insurance. Once property owners are assured that the consequences to them of a catastrophic fire have been sufficiently reduced or eliminated through insurance, they may reduce their commitment to, and expenditure on, fire reduction equipment and practices. At the extreme, they may even deliberately create fires to reap the reward of having sold the risk to the insurer.

The second major problem of asymmetric information, moral hazard, results from the creation of an incentive to undertake more risky behaviour, or even to cheat, once the risk of doing so has been sold to another party.

This problem is especially important for innovation. The gains from innovation come from activities and projects that are inherently risky. What constrains innovators from pushing forward with risk is the consequences of failure – loss of their investment and the time committed to the project. If any agency effectively 'insures' the innovator against all risk, whether it be an investor, a bank, or a government, while leaving the potential innovator in control of key decisions, the potential exists for the innovator to skew their projects towards only the most risky. With the downside taken care of by someone else, why not shoot for a big upside? While the 'insurer', particularly if it is a government, may in fact be attempting to encourage innovators to be more adventurous, completely removing risk may tempt the innovator towards excessive risk-taking.

The two problems outlined here are well recognised by economists and historians of markets. They are both information problems, in which incentives exist for parties on one or both sides of a transaction not to share information. The consequence of information asymmetry is to undermine the willingness and ability of market participants to buy and sell risk. Its presence means that markets for knowledge ('intellectual property') rarely function smoothly. Even good ideas are so heavily discounted that innovators frequently fail to gain sufficient returns to justify the resource commitment required to undertake them.

The information-processing demands of innovation, however, induce another whole class of problem that retards the smooth functioning of markets for risk. These are problems, not of information asymmetry but of information *absence*. The vital distinction between situations in which the probabilities of various outcomes can be known in advance, and hence managed with confidence through pooling and diversification techniques such as those discussed above, and those in which probabilities cannot be known in advance, was first highlighted by University of Chicago economist Frank Knight. Knight proposed two conceptually distinct categories, risk and uncertainty, for understanding what is commonly lumped together as 'risk', and suggested important implications for his distinction:

> *The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known (either through calculation* a priori *or from statistics of past experience), while in the case of uncertainty that is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in such a high degree unique.*[5]

In no successful economy is innovation risk managed by markets alone. … Nations that have succeeded in establishing sets of institutions to achieve such risk-sharing have succeeded in innovating in the complex and uncertain fields of software, electronics and the life sciences. Those that haven't developed such 'national systems of innovation' have failed to build those industries.

Innovation is clearly in Knight's second category. This is a critical distinction for economic practice:

> *The best example of uncertainty is in connection with the exercise of judgment or the formation of opinions as to the future course of events, which opinions (and not scientific knowledge) actually guide most of our conduct. Now if the distribution of the different possible outcomes in a group of instances is known, it is possible to get rid of any real uncertainty by the expedient of grouping or 'consolidating' instances.*[6]

Knight argued that if the probabilities could *not* be known in advance, the tools of 'consolidation' or the 'insurance principle' – through portfolio diversification such as that discussed above would prove much less reliable:

> *The application of the insurance principle, converting a larger contingent loss into a smaller fixed charge, depends upon the measurement of probability on the basis of a fairly accurate grouping into classes.*[7]

For innovation, such 'measurement of probability' and 'grouping into classes' is rarely possible. Innovation projects are by nature learning and knowledge-creation efforts. As such, each is unique. It is all the more important, therefore, that risk managers be able to make precisely informed judgments *about each specific case.* Doing this across organisational boundaries is always more difficult than within the shared culture and cognitive frame of a common organisation, at least if that organisation is healthy. The conclusion is that market-mediated inter-organisational relations inevitably inhibit, sometimes severely, the intimate knowledge and close relations essential to both knowledge integration and project selection for risk management. Escalating complexity and uncertainty have only exacerbated the difficulties to which Knight drew our attention.

To summarise, the growth of markets for risk is retarded in the case of innovation by three factors: inability to arrive at an agreed price due to asymmetric information; adverse selection leading to excessive discounting; and difficulty conducting learning and integration across organisational boundaries. These problems have meant that markets for intellectual property are flawed and poorly developed, and in no successful economy is innovation risk managed by markets alone. It has proven necessary for innovation risk to be shared by institutions broader than the modern corporation. Nations that have succeeded in establishing sets of institutions to achieve such risk-sharing, without inducing adverse selection or moral hazard, have succeeded in innovating in the complex and uncertain fields of software, electronics and the life sciences. Those that haven't developed such 'national systems of innovation' have failed to build those industries.

5. Risk Management Vehicles

If markets can't bear the burden of innovation risk alone, who can? In fact, no one best vehicle exists that is optimal for all technologies. Because the structure of risk varies, so too must the structure and organisational form of risk management. Some types of risk require large and diverse management vehicles, others small and tightly integrated organisations. To manage innovation risk successfully, it is necessary to match the source of finance with the type of risk to be incurred. Greater scale means that larger individual minimum commitments must be made to participate in the experimentation process, which implies a larger portfolio. Greater risk intensity, or lower individual successful probabilities, must be offset by higher potential pay-offs. Longer duration means positions must be maintained for longer before a return can be expected, and often require ongoing rather than limited-lifespan vehicles.

The growth of markets for risk is retarded in the case of innovation by three factors: inability to arrive at an agreed price due to asymmetric information; adverse selection leading to excessive discounting; and difficulty conducting learning and integration across organisational boundaries.

Put simply, the greater the scale of commitment necessary, the lower the individual probability of success (greater the risk intensity), and the longer the duration of experimentation processes, the wider must be the base over which the risk-management vehicle must diversify. Vehicles to manage *minimal* risk are relatively straightforward to construct, and many nations possess them. But it is important to recognise that the vehicles required to manage larger, more intense and more prolonged risk must be larger, more complex and of longer duration. Fewer nations have been unable to construct these.

This fact explains why some nations are outstanding at entrepreneurship but poor at technological innovation, or vice versa, strong in invention but poor at entrepreneurship. In fact, most entrepreneurs don't innovate. Their new businesses create a 'me-too' product or service, incurring little technical risk. They start small and remain small, although such businesses can provide a generous income to an individual entrepreneur. While small, 'me-too' firms are numerous, they often enjoy only a relatively short lifespan. They contribute little to the growth of a modern capitalist economy, and little to technological innovation. Such ventures can be, and are, funded from undiversified personal resources, or from family and friends. Even for firms that eventually grow larger, most initial finance comes from undiversified sources.

But these businesses, too, while they might at the outset be financed from personal savings, as they grow and take on more ambitious innovation projects, they demand both more finance and more-diverse finance. Most such firms take several years to define a particular field in which they possess distinctive competence. During this period, their customers implicitly agree to share their risk. Most such companies succeed by 'out-hustling' others with similar ideas, though a few develop rapidly based on distinctive ideas from the outset.[8] Such firms typically must live for five to eight years before, if successful, they develop any competence that would merit formal venture financing. They also are often financed at first with a combination of personal assets and aggregated friends and family assets.

As risks become larger, of longer duration, and of greater intensity, increasingly broad *organisational* coordination is necessary if risk is to be effectively diversified. The range of possible risk-management and integration vehicles can be arrayed along a spectrum, from the simple and small scale, through to the large and complex. If the demands of particular innovation tasks are not matched to appropriate institutional and organisational vehicles, innovation will appear unacceptably risky and not be attempted.

For initially larger and/or riskier undertakings, sources of capital that appear small in the bigger picture assume much greater importance. Such ventures usually require finance beyond the reach of most individuals, and very likely beyond the resources of those who initiated the idea that spawns the company. These ventures are much riskier, and frequently require longer time frames before ideas either come to fruition or are shown to fail. To cope with such demands, entrepreneurs must turn to investors who can mobilise greater resources, and diversify the risk further.

The three main vehicles for financing innovation investment in a modern economy are: large corporations, including banks; venture capital and other pools of private investors; and government. At an early stage, formal equity and debt markets – the stock and bond markets – usually play little role. In almost no country other than Australia does the stock market attempt to finance innovation, especially in its early phases. Such markets usually become involved only much later, serving to enable the successful entrepreneur to monetise his or her investment and capital gains, and withdraw funds from both through an initial public offering. These vehicles play the vital roles of diversifying risk and overcoming information asymmetry to select investments. But each enjoys a divergent set of strengths, and suffers different weaknesses.

The three main vehicles for financing innovation investment in a modern economy are: large corporations, including banks; venture capital and other pools of private investors; and government ... In almost no country other than Australia does the stock market attempt to finance innovation, especially in its early phases.

Large corporations can usually gain superior information about the character of innovation projects. In theory at least, they have full access to the data and judgments generated by their employees on the risks and potential returns of innovation projects under consideration. They can also combine and integrate information, in an ongoing and cumulative social learning process, over time expanding their capability both to manage and to assess such projects. Their information flow is, of course, subject to the vicissitudes of organisational politics – empire-building, career-positioning, pleasing the boss and so on – but by keeping information internal to the organisation, calling upon the effort and commitment of employees, and holding employees accountable for their performance over time, large corporations do have a better chance to acquire the information needed to select the best projects for inclusion in their portfolio.

On the disadvantage side of the ledger, such a portfolio will necessarily be circumscribed in several ways. First, the number of projects included cannot grow very large. A company can conceivably manage tens, perhaps even hundreds of projects, but not thousands. Second, the aggregate resources that can be committed will be limited by the firm's size, its cash flow, and industry norms about the appropriate ratio of sales to R&D expenditure. Third, to achieve the advantages of knowledge integration, and to make project management effective, firms must not diversify too far from their core expertise. Management must know enough and have sufficient experience to make informed judgments about the projects selected for their portfolio. Equity and bond markets are sceptical of firms that attempt to expand into arenas in which the firm lacks established competence and experience. Fourth, public firms, in particular, need to satisfy the short-term cash-flow interests of their investors. Given the favourable tax treatment that prevails for dividends, in Australia especially, investors in public firms expect that management will pay out a large proportion of earnings to shareholders, limiting what can be retained for investment in future innovation. They also expect that firms will not undertake activities that are disproportionately more risky than those in the operational core.

These four factors limit in practice how much true diversification a public firm can achieve for innovation projects: the projects must be related reasonably closely to the firm's core activities, they must not be too risky or too different, there must not be too many of them, and the quantity of resources retained for investment in innovation must not be too great. In short, while corporations can usually enjoy access to better information than markets, the breadth of diversification than can be achieved without jeopardising relations with markets is inherently limited. Corporations thus are most capable at managing medium-sized portfolios of related projects, none of which is too large or risky by comparison to the firm itself. Ideally, their projects would be closely related to, and they would leverage and strengthen the firm's core operational activities.

Four factors limit in practice how much true diversification a public firm can achieve for innovation projects: the projects must be related reasonably closely to the firm's core activities, they must not be too risky or too different, there must not be too many of them, and the quantity of resources retained for investment in innovation must not be too great.

Venture capital is the second organisational form through which innovation risk is managed in free-market economies. Venture capital pools differ from companies, in that they seek to invest in entirely new, potentially high-growth, businesses, grow them, and sell their stakes when mature, rather than manage them over the long term. These young businesses can be quite unrelated to one another; indeed, from the perspective of achieving true diversification – unrelated risks – it is ideal that they are quite different. But venture capitalists differ from other pooled investment funds in that they seek to add their own expertise about growing small companies to those of existing management teams, improving the probability that their firms will succeed.

The lifespan of a venture fund is finite, usually seven years. Other investment groups, such as pension funds or wealthy individuals, commit a proportion, usually a small proportion, of their resources to the venture fund in the hope of gaining far above average returns, more than compensating for the extra risk they assume. Venture funds range in size from a few million dollars to about a billion. Venture capitalists hope to make investments in a limited number of companies, typically 10 to 30, of a few million dollars each. Their goal is to recognise opportunities that others do not, buy a stake early, help mature these businesses, and ultimately bring their products to market, before selling their stake for a large gain. This process is, of course, inherently high risk. By investing in businesses that have yet to prove themselves in actual markets, venture capitalists accept, and hope to master, a high degree of risk.

How do they do this? To what types of risk are venture capitalists best suited? In essence, venture capitalists aim to combine more diversification than companies can gain with better knowledge than equity markets of opportunities for business growth. Venture capitalists aspire to know more than markets – to see the opportunities faster, apply better skills to analyse opportunities, and employ superior management expertise to help their businesses grow – and to pool a sufficient range of investments that the inevitable failures are more than compensated for by the winners.

But, like all other risk-management vehicles, venture capitalists are expert in only certain types of businesses and certain types of risk. They specialise in understanding market and managerial issues. They are rarely qualified to assess or cope with technical risk. Unlike companies, therefore, most venture capitalists attempt to remove or substantially reduce technological risk before committing to an investment. Discussions between technological entrepreneurs and venture capitalists typically begin with at least 'proof of concept': demonstration that the device, software program, or service will actually function as claimed.

In the fields in which venture capital has flourished, in particular information technology, software and telecommunication devices, these conditions can be met. It is usually possible to show at the outset that the proposed concept of a young company is technically feasible and practical, at least in principle. A working prototype or mock-up can be assembled. The underlying physics and engineering are usually well characterised. This is true as well of electronics and the semiconductor industry.

Like all other risk-management vehicles, venture capitalists are expert in only certain types of businesses and certain types of risk. They specialise in understanding market and managerial issues. They are rarely qualified to assess or cope with technical risk.

In these fields, other parameters amenable to venture funds are also met. Projects typically take less than five years to bring to fruition or to fail. This is critical for venture funds, for in the seven-year lifespan of a typical fund, one or two years will be devoted to finding suitable investments, and one or two years will be expended at the end to exit positions (successful or otherwise). That leaves only three to five years in which their firms must be tested. And in the industries in which venture capital has thrived the individual investments are not too large. If a typical fund invests $100 million, and wants 20 positions, each investment cannot average more than $5 million. This profile nicely fits the typical software company. It can be financed for a few million, takes a few years to test, and its technology can be well described in advance of financing the new firm. Of course, venture funds can combine their investments with others, but it is difficult to fund projects that require hundreds of millions of dollars, or many years, in this way.

The limits of venture capital are not apparent in the other major field of contemporary technological innovation: life sciences. Here, conditions amenable to venture capital are much less commonly achieved. First, technical risk cannot be taken off the table. Most life science projects and new companies come into being precisely to determine whether the company's concept will prove technically feasible. The underlying science is not mature or well understood, and scientific outcomes must be established by physical experimentation. Thus, in life sciences, potential investors confront irreducible risk of all three kinds. Assessing the kind of technical risk frequently encountered in life sciences demands deep and sophisticated knowledge of the focused sub-field within which the project will operate. And even with such knowledge, as in the case of scientific peer review, it is often possible to gain only an imprecise estimate of a project's success potential. Detailed familiarity with the current state of relevant literature, as well as knowledge of activity under way at leading labs worldwide, is often required to assess such projects. Certainly, very few venture capitalists, even those with advanced scientific training in a field of biology, are likely to possess the exact expertise required to estimate success probabilities in this field.

Further limitations are imposed upon venture capitalists in biotechnology by the typical size of their funds, the number of positions they wish to hold, and therefore the maximum size of commitment they consider it prudent to make to any one nascent company. These parameters will be driven by the venture capitalist's assessment of the success probability or risk intensity of the projects in which they will invest. For example, a $300 million fund, investing $10 million in each of 30 projects, with a potential pay off of three times initial investment, would need at least 10 successful projects (or 33 per cent success rate) to return its investments with no profit. To gain an industry-expected return of 40 per cent, the fund would need at least 14 successful projects (a 47 per cent success rate). If the expected success rate drops to 5 per cent (the rate many analysts think typical of pharmaceutical projects entering clinical trials), the return on the few successful projects must rise to 200 times to return the fund's capital, and 280 times to gain a 40 per cent return. Even if achievable, this is a highly skewed distribution of risk and returns.

Clearly, these are severe conditions to impose on any investment portfolio. The implication is that the minimum effective scale of a fund – the breadth of diversity it requires to be confident of meeting its targets – will be driven by a combination of the risk intensity (success probability) typical of the technology in which it seeks to invest, the minimum size of investment required, and the expected return for winners. Lower probabilities dictate greater diversification and larger total fund size. But even when these conditions are met, some very profitable investments offering potential returns many times their original invested capital may not be wise, under conditions of exceptionally low (but not unheard of) expected success rates.

Government brings to the innovation challenge several major advantages over other risk-management contenders, along with two central weaknesses. The most obvious advantage is that government can diversify its risk over the widest base of all: the entire citizenry.

The final major vehicle available to finance innovation is government. Government brings to the innovation challenge several major advantages over other risk-management contenders, along with two central weaknesses. The most obvious advantage is that government can diversify its risk over the widest base of all: the entire citizenry. Not only can it achieve huge diversification, but it can also broaden its capital raising, incorporating means from raising taxes to issuing its own debt. It can also diversify the form in which it take its returns to include non-financial forms, such as more and better employment, better health outcomes, improved security, or simply enhanced national prestige and the betterment of humanity. On top of these advantages, it can readily take a long-term perspective, both in the investments it makes and in the way it finances them. Government would seem, then, to be an ideal risk-bearer, especially for large, complex and long-term projects. And indeed, government has often financed such projects, ranging from the space program, to Airbus, the new commercial-aircraft manufacturer in Europe, to laying the foundation for a semiconductor industry in Japan, Taiwan and Singapore.

But government suffers from two important drawbacks as a risk-taker, both stemming from the character of its resource-allocation and decision-making processes. First, precisely because government possesses such a broad range of responsibilities and powers, and can bear and survive large-scale risk – indeed, if it is the government of a significant economy, it can survive almost any financial risk – it can suffer from inherent discipline problems. Government can potentially invest in almost any project, even those with virtually no chance of success, and survive the consequences. Worse still, government, and especially non-elected government officials, face no competition. Government is simply not subject to the same market-based discipline as other risk-managers, or indeed virtually *any* discipline other than the public's scrutiny and willingness to bear taxes. It is a perfect monopoly. One consequence of all this is that government is particularly vulnerable to allocating resources to projects characterised by not only great risk, but little or no social pay-off.[9] This is especially so when such projects help politicians win re-election, either because they are popular or supported by wealthy backers.

The result is that government resource allocation can be deeply flawed. Key individuals in government rarely bear any risk on their own account; they are playing with other people's money. While in a democracy at least they need to retain public support, because government can readily delay financing its investment until after the current decision-makers have departed, governments can allocate resources in ways that are popular today, but make little long-term sense. Frequently, too, these decisions are made by personnel with poor training or experience in financial risk management. A capital allocation system in which successful projects are those backed by friends of government officials or politicians is perhaps the worst form of risk-management available. And the greater the arena of responsibility allocated to government, the greater the probability such disaster will emerge.

> But government suffers from important drawbacks as a risk-taker, both stemming from the character of its resource-allocation and decision-making processes. … Government is simply not subject to the same market-based discipline as other risk-managers... The result is that government resource allocation can be deeply flawed.

How might such drawbacks be surmounted, to gain the advantages of government as a risk-bearer, but avoid the distorting effects of government decision-making processes? The answer is in the first place to circumscribe government's role to areas in which the market, or market-oriented vehicles, have been demonstrated not to work (that is, in which markets and other institutions fail, and not because they are simply bad ideas), and then to require both transparency and the strongest possible competition in resource allocation. Ideally, after broad public debate government would decide which areas of risk it *should bear* in the interests of social welfare, and then hand over decision-making on individual projects to a group or groups that are exposed to both public scrutiny and competition. The first condition requires that it be firmly established that the type of risk under consideration should be borne by someone – that is, that the potential project offers substantial social pay-off if successful – and that no other vehicle can do so, whether because the risk cannot be diversified, is too long term, or just too complex. The second condition requires that government officials themselves *not* make risk-management investment and resource-allocation decisions, but that purpose-designed vehicles be developed for these tasks. One key is for government not to bear all risk, but only to share it with market exposed vehicles.

An Example: The Pharmaceutical Industry

The fact that the structures of risk and appropriate management vehicles vary suggests that in large and complex sectors, such as health or defence, a division of labour will arise among various institutions for bearing risk. The pharmaceutical industry of the United States, the world leader in this sector, provides an instructive example of how one such system divides responsibility.

Bringing a new drug to market requires successful navigation of a multi-stage, time-consuming and labyrinthine process. In 2004, the cost of developing and testing a new drug was estimated to be greater than $1 billion, and to take more than 10 years. These two features alone suggest the need for both large and patient sources of capital. But in addition, drug development is highly risky, and returns come from only a very few successful projects. Ninety-five per cent of drug candidates entering clinical trials fail to gain final approval and don't get to market. And immediately successful drugs come off patent, imitators produce generic copies and prices plummet. Yet, year after year the pharmaceutical industry is on average among the most profitable in the world. This fact implies that the 5 per cent of new drug candidates that *do* make it to market can deliver very large sales and high margins. In other words, while new products produce sufficiently strong profits to make the industry one of the fastest growing and highest margin in the world, for the industry taken as a whole, risk is lumpy, long-term, and returns are highly skewed.

Significantly for the present discussion, the industry cannot be considered as a single entity. Each of the risk parameters discussed above varies as a drug candidate moves through the stages of the R&D process. The likelihood of a product succeeding rises as it crosses key hurdles, as is illustrated in Table 2.1.

The fact that the structures of risk and appropriate management vehicles vary suggests that in large and complex sectors, such as health or defence, a division of labour will arise among various institutions for bearing risk.

Table 2.1: Launch probability and project numbers in the pharmaceutical industry

	Target generation	Lead generation	Preclinical trials	Phase I clinicals	Phase II clinicals	Phase III clinicals	Market launch
Number of projects for probablity of one launch	33 333	10 000	100	20	5	2	
Probability of market introduction from stage:	0.003%	0.01%	1%	5%	20%	50%	

(Source: Author's estimates)

During the earliest stages, in which scientists search for target molecules in the biochemical chains that cause disease (a process known in the industry as 'target generation') and then look for active molecules that can disrupt those disease-inducing chains ('lead generation'), the probability of any individual project producing a successful drug is exceedingly low, in fact on the order of 1 in 33 000 (for target generation) or 1 in 10 000 (for lead generation). As candidates move into preclinical (animal trials) stage, the odds of success rise to 1 in 100; then in clinical trials (testing in humans) the odds rise from 1 in 20 for Phase 1 (which tests in a small sample whether the drug is safe), to 1 in 5 for Phase II (which tests efficacy, also in a small sample), to 1 in 2 for Phase III trials (a large, statistically significant sample). The process from preclinicals to Phase III clinicals typically takes about 10 years.

By combining this information on probabilities with the cost of undertaking such projects, it is possible to estimate the degree of diversification required to manage risk adequately. The cost of bringing a single product through Phase II clinical trials is estimated to be US$50 million; and through the end of Phase III, US$500–800 million. Prior to clinical trials, projects are much smaller and cheaper, but many more are required. To ensure a likelihood of one project getting to market from the lead and target generation stage, tens of thousands of projects must be initiated, at a cost of billions of dollars. To be likely to succeed in taking a single potential new drug from Phase I through to the end of Phase II clinical trials, an organisation needs to start about 20 (carefully selected) projects, which if they did cost our estimated average $50 million each (some drop out before Phase II, of course, providing some savings), it would suggest a portfolio of around $1 billion. To take the drugs through to the end of Phase III calls for an additional commitment of around $1 billion, bringing the total portfolio to around $2 billion.

What sort of organisations can manage a risk of such magnitude? Clearly, a division of labour is required. How the US innovation system divides the tasks is outlined in Table 2.2.

Table 2.2: Risk management division of labour in the pharmaceutical industry

Risk manager	Risk manager	Risk manager
Government and Not-for-profits	Venture capital and pharmaceutical companies.	Pharmaceutical companies.
Portfolio 10 000s projects.	Portfolio 10s-100s projects	Portfolio<10 projects
$10s billions.	$1005 millions.	$2–4 billions.
Project selection on basis of science.	Project selection on commercial and science basis.	Project selection on commerdal basis.

	Target generation	Lead generation	Preclinical trials	Phase I clinicals	Phase II clinicals	Phase III clinicals	Market launch
Number of projects for probablity of one launch	33 333	10 000	100	20	5	2	
Probability of market introduction from stage:	0.003%	0.01%	1%	5%	20%	50%	

(Source: Author's estimates)

No single organisation could possibly operate and coordinate tens of thousands of projects, at a cost in the billions of dollars, other than the government, which in the United States combines with an extensive network of not-for-profit organisations such as the leading research universities to shoulder the task. The US government overcomes the drawbacks of the government resource-allocation process referred to above, not by refusing to 'pick winners' (in Australian parlance) or absenting itself, in the hope the market will pick up the ball, but by selecting a sector, in this instance biology, then 'outsourcing' resource-allocation decisions to a decentralised network of scientific peer-review panels. These panels attempt to ensure that the money flows to the most scientifically promising projects, and that results and prospects are reviewed by those closest to the field. The system is, of course, far from perfect – it is subject to personality politics, entrenched interests, distortions due to professional jealousy, and many other pressures – but by and large it works. The result is that the United States has a commanding lead in basic science, and a proliferation of prospects for new drugs. Note that at this stage the US system *does not* attempt to rely on equity markets to finance research and development.

At the next stage, in which tens of projects are needed to gain sufficient diversification, matters are less clear. Venture capital is certainly active in financing early clinical trials for promising candidates in the United States, as are pharmaceutical companies. But even in an economy the size of the United States, few venture capital organisations can build a $1 billion portfolio of drug development projects. This stage of the development chain is therefore still problematic, and it is the arena in which many of the difficulties cited in the previous section surface most noticeably. Without strong ties to pharmaceutical companies, it is unlikely this phase of the development process could adequately be funded, even in the United States.

For stage III clinical trials and beyond, to marketing and distribution, only the pharmaceutical companies can both make the required judgments and finance a sufficiently large portfolio. The rising cost of the complex and expensive clinical trials now required to meet regulatory approval, and hence the even greater size of project portfolio required to diversify the risk, is certainly one factor behind the merger wave experienced by the global pharmaceutical industry in the late 1990s.

The calculations cited above apply to any typical pharmaceutical product, whether biotech-derived or traditional small-molecule chemistry. But the pharmaceutical industry is only one example of such a division of labour. The important insight here is that no one-best, one-size fits all, mechanism exists for innovation risk management in a modern economy. What works best for the barber shop or family construction company will be unlikely to serve the needs of a new commercial aircraft manufacturer. As the balance between risk and reward tilts and narrows, and the degree of technical expertise required expands, the base over which risk must be diversified widens. It shifts from individuals, to families, to small-pooled vehicles such as angel funds, to medium-sized pooled funds such as venture-capitalists, and then to very large pooled funds such as pension funds, and ultimately to government itself.

The kinds of institutional structures a society develops for managing risk plays a determinative role in shaping in which technologies the society specialise, and what types of businesses are formed. To undertake entrepreneurship in highly complex and uncertain technologies, requiring the coordination of many specialists and experiments over long periods of time, requires the pre-existence of large and diverse institutions capable of managing the scale and scope of the risk created therein.

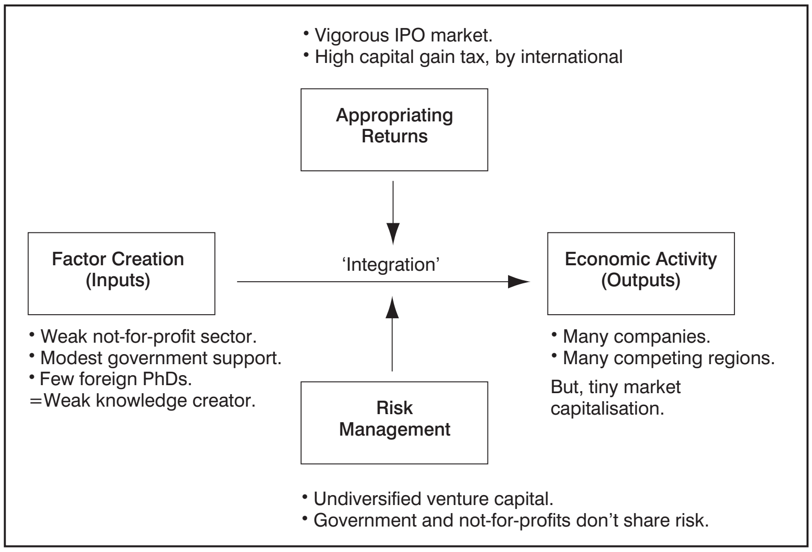
The US government overcomes the drawbacks of the government resource-allocation process, not by refusing to 'pick winners' (in Australian parlance) or absenting itself, in the hope the market will pick up the ball, but by selecting a sector, such as biology, then 'outsourcing' resource-allocation decisions to a decentralised network of scientific peer-review panels.

7. Australia's Innovation System

A key role then, and perhaps the key role of an innovation system, is to meet these needs. Institutional arrangements that satisfy these demands facilitate innovation; those that do not retard it. An important distinction among national innovation systems is the relative emphasis they place on one or other of the vehicles discussed above for entrepreneurial finance and risk management. Which vehicles predominate can exercise a strong influence over the types of risk the nation's system is best equipped to manage, and, in turn, to which type of technology it will be most comfortable committing. The nature of the dynamic 'fit' between the technically derived structure of risk, as described above, and various forms of risk management vehicle, is complex. While all approaches are employed to at least some extent in most successful countries, the weight given to each varies considerably. US and 'Anglo-Saxon capitalism' typically relies more heavily on venture capital; European 'welfare capitalism' gives a greater role to government and banks; and Japanese '*keiretsu* capitalism' relies more on large corporations[10].

How does Australia's innovation system measure up as a risk manager? Unfortunately, Australia's innovation system fails on the two fronts most often cited by critics; that is, its low level of support for factor creation, in particular in education and basic research, and its poor allowance for capturing above-normal profits from innovation (through, for example, capital gains tax concessions and premium prices). It also fails on the creation of an effective risk-management vehicle, suited for the tasks of contemporary innovation. The Australian innovation system is summarised schematically in Figure 2.1.

Figure 2.1: Australia's innovation system



How does Australia's innovation system measure up as a risk manager? Unfortunately, Australia's innovation system fails on the two fronts most often cited by critics; that is, its low level of support for factor creation, in particular in education and basic research, and its poor allowance for capturing above-normal profits from innovation (through, for example, capital gains tax concessions and premium prices).

On the factor-creation side of education, training and basic research (the creation of 'options' to be tested in development activities), Australia's system is weak. The not-for-profit sector is small, and does not orient towards innovation. It is not encouraged by government with favourable tax treatment or other means. Australia lacks a tradition of broad-based giving to science and education, such as exists in the United States, and it does little to encourage its development. Australia rather pursues never-ending debates as to whether a certain activity should be public sector (government) or private sector (business). Other than sporadic lamentation of the lack of a philanthropic 'culture', few participants in the debate seriously consider how to develop a sector independent from either, to form the basis of factor creation in innovation.

For returns appropriation, Australia's system is also not encouraging. Capital gains are taxed at a much higher rate in Australia than in competitor countries (the United States taxes capital gains at 15 per cent, for example, compared to Australia's 25 per cent), and no encouragement is given to innovators within that regime. Prices for innovative goods such as new drugs are pushed downwards by government in Australia, and little preference is shown for local innovators in government purchasing.

But the situation is worse for risk management. Despite recent growth, Australia has developed little venture capital, and most of what does exist avoids technologically risky investments. Only 5 per cent of the already small venture capital pool in Australia goes to biotechnology, for example, a sector several Australian governments have identified as one the nation would like to develop.[11] Australia's large companies have among the lowest ratios of R&D expenditure to sales in the world, reflecting the fact they are largely confined to non–innovation-oriented sectors in which such investment is peripheral to competitive success. Government does not share innovation risk, beyond a scattering of programs at the initial start-up phase (an approach that exacerbates the problem of excessive fragmentation). In short, none of the vehicles most successful in innovating nations that are employed to manage innovation risk are well developed in Australia.

8. Conclusion

These characteristics of the Australian innovation system all derive from a common underlying philosophy. Today's policymaking elite is convinced that:

- innovation should be driven by the market
- it is inappropriate for the institutional system to discriminate between innovation and replication as economic activities
- the system should not discriminate among types of technologies (these beliefs are often summarised in the Australian phrase, 'the playing field must be level')
- if the market does not support innovation, so be it.

This philosophy, and the set of institutional and policy approaches it has shaped, makes perfect sense if Australia wants only to consume technology, and not to produce it. If, on the other hand, Australia aspires to be a participant in technology creation – and there are powerful arguments that it ultimately must be if it is to remain prosperous and technologically capable – then it needs now to investigate how appropriate risk management vehicles can be developed. It should be apparent that the market alone will not come to the nation's rescue.

Despite recent growth, Australia has developed little venture capital, and most of what does exist avoids technologically risky investments. Only 5 per cent of the already small venture capital pool in Australia goes to biotechnology, for example, a sector several Australian governments have identified as one the nation would like to develop.

Endnotes

1 Ludwig von Mises, *Human Action: A Treatise on Economics*, fourth revised edition, Fox & Wilkes: San Francisco, 1996.

2 Criticality refers to the standard of performance that must be reached; for example, the tolerance for variance or failure.

3 Gary Pisano, 'R&D Performance, Collaborative Arrangements, and the Market-for-Know-How: A Test of the "Lemons" Hypothesis in Biotechnology,' *Harvard Business School Working Paper*, pp. 97–105, 1997.

4 George Akerlof, 'The Market for "Lemons": Qualitative Uncertainty and the Market Mechanism.' *Quarterly Journal of Economics,* 84, pp. 488–500.

5 Frank H. Knight, *Risk, Uncertainty and Profit,* Beard Books, 1921 (2002), p. 233.

6 Frank H. Knight, 2002, pp. 233–4.

7 Frank H. Knight, 2002, pp. 233–4.

8 Amar V. Bhide, 'Hustle as Strategy', *Harvard Business Review,* September 1986.

9 Prominent examples of this dynamic are detailed in Fiona Hill and Clifford Gaddy, *The Siberian Curse: How Communist Planners Left Russia Out in the Cold,* Brookings Institution, and Andrei Shleifer and Robert W. Vishny, *The Grabbing Hand: Government Pathologies and Their Cures,* Harvard University Press, 1998.

10 These definitions of 'varieties of capitalism' are explored more fully in Peter A. Hall and David Soskice, *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage,* Oxford University Press, 2001; Suzanne Berger and Ronald Dore, *National Diversity and Global Capitalism,* Cornell Studies in Political Economy, Cornell University, 1996; and Ronald Dore, *Stock Market Capitalism; Welfare Capitalism: Japan and Germany Versus the Anglo-Saxons,* Oxford University Press, 2000.

11 Editorial, 'Toward a "knowledge nation", *Nature,* 411(6838), 7 June 2001.

3. A Perspective on the Knowledge Economy in the Australian Context

Keith Smith[1]

1. Introduction

In recent years processes of learning and knowledge have attracted increasing attention as a result of claims that knowledge-intensive industries are now at the core of growth, and that we are now entering a new type of knowledge-driven economy or even a completely new form of 'knowledge society'. There is strong statistical evidence from R&D and innovation surveys that knowledge-creating activities are absorbing a higher proportion of firms' expenditures, and there is considerable case study evidence suggesting that knowledge is an increasingly important resource for firms.

Unfortunately, both from analytical and policy perspectives, our understanding of the knowledge economy has been seriously one-sided. Most attention has focused on directly science-based industries, in the sense of industries with high levels of direct R&D and strong links to universities: computing and pharmaceuticals in particular. Associated with this emphasis are so-called 'frontier technologies', such as electronics, biotechnology and nanotechnology. A criticism of such policy approaches is that they rest on a 'scientised' model of innovation that stresses scientific discovery rather than learning as the basis of innovation, neglecting the real characteristics of innovation in the economic activities on which our economy largely rests.

High technology or science-based industries, and the technologies underlying them, are very important. But they are also very small. Taken together, these high-tech activities account for around 3 per cent of GDP in most OECD economies.[2] We tend to neglect the role of major low and medium technology activities (both manufacturing and services) in our understanding of the knowledge economy. This is a serious failing, because in Australia (as in most OECD economies in fact) these are the sectors on which the economy is really based. Industries such as food-processing, timber products, textiles and clothing, mining, wine, mechanical engineering, and services such as hospitality, transport, health or finance are large. They perform little direct R&D. Yet innovation survey data shows that many of them are innovating, and many parts of these sectors are growing rapidly. What is the knowledge basis of such innovation?

Understanding of the knowledge economy has been seriously one-sided. Attention has focused on directly science-based industries … These high technology industries are very important. But they are also very small … We tend to neglect the role of major low and medium technology activities (both manufacturing and services) in our understanding of the knowledge economy. This is a serious failing.

The argument here is that we need to place greater emphasis on two dimensions of knowledge-creation in such industries, neither of which is particularly visible in available indicators. On the one hand, these are industries that have significant non-R&D inputs to innovation. Such inputs and expenditures include market research, training and skill development, design, the application of new capital goods, and knowledge drawn from patents and licenses. In all industries, these non-R&D inputs are significantly greater than R&D expenditures. Such non-R&D aspects of innovation are sometimes referred to in the making of innovation policy, but are often ignored in practice.

On the other hand, these industries are often intensive users of R&D, and intensive users of scientific knowledge. However, the key thing about R&D inputs in such industries is that they are *indirect:* they flow from the 'knowledge infrastructure' of society, through personnel movements, inter-firm cooperation, links with universities or research institutes, engineering consultants and so on. The R&D/science use of such industries is as a result not measured with available science and technology indicators, and they are often regarded as traditional and low-technology sectors. Yet many of these industries – in particular, food-processing – have a good claim to be at least as science-based as something like ICT. Because the science and R&D use of these industries flows indirectly from the overall knowledge infrastructure, the growth and innovation performance of such industries – and hence of the overall economy – depends on the structure, efficiency and funding of the infrastructure.

2. Problems with R&D measures

Much analysis of knowledge-creation rests on intramural R&D carried out by firms. However, it is a mistake to identify knowledge-creation with R&D. Conceptually, the use of R&D data often implies a view of innovation that overemphasises the discovery of new scientific or technical principles as the point of departure of an innovation process (an approach sometimes called the 'linear model' of innovation). It sees innovation as a set of development stages originating in research, and it is this prior significance of research that licences using R&D as a key knowledge indicator. From a practical point of view, the definitions of R&D in the OECD's *Frascati Manual,* which structure R&D data collection in OECD economies, exclude a wide range of activities that involve the creation or use of new knowledge in innovation.

Much analysis of knowledge-creation rests on intramural R&D carried out by firms. However, it is a mistake to identify knowledge-creation with R&D. Conceptually, the use of R&D data often implies a view of innovation that overemphasises the discovery of new scientific or technical principles.

By contrast, modern innovation theory sees knowledge-creation in a much more diffuse way. First, innovation rests not on discovery but on learning. Learning need not necessarily imply discovery of new technical or scientific principles, but can readily be based on activities that recombine or adapt existing forms of knowledge; this in turn implies that activities such as design and trial production (which is a form of engineering experimentation) can be knowledge-generating activities. A second key emphasis in modern innovation analysis is on the external environment of the firm. Firms interact with other institutions in a range of ways; these include purchase of intermediate or capital goods embodying knowledge. The installation and operation of such new equipment is also knowledge-creating. Then there is the purchase of licences to use protected knowledge. Finally, firms seek to explore their markets. Given that innovations are economic implementations of new ideas, then the exploration and understanding of markets, and the use of market information to shape the creation of new products, are central to innovation. These points imply a more complex view of innovation: one in which ideas concerning markets are a framework for new product concepts based on the recombination and creation knowledge via a range of activities. In this perspective R&D is important, but tends to be seen as a problem-solving activity in the context of innovation processes, rather than an initiating act of discovery.

3. Non-R&D Inputs to innovation

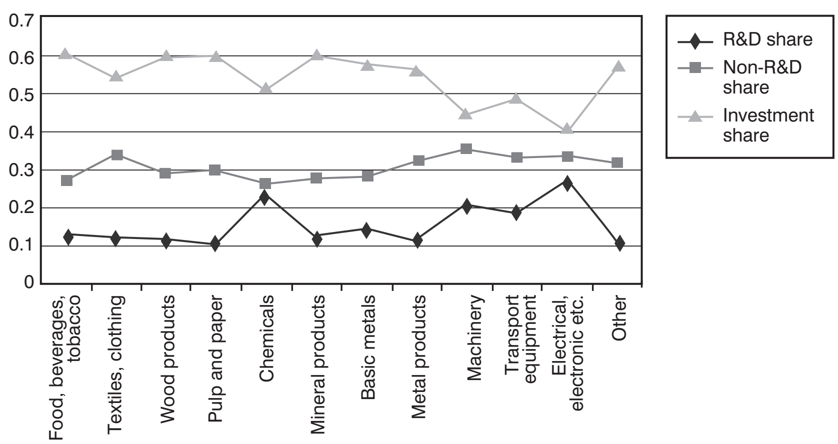
Many non R&D expenditures on innovation are in principle measurable. Collection of data on such phenomena has been attempted in probably the only systematic data source on non-R&D innovation expenditures; namely, the EU's *Community Innovation Survey* (hereafter CIS), which collects data – for all European countries –

not only on R&D but also on non-R&D innovation expenditures, including training, market research related to new product development, design, expenditures on patents and licenses, and most importantly on capital investment (again related to new product development).

In this section we draw on some results from CIS data from the Europe-wide survey of 1992, on the general firm and industry distributions of R&D and non-R&D expenditures on innovation. The data relate to the 1992 CIS, and the results are drawn from a report to the European Commission on innovation expenditures in European industry. The data are divided into three categories: capital investment related to new product development, R&D, and non-R&D expenditures (covering training, market research, design, trial production and tooling up, and intellectual property rights costs).

The first point, perhaps a rather obvious one, is simply that R&D is but one component of innovation expenditures, and by no means the largest:

Figure 3.1: Composition of innovation expenditures by industry, all firms pooled, mean

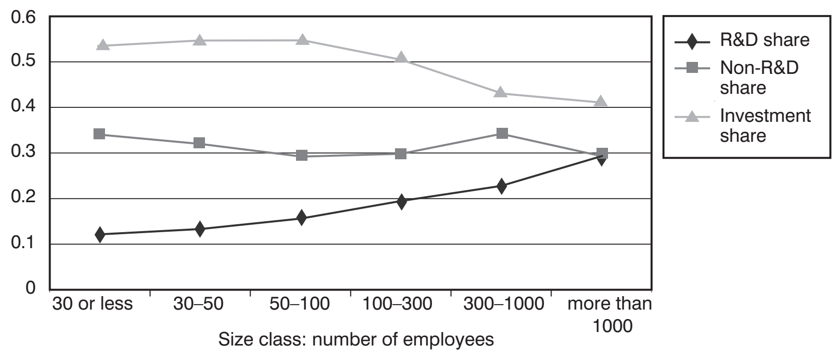


(Source: Rinaldo Evangelista, Tore Sandven, Giorgio Sirilli and Keith Smith, *Innovation Expenditures in European Industry*, Report to the European Commission, DG-XIII-C, European Innovation Monitoring Initiative, p. 46)

There is, as we would expect, variation in the share of R&D expenditures in total innovation expenditure across industries, with electrical, electronics, and chemicals (here including pharmaceuticals) having high shares; this is exactly what we would expect from the R&D statistics. To this variation across industries there roughly seems to correspond a variation in the opposite direction for the share of investment expenditures: firms that have relatively low R&D shares have higher investment shares. This in turn implies that non-R&D expenditures (design, training, market research and so on) vary somewhat less across industries. The mean R&D share by industry varies between about 0.1 and 0.25, the mean non-R&D share is generally close to 0.3, while the mean investment share varies between about 0.4 and 0.6.

Figure 3.2 shows the composition of innovation expenditures by size class for all countries pooled.

Figure 3.2: Composition of innovation expenditures by size class, all firms pooled, mean



(Source: Rinaldo Evangelista, Tore Sandven, Giorgio Sirilli and Keith Smith, *Innovation Expenditures in European Industry,* Report to the European Commission, DG-XIII-C, European Innovation Monitoring Initiative, p. 47)

What we have here is, once again, a rather consistent non-R&D expenditures share, but on the other hand a clear relationship between firm size and the share of R&D expenditures, with this share increasing consistently with firm size. To this there seems to correspond, though less clearly, a decrease in the share of investment expenditures with firm size. The implication here is that small firms rely more on the acquisition of capital goods in innovation expenditures, so that knowledge structures in SMEs are likely to be more heavily dependent on embodied knowledge within capital equipment.

3. Measuring Indirect Uses of R&D

The data presented above suggests a strong case for not focusing simply on direct R&D when we consider expenditure by firms and industries on innovation and knowledge-creation, and suggests also a need to look into the significance of other sources of knowledge. It seems particularly important to look at capital investment, which represents a very significant component of innovation expenditure: in fact, this is the largest single component in every industry. In this context it is important to note that capital expenditure is a key mode of 'embodied' knowledge spillover from the capital goods sector to using industries. Can we find a way of incorporating such embodied spillovers into our understanding of the knowledge intensity of the using industry by an empirical account of their knowledge contents?

Table 3.1 uses OECD data to compare direct and indirect R&D inputs across industries. OECD has made an important modification of the direct R&D measures with the addition of 'acquired technology', calculated as the R&D embodied in capital and intermediate goods used by an industry, and computed via the most recent input–output table. The method for calculating acquired R&D is to assume that the R&D embodied in a capital good is equal to the capital good's value multiplied by the R&D intensity of the supplying industry. The most recent year for which relevant input–output data is generally available is 1990. The overall structure of the classification can be seen in Table 3.1, which shows direct R&D intensities for the main industrial groups for 1997, plus the proportion of acquired to direct R&D for 1990, the last year for which it was calculated.

Table 3.1: Classification of Industries Based on R&D Intensity

	ISIC Rev 3	Direct R&D Intensity 1997	Acquired R&D intensity as per cent of direct R&D intensity, 1990
High-technology industries			
Aircraft and spacecraft	353	12.7	15
Pharmaceuticals	2423	11.3	8
Office, accounting and computing machinery	30	10.5	25
Radio, television and communications equipment	32	8.2	17
Medical, precision and optical instruments	33	7.9	29
Medium–high-technology industries			
Electrical machinery and apparatus	31	3.8	42
Motor vehicles and trailers	34	3.5	29
Chemicals	24 exc 2423	2.6	18
Railroad and transport equipment n.e.c	352+359	2.8	88
Machinery and equipment n.e.c.	29	1.9	104
Medium–low-technology industries			
Coke, refined petroleum products and nuclear fuel	23	0.8	30
Rubber and plastic products	25	0.9	127
Other non-metallic mineral products	26	0.9	285
Building and repairing of ships and boats	351	0.7	200
Basic metals	27	0.7	289
Fabricated metals products	28	0.6	133
Low-technology industries			
Manufacturing n.e.c. and recycling	36–37	0.4	
Wood, pulp, paper, paper products, printing and publishing	20–22	0.3	167
Food products, beverages and tobacco	15–16	0.4	267
Textiles, textile products, leather and footwear	17–19	0.3	250

Sources: OECD, *Science, Technology and Industry Scoreboard 1999: Benchmarking Knowledge-based Economies* (OECD: Paris 1999), Annex 1, p. 106; OECD *Science, Technology and Industry Scoreboard 2001: Towards a Knowledge-based Economy,* Annex 1.1, pp. 13–139

Note: The ISIC classification was revised in 1996, though changes were relatively minor. 1990 data have been reassigned to the most relevant Rev 3 category.

Table 3.1 shows that 'acquired technology' as a proportion of direct R&D rises dramatically as we move from high- to low-technology industries. Of course the absolute amounts of R&D being used remain higher in many of the high-tech sectors. However, the key point is that many low- and medium-tech sectors are accessing significant volumes of R&D in ways that are not reflected in usual R&D

data. This suggests, incidentally, that technology intensity is likely to be very sensitive to how the measurement of acquired technology is carried out.

4. Knowledge flows across industries

How do capital investment, intermediate good acquisition and non-R&D expenditures relate to the structure of knowledge in an industry? Most analyses of learning have focused on analysing the characteristics of learning processes, or on the broad types of knowledge that are involved, rather than on the specific content and structure of industrial knowledge bases.

So how can the knowledge content of an industry be understood and described? We can distinguish between three areas of production-relevant knowledge; namely, firm-specific knowledge, sector or product field-specific knowledge, and generally applicable knowledge. At the firm level, the knowledge bases of particular firms are highly localised, and specific to very specialised product characteristics, either in firms with one or a few technologies which they understand well and which form the basis of their competitive position, or in multi-technology firms. Second, there are knowledge bases at the level of the industry or product-field. At this level, modern innovation analysis emphasises the fact that industries often share particular scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials and so on of products.[3] This part of the industrial knowledge base is public (not in the sense that it is produced by the public sector, but public in the sense that it is accessible knowledge which in principle is available to all firms): it is a body of knowledge and practice that shapes the performance of all firms in an industry. Of course, this knowledge base does not exist in a vacuum. It is developed, maintained and disseminated by institutions of various kinds, and it requires resources (often on a large scale). Finally, there are widely applicable knowledge bases, of which the most important technically is the general scientific knowledge base. This is itself highly differentiated internally and of widely varying relevance for industrial production, but some fields – such as molecular biology, solid-state physics, genetics or inorganic chemistry – have close connections with major industrial sectors.

How can the knowledge content of an industry be understood and described? We can distinguish between three areas of production-relevant knowledge; namely, firm-specific knowledge, sector or product field-specific knowledge, and generally applicable knowledge.

5. Distributed knowledge bases

If these points about knowledge bases are reasonable, then the relevant knowledge base for many industries is not internal to the industry, but is distributed across a range of technologies, actors and industries. What does it mean to speak of a ‘distributed knowledge base’? A distributed knowledge base is a systemically coherent set of knowledge, maintained across an economically and /or socially integrated set of agents and institutions.

Inter-agent or inter-industry flows conventionally take two basic forms: ‘embodied’ and ‘disembodied’. Embodied flows involve knowledge incorporated in to machinery and equipment. Disembodied flows involve the use of knowledge, transmitted through scientific and technical literature, consultancy, education systems, movement of personnel and so on.

The basis of embodied flows is the fact that most research-intensive industries (such as the advanced materials sector, the chemicals sector or the ICT complex) develop products that are used within other industries. Such products enter as capital or intermediate inputs into the production processes of other firms and industries; that is, as machines and equipment, or as components and materials. When this happens, performance improvements generated in one firm or industry therefore show up as productivity or quality improvements in another. The point here is that technological competition leads rather directly to the inter-industry diffusion of technologies, and therefore to the inter-industry use of the knowledge that is 'embodied' in these technologies. The receiving industry must of course develop the skills and competences to use these advanced knowledge-based technologies. Competitiveness within 'receiving' industries depends heavily on the ability to access and use such technologies.

As examples, consider fishing and fish farming, both of which are apparently low-technology sectors in terms of internal R&D. This is a large industry worldwide, with aquaculture growling particularly strongly; this is moreover an important growth sector for developing countries. Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies (linked to winch, trawl and ship management systems), optical technologies for sorting fish, computer systems for real-time monitoring and weighing of catches, and so on. Within fish farming, these high-technology inputs include pond technologies (based on advanced materials and incorporating complex design knowledge), computer imaging and pattern recognition technologies for monitoring (including 3D measurement systems), nutrition technologies (often based on biotechnology and genetic research), sonars, robotics (in feeding systems) and so on. These examples are not untypical of 'low-technology' sectors – on the contrary, most such sectors can not only be characterised by such advanced inputs, but are also arguably drivers of change in the sectors that produce such inputs.

Consider fishing and fish farming, both of which are apparently low-technology sectors in terms of internal R&D. This is a large industry worldwide, with aquaculture growing particularly strongly. Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies, optical technologies and so on.

The disembodied flows and spillovers are also significant. Underlying the technologies for fishing and fish farming mentioned above are advanced research-based fields of knowledge. Ship development and management relies on fluid mechanics, hydrodynamics, cybernetic systems and so on. Sonar systems rely on complex acoustic research. Computer systems and the wide range of IT applications in fisheries rest on computer architectures, programming research and development, and ultimately on research in solid-state physics. Even fish ponds rest on wave analysis, CAD/CAM design systems. Within fish farming the fish themselves can potentially be transgenic (resting ultimately on research in genetics and molecular biology), and feeding and health systems have complex biotechnology and pharmaceutical inputs. In other words, a wide range of background knowledge, often developed in the university sector, flows into fishing: mathematical algorithms for optimal control, molecular biology, and a wide range of sub-disciplines in physics for example.

We could extend this kind of thinking more generally to food production. Clearly, many different kinds of skills, scientific disciplines and knowledge areas are involved in the functions and activities in the food-processing industry. Nevertheless, most of this knowledge can be categorised into two main knowledge areas: food science and food technology. The Institute of Food Science & Technology (UK) defines these terms as follows:

> *… food science integrates the application to food of several contributory sciences. It involves knowledge of the chemical composition of food materials (for all food consists entirely of chemical substances); their physical, biological and biochemical behaviour; human nutritional requirements and the nutritional factors in food materials; the nature and behaviour of enzymes; the microbiology of foods; the interaction of food components with each other, with atmospheric oxygen, with additives and contaminants, and with packaging materials; pharmacology and toxicology of food materials, additives and contaminants; the effects of various manufacturing operations, processes and storage conditions; and the use of statistics for designing experimental work and evaluating the results.*
>
> *Likewise, food technology draws on, and integrates the application to food of, other technologies such as those of steel, tinplate, glass, aluminium, plastics, engineering, instrumentation, electronics, agriculture and biotechnology.*[4]

Despite the fact that food-processing is an industry with relatively low levels of internal R&D, it might well be claimed that this is one of the most knowledge-intensive sectors of the entire economy.

These knowledge bases fed directly into the key activities of food-processing, such as selection and preparation of materials, cooking, nutritional and contaminations monitoring, packaging, and distribution. To sum up: despite the fact that food-processing is an industry with relatively low levels of internal R&D, it might well be claimed that this is one of the most knowledge-intensive sectors of the entire economy, if only through the knowledge embodied in monitoring equipment and instrumentation. Presumably this is not unrelated to the fact that many of the sub-sectors of the industry are rapidly growing.

6. Collaboration and Knowledge Infrastructures

How important is the 'knowledge infrastructure' of universities, research institutes, and other publicly supported agencies in knowledge creation and use in Australia?

One of the big results of modern innovation research is that innovating firms tend to be collaborating firms. They collaborate with customers, suppliers, competitors, consultants, universities and research institutes. Surveys across a number of OECD economies have confirmed very similar patterns of collaboration. In Australia and other OECD countries the proportions of collaborating firms across industries looks as set out in Table 3.2.

Collaboration with universities is highest in three industry groups: petroleum, coal and chemical; metal products; and machinery and equipment. It is difficult to interpret these figures, but seeing that Table 3.2 refers to direct collaboration of specific innovation projects, it could be argued that 17 per cent is a high figure, given Australia's industrial structure and firm size distribution.

More generally, it should be remembered that knowledge infrastructures produce impacts that cannot be grasped either via looking at short-term collaboration, or by looking at commercialisation data, or other forms of direct interaction. Infrastructures produce complex effects via education and training, interpersonal contacts, personnel exchange, the general flow of ideas, consultancy, design of

Table 3.2: Distribution of collaboration partners in selected countries, percentages, unweighted

	Australia	Austria	Denmark	Norway	Spain	Sweden (East Gothia)
Private customers	64	56	71	59	53	61
Government customers	15	33	21	20	25	30
Suppliers of materials and components	52	62	74	57	58	83
Suppliers of machinery and production equipment	26	29	44	35	49	55
Suppliers of technical services, testing and control	43	42	43	45	–	42
Marketing/management consultants	28	18	32	18	33	–
Competitors	7	20	13	28	15	35
University and research centres	17	33	17	23	60	36
Parent/subsidiary	30	39	33	–	37	–

Source: Basri, E. 2001, 'Interfirm Collaboration in Australia in an International Context: Implications for Innovation Performance and Public Policy, in *Innovative Networks. Cooperation in National Innovation Systems,* OECD, Paris, pp. 143–168
Note: Firms can have more than one collaboration partner.

instrumentation, and so on. Within such important sectors for Australia as food and wine, infrastructural organisations interact with firms and through this shape and reshape the knowledge bases of the sectors. The Australian 'knowledge economy' depends on these infrastructures, and the composition, funding, management and strategic direction of the knowledge infrastructure are central to future performance. It might be added that infrastructures provide crucial location-specific assets that shape the location decisions of global firms; this too is important for Australia in the knowledge economy.

7. Conclusion: distributed knowledge bases and the knowledge economy

A key point of the empirical analysis presented above is that if we accept the idea that modern economies are in some sense more knowledge-intensive, this does not necessarily mean that only some sectors or technologies are the bearers of the new knowledge economy. On the contrary, the knowledge bases of mature industries are cognitively deep and complex, and are moreover institutionally distributed: they are generated via 'knowledge systems', in the sense described by David and Foray.[5]

This is important for resource-based economies such as Australia. It might be argued that the potential growth trajectories for Australia rest as much or even more on such sectors as engineering, food, wood products, wine, vehicles and so on, as on radically new sectors such as ICT or biotech. ICT has of course grown rapidly, but from a very low base, and with a very low share of output. However, growth within the less glamorous sectors is certainly innovation-based, and moreover it rests on deep knowledge bases, which from time to time are subject to discontinuous change. One suggestion which emerges from all this is that growth is based not just on the creation of new sectors but on the internal transformation of sectors which already exist; that is, on continuous technological upgrading. This internal transformative capacity rests, in turn, on complex innovation systems that create, distribute and maintain advanced (often basic scientific) knowledge.[6] We can suggest that many so-called low-tech sectors are intensive in their use of scientific knowledge – industries such as food production, machinery, printing and publishing, wood products, and a range of services, have significant indirect science inputs. The depth and complexity of industry knowledge bases are not linked to their direct R&D performance, and indicators or industrial classifications based on this are misleading.

These types of industries are based on knowledge distributed across agents, institutions and knowledge fields in the knowledge infrastructure. Many of the relevant knowledge fields lie in the sciences. These science inputs are supported by little-explored, indirect links with universities, research institutes and supplier companies. Thus 'low-tech' industries are knowledge intensive, and are frequently part of 'high-tech' systems, and both scholars and policymakers should be aware of their significance for growth. If the term 'knowledge economy' is to have any real significance, then it must take such processes and activities into account, not only as bearers and users of knowledge, but also as drivers of change. This recognition takes us towards new problems. If we reject the implicit technological determinism of many 'high-tech' approaches to the relationship between innovation and growth, then we must face more squarely the question of the sources and determinants of innovation. On the one hand, we need to analyse the innovation decisions of firms in such sectors: how do they assess potential innovation markets, and under what circumstances can they muster the resources to invest in the complex of physical and intangible assets that make up a knowledge-intensive approach to production? Why are some firms in these industries far more successful than others in learning and innovation? This is primarily an issue in corporate strategy and control.[7] On the other hand, we need a theory of the knowledge system which helps us understand how and under what circumstances knowledge-creating institutions actually generate and sustain cognitive flows, between themselves and into the production system.[8]

Growth is based not just on the creation of new sectors but on the internal transformation of sectors which already exist; that is, on continuous technological upgrading. This internal transformative capacity rests, in turn, on complex innovation systems that create, distribute and maintain advanced (often basic scientific) knowledge.

These issues have significant policy implications. Within most OECD economies, policymakers remain heavily focused on ICT, biotech and nanotechnology issues (both in innovation and diffusion-oriented policies) to the exclusion of most of the areas of knowledge that are in fact producing change across major industries. Policy remains focused on a science-based model of innovation, to the exclusion of a genuinely learning-based approach. Moreover, there does seem to be, on the face of it, real asymmetries in the policy attention given to arenas of knowledge advancement: there is a neglect of key areas of change that are reshaping not the alleged economy of tomorrow but the economy we have actually got.

Endnotes

1 The author would like to thank the Australian Business Foundation for generous support in the writing of this paper.

2 By 'high-technology industries' I mean those conforming to the OECD classification; namely, industries that spend more than 4 per cent of turnover on R&D.

3 Richard Nelson calls this the 'generic' level of a technology. Nelson, R., *Understanding Technological Change as an Evolutionary Process* (North Holland: Amsterdam), 1987, p. 75.

4 Source: <http://www.blacksci.co.uk/products/journals/ijfst.htm>.

5 David, P. and Foray, D. 'Accessing and Expanding the Science and Technology Knowledge Base', *STI Review*, 16, 1996.

6 See M. Gibbons et al. *The New Production of Knowledge. The Dynamics of Science and Research in Contemporary Societies*, London, Sage, 1994, for arguments on the ways in which this has affected scientific research.

7 See Lazonick, W. and O'Sullivan, M. 'Organization, Finance and International Competition', *Industrial and Corporate Change*, vol. 5, no. 1, 1996, pp. 1–49, and O'Sullivan, M. *Contests for Corporate Control. Corporate Governance and Economic Performance in the United States and Germany*, OUP, Oxford, 2000.

8 Some of the important issues here are discussed by Paula Stephan, in 'The Economics of Science', *Journal of Economic Literature*, vol. XXIV, no. 3, 1996, pp. 1199–262.

4. Innovation Systems in Australia

Don Scott-Kemmis[1]

1. Innovation Systems Frameworks

Countries differ in their capacity to produce, acquire and use knowledge. They differ in the level of their investment in innovation, the roles of the public and private sectors, the industries and technology fields of greatest importance and the rates of change in those patterns, the level of cooperation among organisations, the modes of financing innovation, attitudes to risk-taking, the regulation of the labour market, and the role of large and small firms. In short, they have different 'innovation systems'. The structure, functioning and integration of the various components of the national innovation system (NIS) have a major bearing on the level, and continuing upgrading, of a nation's innovation competencies. These competencies play a central role in economic growth and change.

Following the seminal works of Freeman (1987), Lundvall (1992) and Nelson (1993), there have been a large number of studies of national innovation systems. These studies have sought to analyse the ability of nations to generate, diffuse and use economically significant knowledge. However, there have not been any comprehensive studies that have analysed Australia from a national innovation systems perspective.

The structure, functioning and integration of the various components of the national innovation system have a major bearing on the level, and continuing upgrading, of a nation's innovation competencies. These competencies play a central role in economic growth and change.

How can we analyse Australia from an innovation systems perspective? The NIS approaches do not provide any 'ready-to-use' frameworks. Studies that use a national innovation systems approach tend either to assume a high level of homogeneity *within* nations, or to focus on only some components of the NIS – often the R&D system. Many studies use a range of innovation-related indicators. While valuable in raising issues and questions to be investigated, indicator approaches rarely provide real insight and answers. There are three particular problems with indicator-based approaches: the indicators are based on relationships (for example, R&D inputs drive innovation) that are themselves in question; aggregation leads to a serious loss of information; there are no indicators for many important categories.

This chapter outlines three complementary indicator-based analyses, each of which reveals important characteristics of the Australian innovation system:

- a review of traditional innovation-based indicators, presented here in terms of two contrasting perspectives on Australian innovation performance
- an analysis of patterns and trends in R&D activity at the national and state level
- an analysis of patterns and trends in Australia's technological and scientific specialisation.

The final section identifies several characteristics of the Australian innovation system; in it several more speculative interpretations of the evidence are developed.

2. Innovation Systems: An Analytical Perspective

National innovation systems can be understood as a nation's capacity to generate, diffuse and use economically significant knowledge. Innovation systems evolve and a primary endogenous driving force is learning: 'if knowledge is the most important resource, then learning is the most important process' (Lundvall 1992). Learning is the central process not only in the generation of knowledge, but also in the diffusion and use of knowledge. Learning occurs at the level of individuals and organisations, but also through various forms of *interaction*s between actors; for example, firms, government agencies, universities, and formal or informal 'bridging organisations'. Among the more important mechanisms for interactive learning are producer–user networks, the pooled labour market and informal meeting places. These patterns of interaction draw on established networks based on antecedent innovations and production links that may only slowly include new actors. For this reason these interactions may lead to path-dependencies in innovative search.

These learning processes are set by *nation specific circumstances* – including the accumulated skills and capabilities of firms, national laws and regulations, culture, and the specialisation in research and education – and are derived from its history. Lundvall (1992) conceptualised a national innovation system as consisting of two main parts: the economic structure and the institutional set-up. The *economic structure* refers essentially to what a nation produces – products, services, technologies, the labour force, skills and so on. The economic structure largely shapes *what* 'nations' learn. For example, if a country has a large mining industry, then different actors are likely to learn a great deal about large projects and logistics. An economic structure may be more or less beneficial in terms of current market growth trends. (For example, a high level of dependence on ICT exports was a 'good thing' in 1999, but far less attractive in 2002.)

The relationships between innovation and economic activity are complex, involve interactions, lags and feedbacks, and evolve continuously. Understanding these relationships requires attention to multiple dimensions, including institutional issues.

The *institutional set-up* refers to the structure of organisations and institutions, and includes the nature and processes of (product, capital, labour, equity, IP) markets and networks, strategies of firms, the type of regulation and structure of incentives shaping, reinforcing or constraining the direction of the innovative search. Hence, the institutional set-up refers to *how* the generation, diffusion and use of economically useful knowledge takes place.

3. The Australian Innovation System: Alternative Views on Performance

Assessing Innovation Related Performance

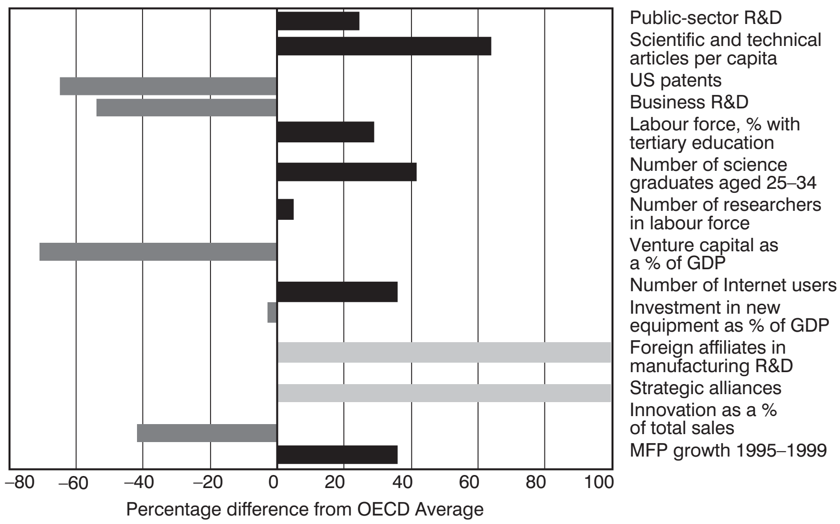
Indicators derive their meaning from assumptions about what phenomena are important and how they can best be estimated. The relationships between innovation and economic activity are complex, involve interactions, lags and feedbacks, and evolve continuously. Understanding these relationships requires attention to multiple dimensions, including institutional issues. Deviations from the performance of a 'model' economy (typically the United States) or from 'best practice' exemplars among OECD countries in specific dimensions do not necessarily signal a problem. Countries are not arrayed along a path of inexorable development. Nevertheless, such comparisons (Figure 1 and Figure 2) can be useful for characterising innovation-related performance if we bear in mind the structure and history of the Australian economy:

- **Diversity.** Australia's population is concentrated in several cities distant from each other. Agriculture is a major industry but is diverse – operating in temperate, tropical and semi-arid areas. Mining is a major industry, but across a continent mining is highly diverse involving coal, iron ore, gold, aluminium, silver, mineral sands, nickel and diamonds – each with different requirements for capital goods, services and infrastructure.

- **Historical legacy.** The legacy of import substitution industrialisation included a range of institutions (for example, labour market regulation, attitudes to entrepreneurship), innovation-related infrastructure (a well-developed public education and research system, but poor research-industry links in many sectors) and competencies (low management and R&D capabilities in industry) that continued to impede innovation performance even when the incentives for innovation increased, following the opening of the economy.
- **Industry structure.** Primary products account for about 8 per cent of Australian GDP (the level for about 30 years), above most OECD countries. The manufacturing share of GDP (about 12 per cent in 2000) is lower and declining faster than in most OECD countries. The services sector is larger (79 per cent of GDP in 2000) and has risen more rapidly than in most OECD countries. Australia has a relatively very small 'high-tech' manufacturing sector. This sector, and particularly large firms in this sector, accounts for the majority of business expenditure on research and development (BERD), and most interaction with the public-sector research system in most OECD countries.
- **Firm size.** Australian industry has a relatively large proportion of small firms. Such firms (less than 100 employees) account for a relatively large share (almost 30 per cent in 1999) of BERD. Such small firms account for twice the proportion of BERD in Australia as in Canada or Finland, and three times more than in the United States or the United Kingdom.
- **Trade.** Australia's trade intensity (trade/GDP) is relatively low, closer to the low trade intensity of large economies like the United States, Japan and France, than to the high trade intensity of small countries like Ireland, Finland, Sweden and Canada. Australia did not participate in the strong growth of trade in manufactures of the 1970s, losing opportunities to develop economies of scale.
- **Specialisation.** Australia has a relatively low level of technological specialisation for a small economy – small advanced economies tend to be quite specialised in some fields of technology. Whereas most countries have become more specialised over the past 20 years, Australia's level of specialisation has remained more or less constant. Australian specialisation is in agriculture, primary metals, mining and oil and gas – a pattern quite similar to that of Canada and Norway.
- **Foreign ownership.** The level of foreign investment in Australian industry is relatively high, and particularly high in the R&D intensive sectors. Overall, foreign affiliates account for almost half of the R&D in Australian manufacturing, a level far higher than all but a few other OECD countries.

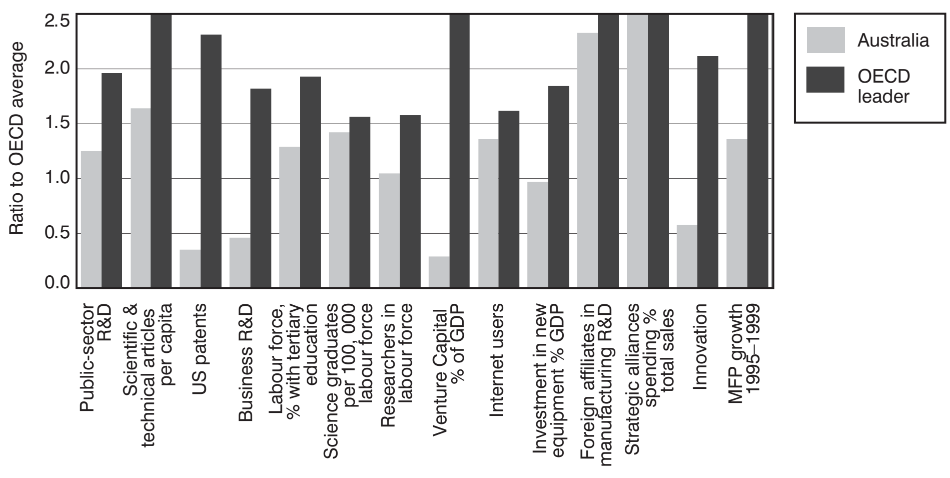
Australia has a relatively low level of technological specialisation for a small economy. Whereas most countries have become more specialised over the past 20 years, Australia's level of specialisation has remained more or less constant.

Figure 4.1: Australia's innovation performance compared to OECD average



Sources: ABS, OECD, US Patents & Trademark Office (2002) and World Competitiveness Yearbook (2002)

Figure 4.2: Australia's innovation performance compared to OECD leader



Sources: ABS, OECD, US Patents & Trademark Office (2002) and World Competitiveness Yearbook (2002)

It is possible to assess a wide range of indicators of the many aspects and dimensions of Australia's innovation system, and of innovation-related performance, and reach two quite different conclusions: either that the innovation system is robust and adaptive; or alternatively that it is weak and 'locked in' to 'old' patterns of specialisation.

Box 4.1: Alternative perspectives on Australia's innovation performance

The dynamic growth perspective

Australia is a broadly based dynamic and flexible economy, diversified across markets, and increasingly in sectors underpinned by competitive domestic markets and flexible labour markets. High-level human resources and strong research organisations facilitate the rapid uptake of new knowledge produced anywhere. Imported knowledge and equipment combined with local knowledge and capability supports active problem-solving and systems integration in a range of sectors generating relatively high levels of productivity. A 'fast-user' strategy combined with natural and human resources is a sound basis for future prosperity. A focus on R&D and patents misses the level of dynamism in technology adaptation and application. Key indicators of this performance include:

- high and increasing productivity
- relatively high level of public sector R&D
- substantial growth in niches markets in key manufacturing sectors: telecom equipment, wine, boats, automobiles and components
- maintaining strong competitiveness in resources sectors through the effective application of new technology, including IT
- Increasing technological specialisation in biotech and pharmaceuticals
- high FDI as % of GDP
- strong performance in international science
- a strong ICT services sector and high growth in 'knowledge-based services'
- rapid and broadly based uptake of ICT.

The laggard perspective

The Australian economy maintains a high level of dependence on natural resources and is failing to develop sustainable new areas of specialisation and growth. Productivity growth in the 1990s is the result of one-offs: micro-economic reform and the uptake of ICT. This performance masks underlying weaknesses in new firm formation and in the growth of new internationally competitive industries. The poor performance of Australian firms in R&D and patenting signals the weaknesses in management, scale and international positioning of Australian industry. Australia's declining position in 'high-tech' sectors and the declining international significance of its science and patents indicates the extent to which Australia is being left behind the frontier of innovation and growth in the world economy. It has:

- the third-lowest ranked in the OECD in gross expenditure in R&D and one of the lowest in business R&D
- the lowest expenditure on innovation among OECD countries
- a relatively very low level of investment in venture capital
- international patenting activity (per million population) that is one of the lowest in the OECD
- 80 per cent of the top 15 export products, which are resource-based commodities with a low level of processing
- a large and growing trade deficit in ICT products and services.

Box 4.2: Dynamic growth perspective[2]

Innovation-related investment

- Australia has been a leader in pubic investment in R&D and particularly in relative investments in basic research. Government investment in R&D as a proportion of GDP is slightly greater than the OECD average.
- 'Knowledge-based industries' contribute 31 per cent of GDP (in 2000) and 'knowledge workers' represent 38 per cent of the labour force – levels similar to comparable OECD countries. The proportion of 'knowledge workers' in the labour force increased at a similar rate to most other OECD countries.
- Expenditure on higher education (1.6 per cent of GDP) is comparable with the OECD average.
- About 18 per cent of the Australian workforce has tertiary qualifications, above the OECD average (14 per cent).
- About 24 per cent of tertiary students in Australia are in science and technology fields, above Canada (16 per cent) and the United States, but below Finland (38 per cent) and many other OECD countries.
- Industry investment in workforce training increased strongly through the 1990s.

Innovation-related performance

- Australian production of scientific and technical articles (about 700 per million population) is greater than the OECD average (about 450 per million).
- Multi-factor productivity (MFP) growth (1.4–1.5 per cent pa over 1990–99), was comparable to or better than most OECD countries.
- The growth in GDP per hour worked (about 2 per cent pa over 1990–99), was one of the highest among OECD countries.
- By the early 1990s R&D intensity in some Australian manufacturing sectors (for example, metal products, iron and steel, shipbuilding) was *above* the OECD average. The service sector in Australia was a particularly strong R&D performer.

Linkages

- Foreign direct investment inflows over the 1990s (1.75 per cent of GDP) were well above the OECD average (1.0 per cent), but outflows (0.8 per cent of GDP) were well below the OECD average (~ 1.4 per cent).
- Australia has been estimated to have one of the highest levels of international inter-firm alliances (about 5.5 per US$ billion GDP) in the OECD. This level is similar to that of Canada.
- Over the past 20 years the rate of growth of Australia's trade intensity has been among the most rapid in the OECD, similar to Canada and Finland. The growth in export performance has been increasingly broadly based in terms both of products and markets.

Exploring new innovation-based opportunities

- Australia is reported as having a high proportion of the population working in new firms (17 per cent), significantly higher than Canada (11 per cent) and Finland (9 per cent).
- Australia has the third highest level of *expenditure* on ICT (10.5 per cent of GDP) in the OECD. The rise in ICT expenditure in the 1990s has been comparable to other OECD countries.
- The share of ICT *investment* in total non-residential investment has risen steadily since the 1980s (22.5 per cent). It is the third highest in the OECD.
- The rate of growth over the 1990s of Australian *biotech patenting* in the Unites States (about 18 per cent pa) was one of the fastest in the OECD (average 8 per cent per annum).
- Australia has steadily increased its relative level of specialisation in most medical-related fields: pharmaceuticals, biotechnology and medical instruments.
- Exports of knowledge-based services have grown strongly over the 1990s, and as imports have declined as a proportion of GDP, net exports have grown more rapidly than for most other OECD countries.
- Australia's relative export specialisation in resource-based products (largely minimally processed) has increased over the past 30 years. Wine and boat-building emerged in the 1990s as new areas of comparative specialisation.

Box 4.3: Laggard perspective

Innovation-related investment

- Business investment in *R&D* (about 0.65 per cent of GDP) is one of the lowest in the OECD, less than half the OECD average (about 1.4 per cent). Business R&D (BERD) grew strongly through the early 1990s, declined from 1995 to 2000 and has increased from 2000 to 2002.
- Overall R&D investment levels rose from the mid-1980s to the mid-1990s to levels (about 1.6 per cent of GDP) significantly below the OECD average.
- *Expenditure on innovation* by manufacturing firms (estimated at about 1.9 per cent of sales) was one of the lowest in the OECD.
- A relatively low proportion of Australian managers hold tertiary qualifications.

Innovation-related performance

- Australian *patenting* levels in the Unites States (about 40 per million population) are comparatively very low, less than a third the level of Canada and Finland. Australian patenting in the United States grew over the 1980–2000 period at a rate similar to other OECD countries, but as a consequence the 'gap' in patenting level widened. Australian patenting in the Unites States is more widely dispersed, with fewer areas of high specialisation than is the case for most other OECD countries.
- Medium-high technology and particularly high-technology industries account for a relatively small share of Australian *exports,* about 32 per cent compared to the OECD average of about 65 per cent. Despite a growth in trade

intensity Australia's deficit in medium and particularly high-tech products has widened through the 1990s.

- Over the 1985–95 period, employment growth in Australia was largely in sectors of low innovation-related investment (R&D, training).
- *Broadband penetration* rates at 0.57 per 100 people are significantly below the OECD average (1.96 per 100 people) and comparable countries such as Canada (6.3 per cent).

Linkages

- From the early 1990s the role of FDI inflows (per cent GDP) increased strongly in most OECD countries – but not in Australia, where Australia's share of FDI inflows declined markedly. The relative size of the stock of FDI in Australia (FDI stock/GDP) is one of the highest in the OECD.
- While Australia has a relatively high number of alliances, a relatively high proportion of these are domestic and a relatively low proportion are 'technological'.

Exploring new innovation-based opportunities

- Investment in venture capital (about 0.06 per cent of GDP) is below the OECD average (about 0.14 per cent of GDP). The proportion of venture capital directed to early stage funding appears to be relatively very low.
- Australian firms tend to focus less on innovation in products and services than do firms in other countries, and have markedly less confidence than do firms in other countries in capturing value from innovation.
- Some evidence indicates that the level of entrepreneurial activity in Australia, while increasing, is lower than in many other OECD countries.
- While ICT imports (~3 per cent of GDP) are the average level for the OECD, ICT export levels are relatively very low (1 per cent of GDP) at less than a third of the OECD average.
- Because Australia has a relatively very small ICT manufacturing sector, the share of ICT employment in business employment (about 4.6 per cent) is one of the lowest in the OECD.
- The rate of growth over the 1990s of Australian *ICT patenting* in the United States (about 10 per cent per annum) was below the OECD average (13 per cent pa).
- Australia has increased its relative level of patenting activity in the 'traditional' resource-based fields.
- Overall, Australian patenting tends to be in areas where technology is moving less rapidly and Australian patents tend to have a relatively high level of linkage to science but they tend to be based on older prior knowledge.[3]
- Australia has increased its relative export specialisation in resource-based products. Canada and Finland also have a comparative export specialisation in resource-based products (largely wood), but these are significantly processed prior to export and both of these countries have strongly increased their relative specialisation in high value-added manufactured products.[4]

3. Characterising the Australian Innovation System.

Before an initial assessment of the performance of Australia's NIS it is useful to draw out three systemic characteristics of the NIS.

Resource-enabled, Knowledge-based, Competition-driven Innovation

Mining and agricultural industries have a vital role in Australia's balance of trade. A substantial part of Australia's research system is linked to these industries, as are a wide range of manufacturing and service sector suppliers. The performance of much of Australia's mining and agricultural industries is dependent on innovation based on complex technologies and high-level capabilities. These industries are resource-enabled but increasingly market and innovation-driven. In major areas of mining and agriculture Australian productivity performance is world leading. In both mining and agriculture the strong and sustained demands for innovation and problem-solving have led to the emergence of specialist providers of equipment and services – although much of the core capital goods are imported. Many of these specialist suppliers are now exporting goods and services.

Dispersion, Fragmentation and Focusing Devices

Australia's innovation systems are highly dispersed: geographically, sectorally, technologically and organisationally. The scope for economies of scale in innovation and production has been more limited than the aggregate picture would suggest. The significance of barriers to focus, critical mass and effective interaction is generally underestimated.

Systems Integration and Problem-solving in the Innovation System

A great deal of innovation in Australia involves essentially systems integration – combining sub-systems and adapting systems to meet Australian needs. These processes often require high-level capabilities to solve problems and incorporate novel design elements, with implications for the role of the public-sector research system and approaches to its evaluation. R&D and patent statistics tell us little about these types of innovation, which are central to productivity. As organisational change is often required for effective technological innovation, managerial competencies will have a major bearing on the effectiveness of technological innovation and the returns to investment. Managerial competencies are also vital for user-producer links and supply chain development that are increasingly associated with technological innovation.

Australia's innovation systems are highly dispersed: geographically, sectorally, technologically and organisationally. The scope for economies of scale in innovation and production has been more limited than the aggregate picture would suggest. The significance of barriers to focus, critical mass and effective interaction is generally underestimated.

Three dimensions provide a useful starting point for assessing overall NIS performance:

- Performance in generating (and renovating) resources required by firms and other problem-solving organisations. These resources include human resources, knowledge, networks, infrastructure, trust and standards.
- Performance in solving problems – that is, in mobilising resources to meet performance gaps. This operates at the level of the firm, the technological 'system', the sector and, in relation particularly to the policy domain, at the national level.
- Performance in ensuring diversity and hence generating options for economic progress – that is, building capacities beyond those needed for current problem-solving, as in developing new competencies, technological trajectories, industries, clusters and innovation systems. (Where national economic,

environmental, social performance is unsustainable and cannot meet the objectives of the society, change in the innovation system is one mechanism for achieving change in the wider economic, social and environmental system.)

In relation to all three of these dimensions it is clear that Australian innovation systems are evolving in response to the opening of domestic and international markets and technological trajectories. According to Bean (2000) over the 10 years from 1988 Australia moved from having some of the highest tariff levels in the OECD to generally the lowest levels. Substantial components of agriculture are shifting from commodity production by developing higher value-added activities based on differentiation in products and marketing-related services. Significant new areas of strength have developed in, for example, wine, scientific and control instrumentation, and some services sectors.

Australia has experienced strong economic growth for a decade or more. However, many standard indicators of innovation have been falling recently.

In relation to the first two of these dimensions the overall evidence suggests that the innovation system is performing reasonably well, when assessed in terms of recent performance. Australia has a strong public-sector research and education system and is an effective user of new knowledge and technology from domestic and international sources. (Over the past decade users have captured the greater share of the benefits from ICT innovation). However, there are some critical caveats to make. This includes: growth off a low base (for example, in some areas of patenting and trade); the drivers of export growth (including the role of the depreciation of the A$); and the sources of productivity growth (particularly the role of one-off factors such as micro-economic reform). According to Sheehan and Messinis (2003), Australia has experienced strong economic growth for a decade or more. However, many standard indicators of innovation have been falling recently. Again these outcomes can be interpreted in different ways. On the one hand, broad economic change can be more important to growth than innovation, since market forces will find the best growth opportunities. On the other hand, Australia's recent growth spurt is unsustainable. It is being driven by rapid growth in borrowings by households, by a surge in net foreign debt and, until recently, by a falling dollar. These and other factors have masked Australia's declining position in the global knowledge economy.

A critical issue for such an assessment is whether there are obstacles to the evolution and upgrading of innovation systems, whether resource allocations, competencies and attitudes remain locked into patterns that are no longer productive. A recent comparative international survey found, as many similar surveys have found over the past 20 years, that, despite persuasive evidence to the contrary, Australian firms consider that their innovation-related performance is 'world class.'[5] There is some evidence that public-sector research organisations remain focused on traditional fields of science, while the business sector is focusing on engineering and software, limiting effective interaction. Bourke, drawing on data for the 1981–97 period, has shown that industry participation in scientific papers (and hence presumably also in research collaboration) is particularly low in Australia, about 2 per cent compared with 8 per cent in the United Kingdom and 9 per cent in the United States.[6]

In relation to the third of these dimensions, one general area that appears to be a continuing systemic weakness is that of the exploration of new industry development through new firm formation, either as start-ups or spin-offs from existing firms. The relatively low levels of venture capital, particularly of early stage finance, appear to be a continuing problem.

In relation to the third dimensions of assessment, it is vital to recognise that, despite the recent performance, the Australian economy remains vulnerable. Our analysis of trade, R&D and US patent data indicates that Australia has increased its relative specialisation in 'low-tech activities'. There may well be a case for a more systemic and sustained approach to upgrading the 'accumulation of skills and knowledge' and more generally ensuring that Australia has an innovation system able to contribute substantially to the development of the economy rather than simply respond to short-term market signals. In this regard it is worth quoting Dowrick (1994) at some length concerning recent discussion on the assumptions underlying the current policy settings:

> The new growth theories point out that the growth-enhancing effect of trade is an aggregate effect; we expect it to hold on average ... *but not in every case. In particular, trade can reduce growth for countries that have comparative advantage in industries with low-growth potential.* Lower growth does not, however, necessarily imply lower economic welfare. Specialisation through trade may move the terms of trade in favour of the low-tech country which is enabled to import cheaper high-tech goods ... *Trade is not, however, necessarily welfare enhancing in the absence of competitive markets.* If there are substantial market failures in the accumulation of knowledge and skills and new goods, then trade is a double-edged sword. On the one hand, trade acts as a conduit for new ideas, stimulating growth and enhancing welfare. On the other hand, trade liberalisation and consequent specialisation in low-tech activities may relegate a country that is historically disadvantaged in the accumulation of skills and knowledge to fall further and further behind.
>
> The pessimistic view of trade liberalisation for Australia is that it might lead us to inefficient specialisation in natural resource-based activities with few incentives for enhancing skills and knowledge. For example, the current recovery in the world economy is already having the effect of improving short-term prospects for the terms of trade and raising the real exchange rate. It is possible that such movements may squeeze out the recent expansion in exports of high value-added manufacturing and lower our prospects for long-run growth and welfare by compounding failures to develop our skill and knowledge base. These are, however, second-best welfare arguments. It is not obvious that we should be using trade policy to rectify failures in the markets for the development of skill and knowledge and new goods. Rather, if we address these problems directly, both the new theory and the econometric evidence suggest that trade liberalisation is likely to enhance both growth and welfare *{my emphasis}*.'

There may well be a case for ensuring that Australia has an innovation system able to contribute substantially to the development of the economy rather than simply respond to short-term market signals.

4. Australian Business R&D – Regional Diversity and Changing Knowledge Base

In 2000–01, business R&D expenditure (BERD) was $4.8 billion. BERD is almost equally distributed between manufacturing and service industries (each accounting for about 45 per cent of BERD), while mining accounts for about 10 per cent. In 2000–01, about 55 per cent of all Australia's business R&D expenditure was undertaken within seven industry groups – three service industries, three manufacturing industries and mining (Figure 4.3).

Australia's Business R&D at the National Level – Major Fields of Technological Skill

The rising significance of ICT in Australian R&D is evident when we look at the fields of research (the ABS requires firms to indicate the distribution of their R&D across both 'core business activity' and 'field of research'). In terms of the broad field of research, engineering and ICT account for over 80 per cent of BERD. But within engineering the largest field of research is in communication technologies. Overall, business R&D expenditure directly focusing on R&D in information, computing and communication sciences, communications technologies, and computer hardware together comprise 38 per cent of all BERD (Figure 4.4). Furthermore, half of the top eight fields of research (representing 65 per cent of Australia's total BERD) are in ICT. Manufacturing and automotive engineering then follow, showing the traditional areas of the R&D skills base. Medical and health research skills are also significant, as is resources engineering – a field strongly associated with the mining industry.

In comparison with leading economies, Australia's gross expenditure on R&D, at 1.53 per cent of gross domestic product (GDP), is relatively modest.

Australian R&D Expenditure at the Level of States and Territories

In comparison with leading economies, Australia's gross expenditure on R&D, at 1.53 per cent of gross domestic product (GDP), is relatively modest. Corresponding data at the state and territory level, however, varies considerably. (However, not all of this variation in gross R&D expenditure as a percentage of GSP (Gross State Product) is due to differences in levels of business R&D expenditure – Commonwealth and Higher Education R&D activity contributes to inter-state variation in R&D intensity.) Figure 4.5 depicts the trend in Australia's BERD as a proportion of GDP with corresponding trends (BERD as a proportion of GSP) for each state and territory. It shows that Victoria has consistently had the highest BERD/GSP ratio (BERD intensity) of the states and territories. BERD in Queensland increased sharply in 1995–96, but then followed the national trend. After falling in 1996–97, South Australia's intensity has increased overall – South Australia is the only state to have surpassed the peak level of BERD/GSP that most states and territories reached in the period 1995–96 to 1997–98. While R&D intensity declined after 1995 in most states the decline was particularly marked in Western Australia.

Figure 4.3: BERD (2000–01) – industry of core business activity

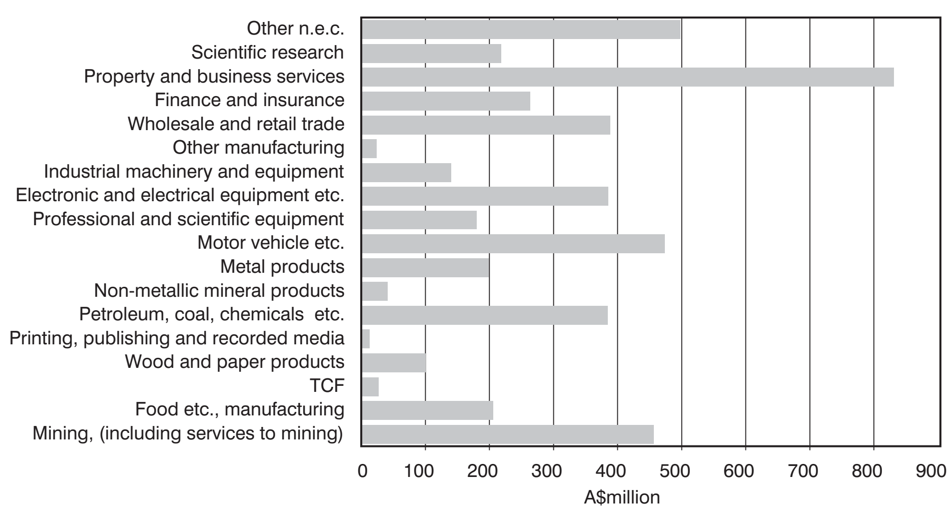


Figure 4.4: Australia – major R&D fields of technological skills (RF), 2000–01 (% of GDP)

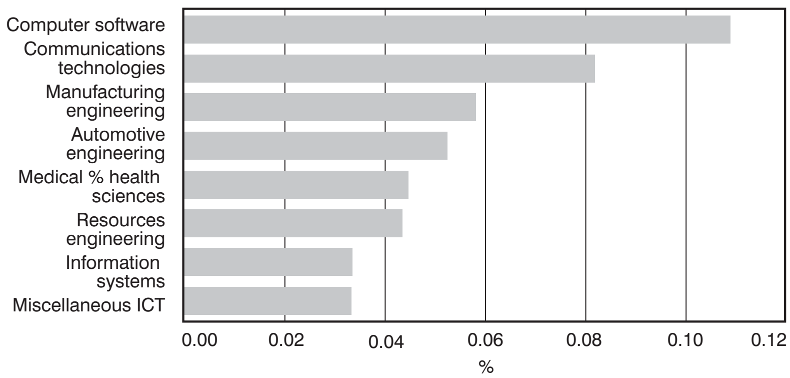


Figure 4.5: Change in national and state-level BERD (as % of GDP or % of GSP)

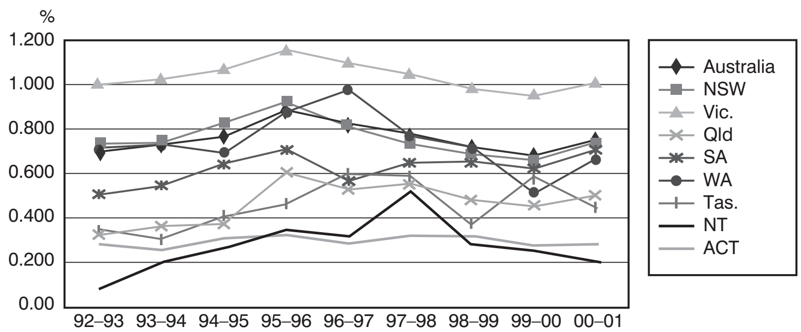


Table 4.1 summarises a range of data on R&D performance and on patenting in Australia by organisations based the major states. It indicates the important sectors in each state in terms of R&D investment, R&D increase over the 1990s, the major fields of research, and relative patenting activity. On the basis of these patterns the characteristic strengths of each state are identified. In the following analysis of R&D patterns and trends at the state level we will discuss two States: New South Wales and Queensland.[7]

New South Wales

New South Wales' gross expenditure on R&D (GERD) as a proportion of GSP ranks below the national GERD intensity average of 1.53 per cent. This level results primarily from lower levels of R&D expenditure in Commonwealth agencies and in universities. However, New South Wales has Australia's second highest intensity of business R&D expenditure (0.71 per cent of GSP), though it is significantly below the corresponding level in Victoria (0.98 per cent).

Figure 4.6 shows the major R&D performing industries in New South Wales: computer services; electronic equipment; finance and insurance; metal products; photographic and scientific equipment; and food-processing. New South Wales' R&D skills base is dominated by computer software – where it has the strongest research capability, both in scale and in R&D intensity (See Figure 4.7). Communications technologies are also relatively strong – being at approximately the same scale as in Victoria, but behind that state in R&D intensity in that field of research.

Table 4.1: Patterns of R&D activity and strength at state level

	New South Wales	Victoria	Queensland	South Australia	Western Australia
Major R&D performing sectors	ICT services; ICT equipment; finance and insurance; metal products; photographic and scientific equipment; and food-processing	ICT services; ICT equipment; chemicals; automotive instruments and parts; medical and pharma-ceuticals; finance and insurance	Mining; ICT services; metal products; petroleum, coal and chemicals	Petroleum, coal and chemical; machinery and equipment wholesaling; ICT equipment; auto engineering; photographic and scientific equipment; ICT services	Metal ore mining; property and business services; ICT equipment; ICT services
Sectors with strong growth in R&D	ICT services; photographic and scientific equipment	ICT services; ICT equipment; finance and insurance	ICT services	Machinery and equipment; wholesaling; ICT services; ICT equipment	Metal ore mining
Major fields of research	Computer software; communi-cation technology; medical	Automotive, mechanical and industrial engineering; communication technology; software; other ICT	Software, metallurgy; resource engineering; automotive, mech. and industrial engineering	ICT; manufacturing engineering; automotive engineering; software	Resource engineering; communi-cation technology; chemical engineering; metallurgy
Patent strength and growth	Electronics; processed food, instruments.	Consumer goods and equipment; mechanical engineering; chemistry and life sciences	Civil engineering; mechanical engineering, consumer goods and equipment	Process engineering; instruments; mechanical engineering	None
Apparent overall strengths	ICT services and equipment; instruments and devices	Communication services and equipment; automotive engineering, biotech	Resources, software	Instruments; automotive engineering	Resources

(Source: Based on the analyses in Working Paper 3: Regional Aspects of Australia's R&D)

Overall, New South Wales is growing above the Australian average in most patent areas (Figure 4.8). Patent data points to relative strengths in electronic equipment, instruments and processed food. These areas show strength in fine measurement and control of devices.

Figure 4.6: NSW – major R&D industries (ANZSIC), 1992–93 to 2000–01 (% of GSP)

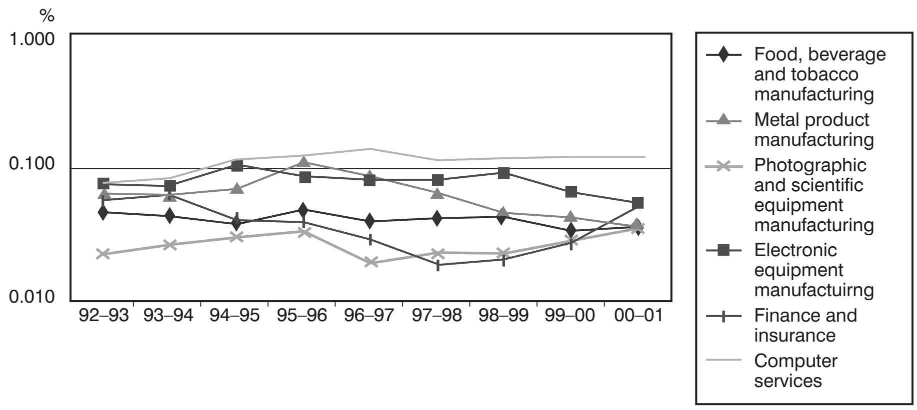


Figure 4.7: NSW business – major R&D technological skills base (RF), 2000–01 (% of GDP)

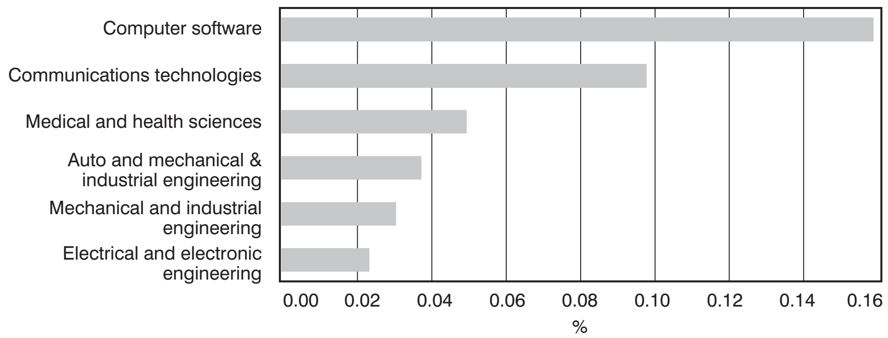
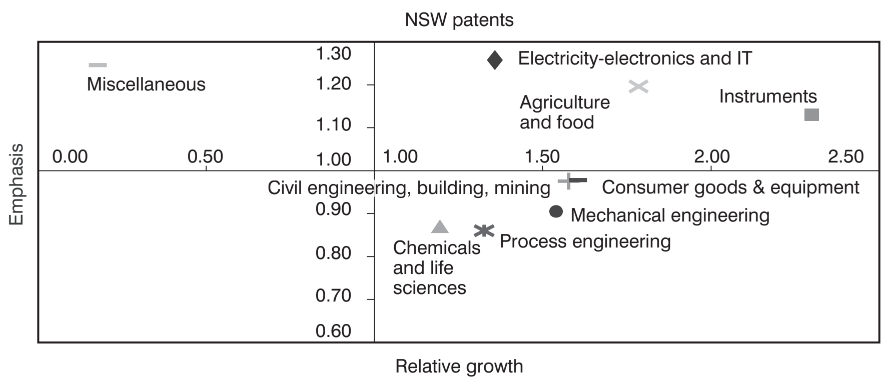


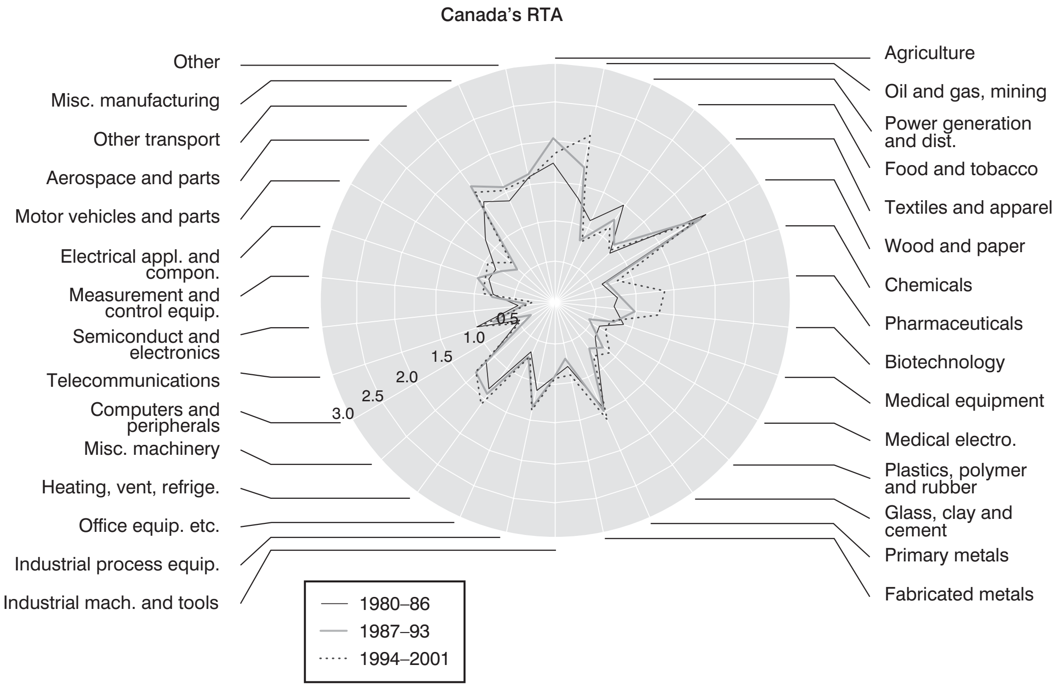
Figure 4.8: NSW – broad patent R&D fields, by relative emphasis and growth

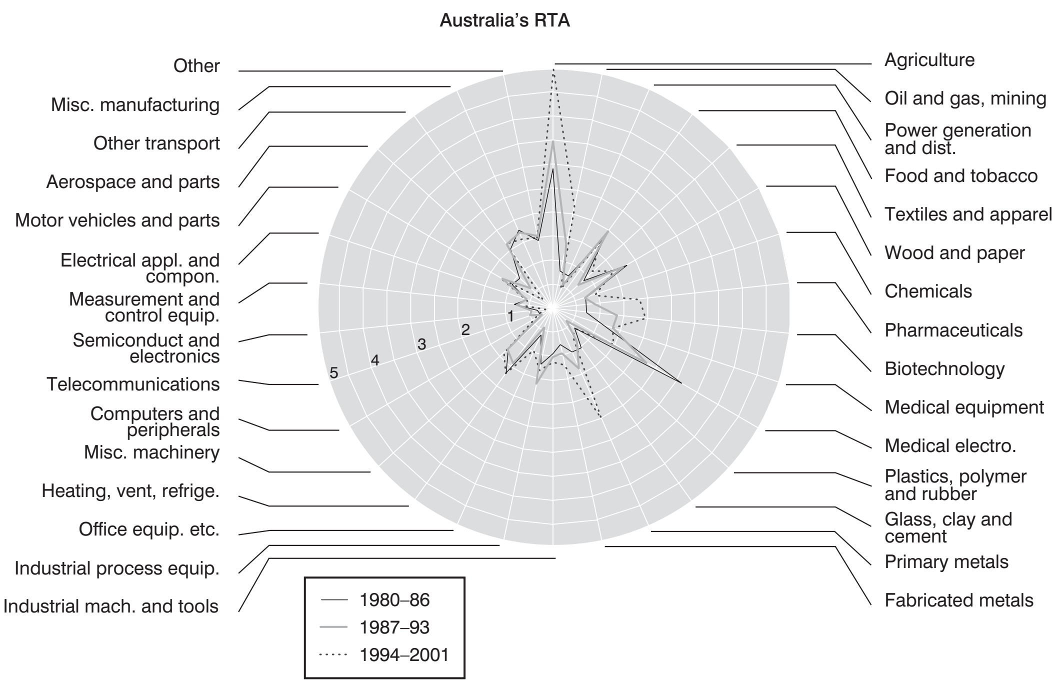


Queensland

Queensland's R&D intensity (1.23 per cent in 2000–01) is lower than other states. Queensland's BERD/GSP peaked at 0.57 per cent in 1995–96 and stood at 0.47 per cent in 2000. The mining industry has consistently been Queensland's largest R&D spender, but has recently been challenged by computer services (Figure 4.9).

Figure 4.14 cont'd: Patterns of revealed technological advantages, 1980-2001, in Finland, Canada and Australia





(Source: Ausis 2003)

Assessing BERD Performance in Australian States

Taken overall, this analysis illustrates several points:

- Service sectors account for almost 50 per cent of Australian BERD, and through the 1990s their share of BERD grew more rapidly than manufacturing, mining or agriculture. R&D in some manufacturing sectors (for example, metal products in New South Wales and Western Australia) declined sharply in the late 1990s.
- The role of ICT as a sector of industry (largely in services) and as a field of research is highly significant and pervasive. The top two fields of research in business are ICT and overall 65 per cent of BERD is allocated to ICT-related research. In 2000–01 computer services was the sector with the greatest level of investment in R&D and communication services was the fifth-largest R&D spending sector. The computer services industry showed the fastest (and by far the most consistent) rate of growth in R&D expenditure over the 1990s in New South Wales, Queensland and South Australia.
- The second, third, fourth and sixth most important fields of research in industry in Australia in 2000–01 were all in engineering: communication engineering, manufacturing engineering, automotive engineering and resource engineering.
- R&D in software and engineering account for the majority of R&D industry but a minor share of R&D in the public sector. The possibility of a mismatch in research allocation and in human resource development needs to be assessed.
- Mining was the second most important sector in terms of BERD expenditure in 2000–01, the most important sector in Queensland and the Northern Territory, and dominated all R&D effort in Western Australia.
- Patterns of R&D activity and directions of change in that activity vary significantly among the states.

Much of the comparative analysis of national innovation systems has focused on the research system … Since such approaches focus on only some dimensions of the innovation system they provide a 'narrow view' on the overall innovation system.

5. Australian Innovation: Patterns of Specialisation and Evolution.

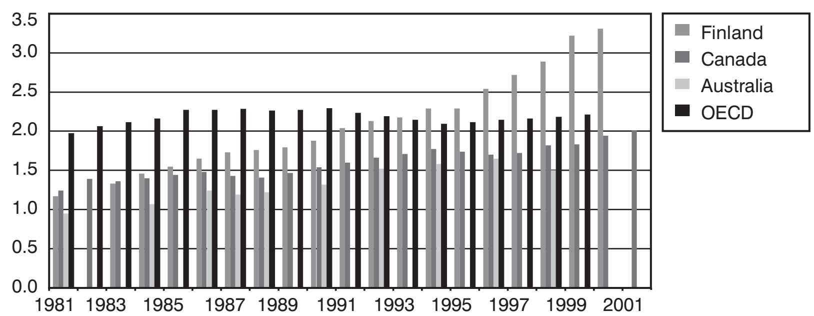
Much of the comparative analysis of national innovation systems has focused on the research system (Nelson 1993). This focus characterises a nation's technological specialisation by assessing the level and direction of innovative effort. Since such approaches focus on only some dimensions of the innovation system they provide a 'narrow view' on the overall innovation system (Lundvall 1992).

The following analysis of the recent (20-year) evolution of Australia's technological specialisation uses indicators based on R&D, patenting and scientific publications (these indicators have significant limitations and need to be interpreted with caution – see Ausis 2003). We compare Australia's performance with that of several OECD countries and in particular with Canada and Finland, as these two countries share a similarly long history of specialisation in natural resource-based sectors.

The Evolution of the Pattern of the Innovative Effort as Indicated by R&D Expenditure

Australia's R&D expenditure pattern is characterised as low in GERD and BERD, but high in the government share of total R&D expenditure (Gregory 1993; *Australian Science & Technology at a Glance,* 2002). Figure 4.12 shows total R&D intensity levels (GERD/GDP) over 1981–2001 for Australia, Canada, Finland and the overall OECD average. Total R&D intensity levels in Australia remained below the OECD average. In the early 1980s, Canada, Finland and Australia had roughly comparable R&D intensities. While levels in Canada and Australia have remained similar, by the late 1990s Finland's R&D intensity was more than double that of Australia.

Figure 4.12: R&D intensity 1981 – 2001: Australia, Canada, Finland and the OECD



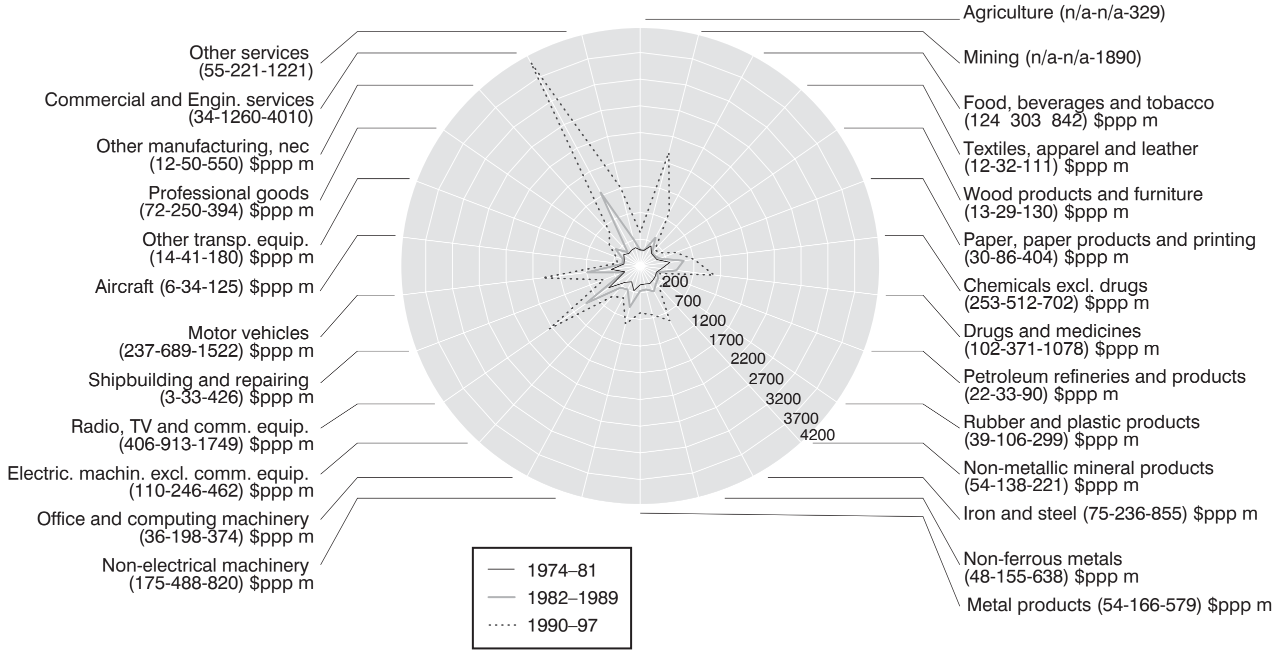
(Source: Ausis 2003)

Patterns of Sectoral Distribution of Business Funding for R&D

In all three countries over period 1974 to 1997 R&D has grown particularly strongly in some sectors (for example, electronics in Finland, communications services and pharmaceuticals in Canada, and commercial and engineering services in Australia). But only in Australia has it grown in all sectors (see Figure 4.13). In both Canada and Finland some significant sectors showed very slow growth or a decline in real R&D expenditure. In terms of BERD, Australia has not developed the level of specialisation of either Canada or Finland. These trends raise questions for further analysis; for example: Why is Australian BERD in motor vehicles almost double that of Canada, which has a much larger industry and exports many (period 1995–2000) more motor vehicles than Australia? Why does Australia show a high growth rate in BERD in metals and metal products when Canada, a major Australian competitor in these sectors, has much lower rates? Why has the food and beverages industry become much more R&D intensive in Australia than in Canada?

However, the commercial and engineering service sector has emerged as a strong R&D performer. R&D expenditure by this sector already reached more than US $1.2 billion in the period 1982–89 and increased to US$4 billion in the period 1990–97. A large part of this expenditure is in software development in such sectors as finance and insurance, wholesale, retail and property and business services.

Figure 4.13 Australian BERD: expenditure by sector and period (million 1995 $ ppp)



(Source: Ausis 2003)

Technological Specialisation: Patenting

Small countries tend to be more specialised than large countries, and open trade regimes tend to lead to increased specialisation. National patterns of specialisation tend to persist over long periods of time.

Australia has been characterised in three different ways in previous studies:

- a follower country with high specialisation
- specialised in low-growth sectors
- specialised in natural resources-based sectors.

Table 4.2: Taxonomy of OECD countries

Group	Group	Countries
Group 1	Large advanced countries with low specialisation	US, France, UK, Japan, Germany
Group 2	Smaller advanced countries with average specialisation	Netherlands, Switzerland, Sweden.
Group 3	Follower countries with high specialisation	Italy, Canada, Denmark, Belgium, Norway, Australia, Finland
Group 4	Small, laggard countries with very high specialisation	Spain, Ireland, Portugal, Greece

(Source: Pianta and Melliciani 1996)

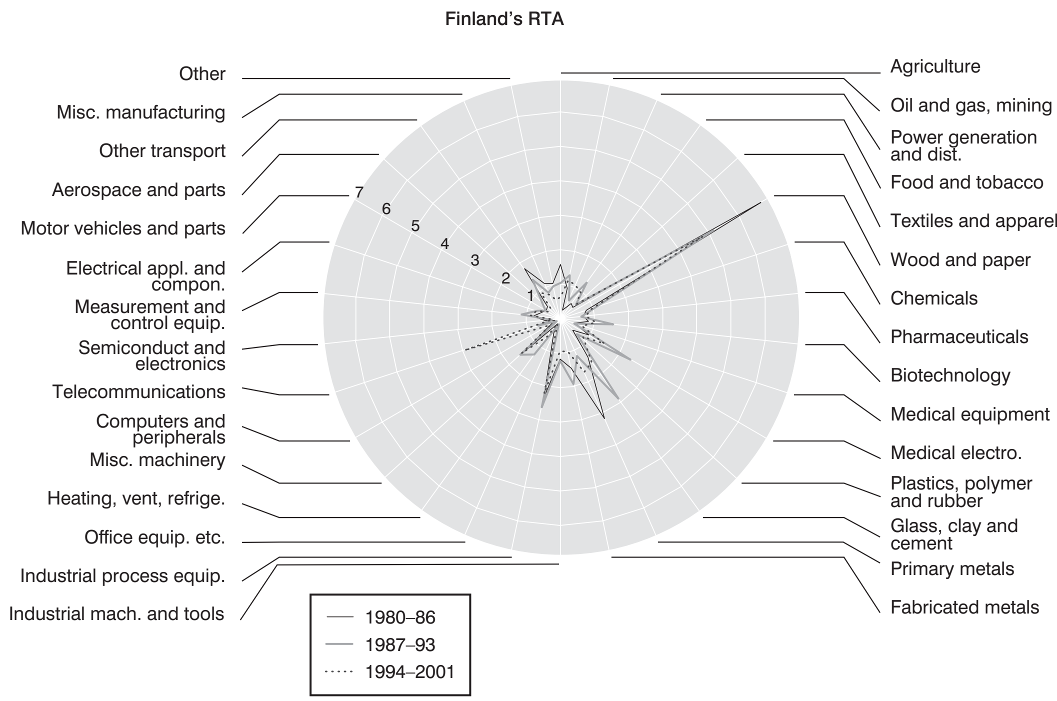
Pianta and Melliciani (1996) grouped OECD countries into four groups (Table 4.2) based on patent, R&D, investment and trade data. They comment that Group 3, 'follower' countries, caught up to Group 1 and 2 countries in terms of GDP per capita by concentrating their efforts in investment activity (rather than R&D) and a few selected fields of technology.

Archibugi and Pianta (1992) relate the technological specialisation at the country level to patterns of change in global patenting activity. A high correlation between national technological specialisation and global patenting trends indicates that a country is positively specialised in those patent classes in which global patenting is growing most quickly and negatively specialised in those patent classes where global patenting has been stagnant or declining. Japan showed the strongest positive correlation. Australia's technological specialisation, like that of Canada, Sweden, Germany, Spain and Portugal, was relatively concentrated in areas of low global patent growth.

We have reviewed these analyses using the most recent data on patenting in the United States, to calculate revealed technological advantage (RTA)[8] for Australia and other OECD countries. Figure 4.14 shows the RTAs for Australia and the two comparator countries, Canada and Finland.

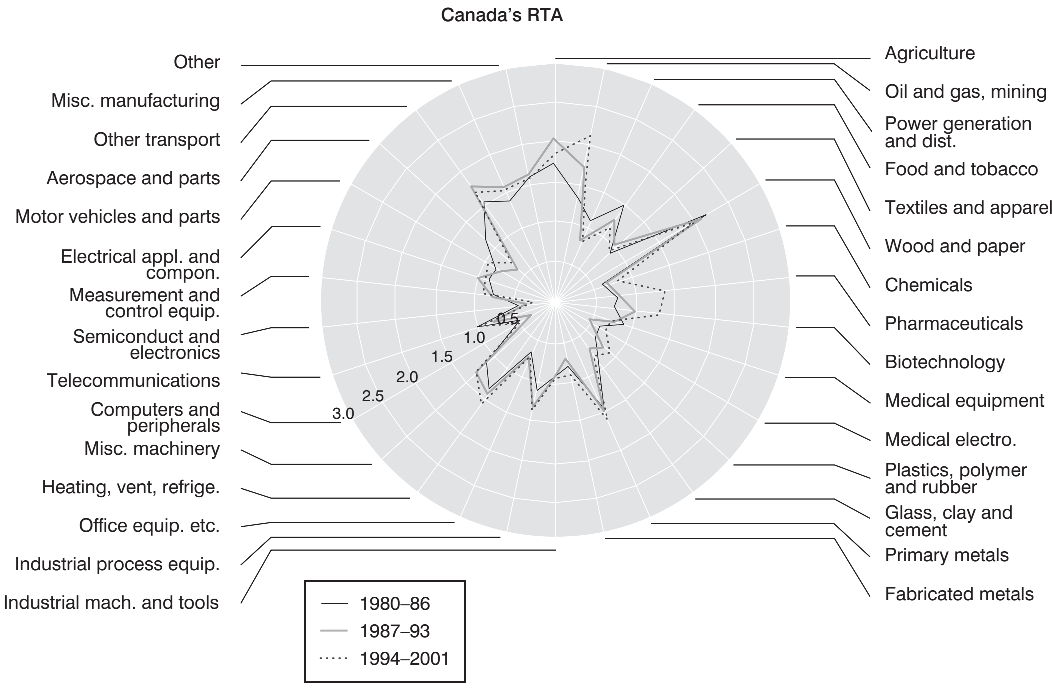
A relatively high proportion of Australian and Canadian patenting is in fields related to natural resources: agriculture, oil and gas, mining, primary metals, and wood and paper products, although both countries have recently developed a level of specialisation in pharmaceuticals and biotechnology. Australia showed a significant specialisation in medical electronics, but this declined over the 1990s.

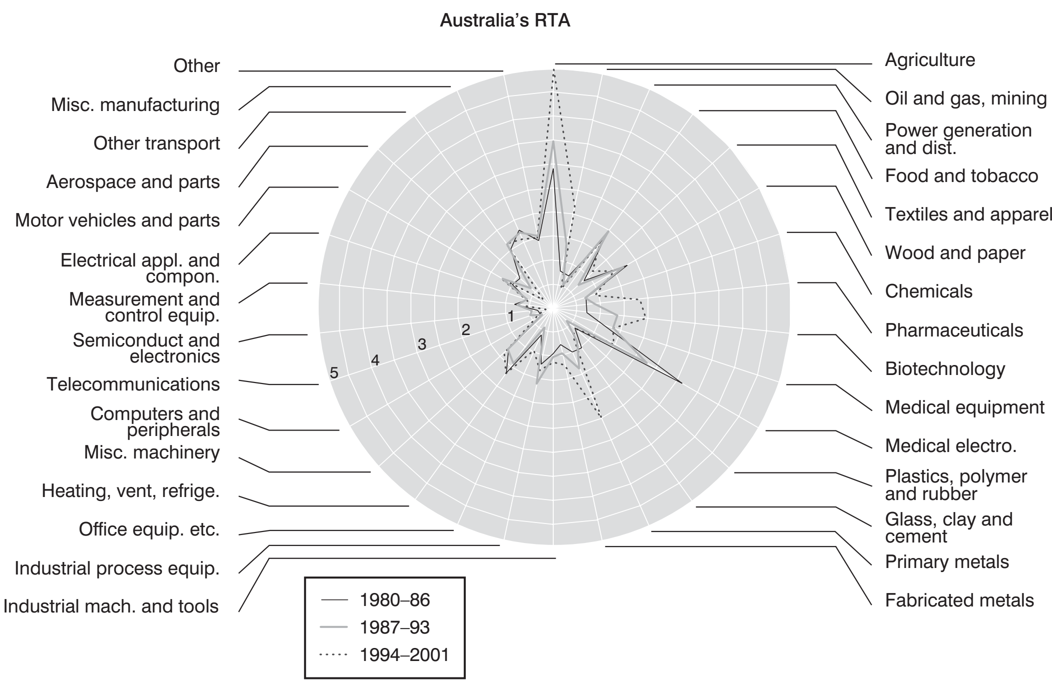
Figure 4.14: Patterns of revealed technological advantages, 1980–2001, in Finland, Canada and Australia



Source: Ausis 2003

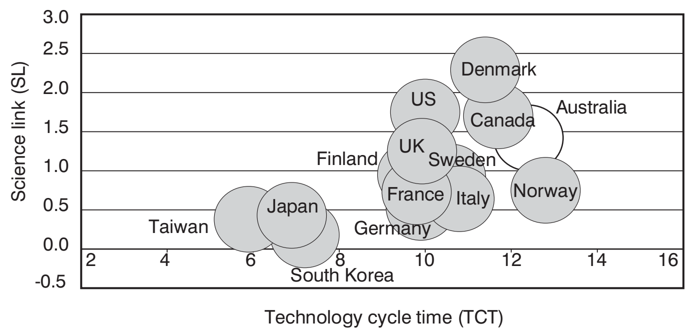
Figure 4.14 cont'd: Patterns of revealed technological advantages, 1980-2001, in Finland, Canada and Australia





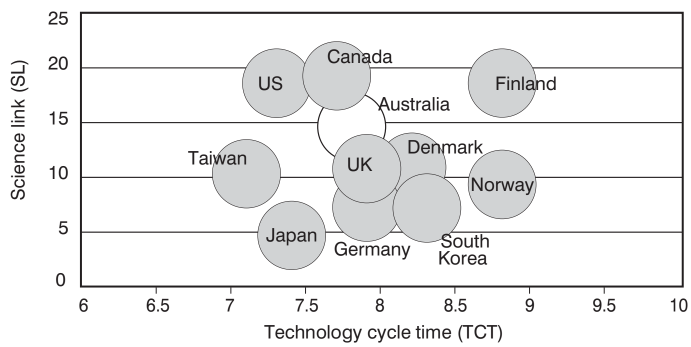
(Source: Ausis 2003)

Figure 4.15: Science linkage vs technology cycle time (1980–2001)



(Source: Ausis 2003)

Figure 4.16: Biotechnology patenting (science linkage and technology cycle time of patenting activity 1980-2001)



(Source: Ausis 2003)

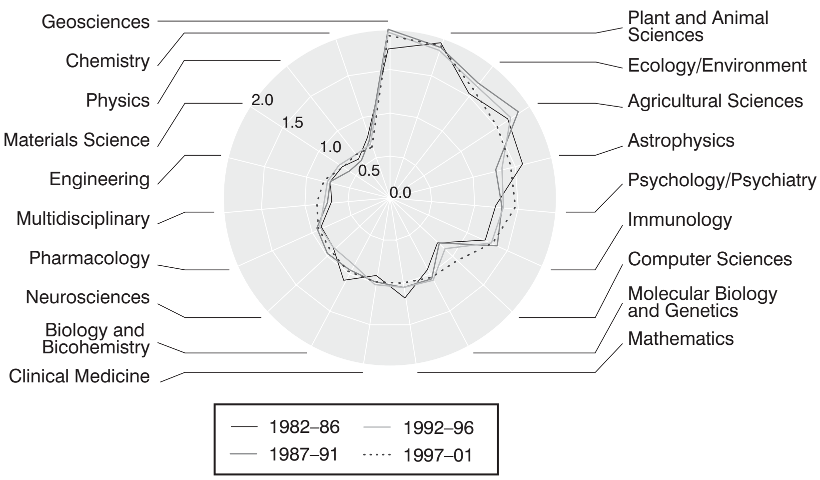
Australia and Canada changed far less than Finland; indeed, the former two countries have deepened their specialisation in natural resource-based sectors.

Patenting Characteristics: Maturity of Technologies and Links to Science

Australian patenting in the United States is relatively concentrated in fields of low patent growth. In the following section we look at the nature of patenting activity in terms of the technology cycle time (TCT) and level of science linkage (SL). The TCT indicator is the median age of the references (that is, 'prior art' citations to publications and patents) cited on the patent. The lower the TCT value the more recent the antecedent knowledge and thus it is assumed the more rapid the technological change. The science linkage (SL) is a measure of the number of these citations that are to the scientific literature. This measure provides an indicator of the link between a technological field and the scientific research base.

Figure 4.15 shows, for a range of OECD countries and Taiwan, aggregate TCT levels for all technological fields covering the period 1980–2001 and aggregate SL levels for all technological fields covering the period 1985–2001. Three groups of countries can be identified:

Figure 4.17: Changes in revealed comparative advantage in Australia's scientific publications output in four periods



Source: Ausis 2003

- a fast-moving technology developer group with low SL levels: Japan, South Korea and Taiwan
- a fast-moving science based group: United States, United Kingdom, Sweden, Finland, Italy, France and Germany
- a slow-moving science-based group: Canada, Australia and Norway.

In the first group, patenting activity is concentrated in fields of rapid technological change – such as semiconductors, telecommunications and computers. But even in areas of slow technological change, these countries focus on the most rapidly changing sub-fields.

In the 'slow-moving science-based group', the high TCT suggests that these countries are involved in activities where the rate of technological change is relatively slow. However, on average Australian patenting in almost all fields exhibits a high TCT. Hence, even in fields where the rate of technological change is high (for example, electronics) the TCT of Australian patents is below the average. Australian patenting in pharmaceuticals and biotechnology (Figure 4.16) are exceptions.

Hence, not only is Australian patenting conservative in that the pattern of specialisation has changed little over 20 years – a period that saw major changes in many countries – but it is also conservative in that patenting tends to be based on older knowledge than is patenting in other countries. A part of the explanation for these observations may be that Australian invention focuses less on generic technologies of wide application and more on application and location-specific niches.

Specialisation in Science

There has been little change in the pattern of specialisation of Australia science over the last 20 years. Australia's strengths at the end of the 1990s continue to be in agricultural sciences, earth sciences, biological sciences, and medical and health sciences; and to be relatively weaker in physical sciences, chemical sciences and mathematical sciences; and in the more applied fields embraced by engineering and information and computing sciences (Bourke and Butler 1999). Figure 4.17 shows the pattern of Australia's revealed comparative advantage (RCA) in fields of science[9] over four time periods. These confirm Australia's consistent specialisation and the overall conservative nature of the pattern of scientific output.[10]

The Perspective from the Narrow View

This analysis from the 'narrow view' points to the enduring significance of Australia's resource-based history for innovative activity. It shows that:

- Australia is specialised *technologically* towards agriculture, mining, primary metals, but has recently increased its activities in biotechnology and pharmaceuticals. (Note that technological specialisation – RTA – is distinct from industrial specialisation.)
- These patterns of specialisation in technological invention are likely to both reflect and reinforce the Australia's *industrial* specialisation.
- There is little evidence of major changes in Australia's technological specialisation, unlike some OECD countries.
- Australian inventions are focused on areas where technological change is relatively slow. Furthermore, within most technological fields, regardless of how fast they are changing, Australia is a slow mover. Again pharmaceuticals and biotechnology are exceptions.
- The strengths of the Australian science system have not changed in the past two decades and reinforce the importance of Australia's unique natural resources and its path dependence. The fields of strengths are geoscience, agricultural science and animal and plant biology, while fields of relative weakness are engineering and computing.
- Recently, there have been some signs of significant change. An emerging specialisation has appeared in the fields of biotechnology and pharmaceuticals. The engineering and commercial services sector has emerged as a major R&D performer. Australian patenting has become more rapid (that is, has shorter TCTs) in several technological fields – both fields of slow and rapid technological change.

While Australia has diversified export markets and products, it's relative level of specialisation in natural resource-based commodities has increased. Overall, the picture that emerges is one of a conservative 'innovation system' that is only slowly (perhaps too slowly) generating sustainable new paths of technological accumulation.

6. Conclusion – Interpreting National Characteristics

Four broad features of the Australian NIS emerge from these and related studies:[11]

The Role of Resource-enabled, Knowledge-based, Competition-driven Innovation

The performance of much of Australia's mining and agricultural industries is dependent on innovation based on complex technologies and high-level capabilities. These industries are resource-enabled but increasingly knowledge based. In major areas of mining and agriculture Australian productivity performance is world leading. In both mining and agriculture the strong and sustained demands for innovation and problem-solving have led to the emergence of specialist providers of equipment and services – although much of the core capital goods are imported. Increasingly, these specialist suppliers are now exporting goods and services. In some industries (for example, mining and wine) the 'knowledge infrastructure', including research and training organisations and a range of intermediary organisations and mechanisms, is well developed and plays a key role in the continuous upgrading of technologies and firm-level capabilities.

Conservative Patterns of Evolution

Nations develop particular economic and industrial structures and specialise in particular types of technologies; these patterns tend to prevail for long periods of time and such *path-dependence* affects processes of technological change.

Australia has a high and sustained level of specialisation in mining and agriculture and a concentration of patenting in areas of relatively slow technological change. Among OECD countries Australia has had one of the lowest levels of change in technological specialisation over the last 20 years. While patenting in biotechnology and pharmaceuticals has grown rapidly over the past decade there is little evidence of significant emerging areas of technological specialisation. Specialisation data also shows that Australia has not registered the emergence of any new major sector or field of considerable strength such as telecom in Finland and Sweden; oil in Norway; semiconductors in Korea and Taiwan, and motor vehicles in Germany. While Australia has diversified export markets and products, it's relative level of specialisation in natural resource-based commodities has increased. Overall, the picture that emerges is one of a conservative 'innovation system' that is only slowly (perhaps too slowly) generating sustainable new paths of technological accumulation.

The phenomena of increasing returns can have a major role in the competitive dynamics of firms, sectors and regions. Through positive feedback mechanisms (such as economies of scale, experience or learning curves) firms, sectors or regions that have a slight lead over competitors can move even further ahead. By benefiting prime movers rather than late-comers, increasing returns reinforces path-dependency. For a nation, increasing returns influences both the types of activities or sectors in which the nation is 'competitive' and the rate of economic growth.
The phenomena of increasing returns are likely to be one of the reasons why the level of value-adding to Australian primary exports has developed slowly.

While changes in national sectoral specialisations are slow, they may still come about, especially if the 'rules of the game' are altered. Such rule changes can result from technological disruption that makes the knowledge base of a sector obsolete, or from transformation of the business logic. For example, a transformation occurred in the wine industry when the mass market was reached by cheap, high-quality standard wines. This transformation required and led to a shift in knowledge base, further consolidating the competitive position of the new leaders, but also requiring complementary shifts in the education and training organisations.

Technology Integration and Adaptation

Australian firms are largely users and adaptors of core technologies and as such could be termed 'systems integrators'. This is a particular capability to add value by integrating or 'assembling' systems, resources and technologies rather than involvement in their development. The core competences of 'systems integrators' are related more to activities such as project management, the integration of heterogeneous sub-systems, risk and financial assessment, logistics, and particularly problem-solving and adaptation to particular applications. The significance of adaptation, and the knowledge of the constituent technologies and of the users application environment that will be required, varies widely. Innovation activity that begins as systems integration can over time involve growing novelty and a progressive shift in the make/buy pattern as firm-specific knowledge and the market demand for specialised systems grows.

Australian firms are largely users and adaptors of core technologies and as such could be termed 'systems integrators'. This is a particular capability to add value by integrating or 'assembling' systems, resources and technologies rather than involvement in their development.

There is no evidence of systemic weaknesses in the capacities of Australian industrial or research organisations to acquire, apply and modify embodied or disembodied knowledge from local and international sources. The available evidence suggests that many Australian firms actively search the global stock of knowledge/technology, and that Australians are among the world's most intensive and rapid users of new ICT technology. On the basis of econometric analysis, Dowrick and Day (2003) estimate that international technology transfer accounts for approximately half of the productivity growth in the market sector of the Australian economy over the 1990s.

While not diminishing the importance of breakthrough innovation or of local discovery, the majority of innovation is incremental, involving improvement in products, processes, methods and so on, and is based on knowledge sourced from outside Australia. Hence, broadly distributed capabilities are vital and investment in human resources is the essential foundation for innovation.

There is a rich constellation of emerging new firms, often in specialised niches, although few appear to be major new trajectories. Such firms are in a diverse range of sectors and include firms bringing new technology solutions to growing markets in health, environmental management, renewable energy technologies and ICT applications in services and resource sectors.

Diversification and Evolution: Emerging New Firms and Niches

While the overall story is one of strong 'path dependency' there are nevertheless signs of change. The increasing 'speed' of Australian patenting and the recent strong growth in pharmaceuticals and biotechnology patenting are one dimension of this change. In sectors such as these, access to marketing channels, and other complementary assets, will require various forms of collaboration with international firms. The management of these international relationships, and the strength of the positioning of Australian firms in global supply chains and collaborations, will shape the level of benefit from innovation captured by Australian firms. The history of ICT development in Australia and many other countries suggests that new technology-based industrial development is most likely to be sustainable where there is a strong nexus between technology development and local patterns of demand.

There is a rich constellation of emerging new firms, often in specialised niches, although few appear to be major new trajectories. Such firms are in a diverse range of sectors and include firms bringing new technology solutions to growing markets in health, environmental management, renewable energy technologies and ICT applications in services and resource sectors. Such firms emerge both from the technology supply side (for example, research organisations, technology suppliers), from the demand side (the commercialisation of a solution developed within or for a user organisation) or from entrepreneurs identifying market opportunities. Services sectors accounted for 77 per cent of Australian GDP and over 82 per cent of employment in 2001–02 and some services sectors (for example, engineering and commercial service) have a sharply growing role in R&D.

However, developing new innovation-based enterprises in Australia remains a challenge:

- the domestic market is a small base from which to finance R&D and other innovation inputs
- there is a small pool of experienced entrepreneurial managers
- under these circumstances capital providers are conservative

- there are few large innovation-based domestic companies that nurture and spin-off new ventures
- accessing export markets is a major challenge for a small company.

The public-sector research and training system in particular and the public sector in general has a large role in the Australian 'innovation system'. A relatively high proportion of Australian GDP is allocated to research carried out in the public sector, and such research accounts for a high share of Australia's GERD. Public-sector research continues to play a major role in the agricultural and health sectors and at least in the more generic and indivisible areas of the mining industry (for example, geology, exploration and environmental management). A relatively high proportion of Australian firms are small enterprises and with very few major high-R&D intensity firms there are few poles of major capability accumulation shaped by corporate decisions about the costs and benefits of innovation.

As Australian managers are relatively inexperienced in managing innovation-based business development and hence are risk averse in this domain, the policies and programs of government (and of institutional investors) will have a major bearing on corporate behaviour in this regard.

Public expenditure, and to varying degrees public agencies and enterprises, continue to have a central role in the provision of much physical infrastructure and in services such as health and education, and play a powerful regulatory role in the provision of other infrastructure and services, recently in the public domain.

As a consequence, public-sector research and training organisations will be important actors in many Australian innovation systems, and, at a higher level, government (state and federal) policy and regulatory regimes are likely to be important influences on the evolution of Australia's innovation systems.

References

Ausis 2003, Working Paper 4. Assessing Australia. IMPP, ANU.

Archibugi, D. and Pianta, M. 1991, *The Technological Specialisation of Advanced Countries.* A report to the EEC on international science and technology activities. Dordrecht: Kluwer Academic Publishers.

Australian Science and Technology at a Glance, 2002, DEST

Bean, C. 2000, *The Australian Economic 'Miracle': A view from the North. Australian Economy in the 1990s,* Reserve Bank of Australia 2000 Conference, p. 95.

Bourke, P. and Butler, L.1999, Relative Strengths in Australian Basic Science – A Summary Bibliometric Map. National Innovation Summit Learned Group Reference Papers. http://www1.industry.gov.au/archive/Summit/Framework/index.html

Dowrick, S. 1994, 'Openness and Growth 'in *International Integration of the Australian Economy,* RBA Annual Conference 1994, <http:/www.rba.gov.au/publicationsand research/conferences/1994>

Dowrick, S. and Day, C. 2003, 'Australian Economic Growth. Why Bill Gates and the Ageing Pessimists are Wrong', National Institute of Economics and Business Public Lecture, 2003.

Freeman, C. 1987, *Technology and Economic Progress: Lessons from Japan,* London, Pinter.

Gregory, R. G. 1993, 'The Australian Innovation System', pp. 324–52, in Nelson (ed.) *National Innovation Systems. A Comparative Analysis,* Oxford University Press.

Lundvall, B. A. (ed.) 1992, *National System of Innovation: Towards a Theory of Innovation and Interactive Learning.* London, Pinter.

Nelson, R. (ed.) 1993, *National Innovation Systems. A Comparative Analysis.* Oxford University Press.

Pianta, M. and Meliciani, V. 1996, 'Technological Specialisation and Economic Performance in OECD Countries, *Technology Analysis & Strategic Management,* Abingdon; June, vol. 8, issue 2.

Sheehan, P. and Messinis, G. 2003 'Innovation in Australia' 2003, in I. McAllister, S. Dowrick and R. Hassan *Cambridge Handbook of Social Sciences in Australia,* Cambridge University Press, Cambridge.

Endnotes

1 This chapter is based in the Australian Innovation Systems Study (Ausis) project, which is supported by the Australian Research Council through the ARC Limkage Program. The partners on this project are: the Innovation Management and Policy Program, National Graduate School of Management; ANU; Department of Industry, Tourism and Resources; Department of Agriculture, Fisheries and Forestry; the Australian Business Foundation; the National Office of the Information Economy; and the CSIRO. This chapter draws on the work of the Ausis project team; in particular, Dr Antonio Balaguer, Dr Kevin Bryant and Dr Magnus Holmen.

2 All data sources are identified in Australian Innovation Systems Study (Ausis). Working Papaer No. 5 *Innovation Systems in Australia,* 2003, IMPP and ANU.

3 Ausis 2002 Working Paper 2: Innovation In Australia: Characterisation of Four Themes in Australian Innovation Systems. IMPP. ANU.

4 Ausis 2003 Working Paper 4: Assessing Australia: Characteristics, Innovation, Structure and Specialisation. IMPP. ANU.

5 Brown, D. *The Innovative Firm.* Arthur D. Little, 2002.

6 The Allen Consulting Group, 2000, *Systemic Mismatches in the National Innovation System;* and Bourke, P. 2000, 'Relative Strengths in Australian Basic Science. A Summary Bibliometric Map'. Research Evaluation and Policy Project, Research School of Social Sciences, Australian National University. National Innovation Summit Learned Group Reference Papers. National Innovation Summit. <http://www1.industry.gov.au/archive/summit/Framework/index.html>. Bourke claims that in the United States industry participated in one in four 'engineering and technology' compared to one in 20 in Australia.

7 For a more detailed discussion of state and territory patterns see Working Paper 3: Regional Aspects of Australia's R&D activities.

8 This terminology, although commonly used in the literature, can be misleading. It does not mean that a country necessarily has an 'advantage' in a technology. In fact, RTA is a measure of a country's current technology specialisation, or the emphasis it places on a particular technology, relative to other countries. The definition of RTA for nations is the ratio of relative share of patents in technological field M in country N over the relative share of patents in technology M for the world. An RTA above 1 for a given technology implies that the country is specialised in this technology.

9 This is defined in an analogous way to RTA. As for RTA, the terminology may be misleading. A high RCA does not necessarily mean that a country has an 'advantage' in a particular science. RCA is a measure of a country's current scientific specialisation, or the emphasis it places on particular science, relative to other countries.

10 This characteristic was discussed in BIE (1996) Australian Science Performance from Published Papers.

11 This discussion draws on a number of exploratory studies carried out in the Ausis project.

5. Australian Biotechnology IPOs: Too Early, Too Small?[1]

Michael R Vitale

David Sparling

1. Introduction

Our intention in this chapter is to describe in some detail one important segment of the Australian biotechnology industry, the group of 24 firms that went public on the ASX in the period 1998 to 2002. These firms all survived the fragile period between university laboratory and Initial Public Offering (IPO), and they managed to convince investors to entrust their capital to the development of new biotechnologies.

The period 1998–2002 was the most active period ever for biotech listings on the ASX. Twenty-two of the 24 newly listed firms were based almost exclusively in Australia, one was created in Australia but already headquartered in the United States, and one was a large New Zealand biotechnology research organisation. We studied the companies and their technologies at IPO, the degree to which they have achieved their financial and technological objectives, and how the firms changed their business models and positioned themselves to weather the current funding drought.

The period 1998–2002 was the most active period ever for biotech listings on the ASX. Twenty-two of the 24 newly listed firms were based almost exclusively in Australia, one was created in Australia but already headquartered in the United States, and one was a large New Zealand biotechnology research organisation.

The 24 companies, which we label 'core biotechs', are Analytica, Antisense Therapeutics, Anadis, AXON Instruments (based in the United States), Bresagen, Biotron, Bionomics, Bioprospect, Compumedics, Chemeq, Cellestis, Epitan, Genesis Biomedical, Genesis R&D (based in New Zealand), GroPep, Metabolic Pharmaceuticals, Norwood Abbey, NSL Health, Network Ltd (formerly Pi2), Panbio, Prana Biotechnology, Peplin, Sirtex Medical, and VRI Biomedical. Each of these companies first listed on the ASX between 1998 and 2002. All faced relatively long development time frames and considerable uncertainty, and all required substantial capital in order to achieve their goals. All formed their business around at least one patentable, biologically based innovation. Unusually for a group of high-tech IPO companies of this age, all are still in business, although NSL Health and Network Ltd have exited the biotechnology sector.

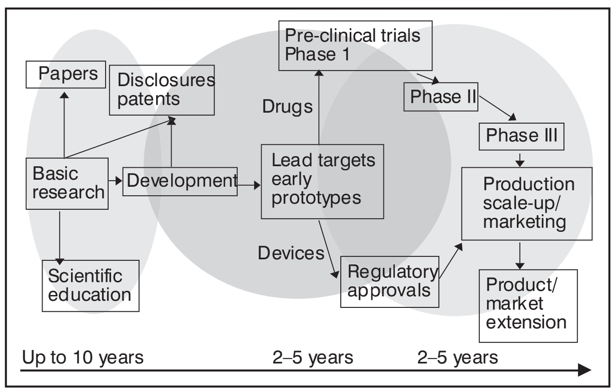
The analysis took two routes. First, we examined the document trail for each firm, from IPO prospectus to recent news reports and financial statements for the 2002–2003 financial year. Since biotechnology firms compete for funds with non-biotech companies on the ASX and with international firms, we compared the results for our sample with those from a random sample of 45 of the 422 ASX non-biotech IPOs during the same 1998–2002 period. The non-biotech sample was in the same annual proportion as the biotech IPOs, reducing concerns over the effects of time from IPO to the present. We also compared the biotech IPOs with US biotech IPOs over the same period. However, numbers only tell part of the story, so in the second phase of the study we conducted in-depth interviews with the managers leading the Australian biotech IPO companies.

The results shed some light on the challenges and successes in the sector and may provide guidance for biotechnology managers and directors. They may also help reshape perceptions and policies related to the industry to assist it to achieve its maximum potential.

2. The Technologies and Target Markets

All 24 firms in the study concentrate on human health, although one also works in the plant and animal industry. Fifteen were classified by primary activity as drug discovery/genomics, five diagnostics, three medical systems/devices and one primarily chemical. The firms operate in the middle area of the drug discovery or technology development process illustrated in Figure 5.1. In all but two cases the technologies originated in an academic institution, medical research institute, or CSIRO, represented by the circle on the left. The business models of the firms tended to involve adding value by further development of the technologies (the middle area), before passing them on to large pharmaceutical or technology firms (on the right), which take the technologies to the market. However, some companies stated that they would take selected non-pharmaceutical products to certain markets themselves.

Figure 5.1: Biotechnology development process



The concentration in human health may appear at odds with Australia's agricultural heritage and its substantial investment in animal and plant research through CSIRO, the Rural Development Corporations and other institutions. This focus was also apparent in other research projects that we conducted with samples of earlier-stage (pre-IPO) Australian biotechnology companies. A number of explanations for this imbalance has been proposed. One view is that, despite the history and the investment, Australian agricultural science is not strong enough to attract much investment. Another view is that intellectual property in agricultural biotechnology is very difficult to protect, as evidenced by Monsanto's experience with seed for genetically modified crops, and therefore agricultural-based firms are not of interest to investors. A third view is that returns from agricultural biotechnology have not been sufficiently high to attract investors, even if those returns are offered at lower risk. These and other explanations await testing in future research. It is worth pointing out that the more focused policies of the New Zealand government have led to the creation of a relatively large number of start-up firms in that country, including Grasslanz, EnCoate, BioPharming, and Bolus Technologies, in the agricultural biotechnology sector. These firms aim to capitalise on New Zealand's successful history in the dairy industry and other areas of agriculture.

3. Pre-IPO Financing

Financial support for the firms prior to IPO came from several directions. Universities, granting agencies and scientists made major contributions of time and money to the invention and early development of the technologies. After the technologies were transferred into the start-ups, the firms relied on a combination of government funding, venture capital, and research and development syndicates, as well as on continued university support in some instances. Although pre-IPO investments are not always clearly identified in a prospectus, we calculate that a total of just over $88 million was invested in the 24 firms before IPO. Five firms had secured venture capital investments averaging $6 million each, seven received investments of about $3 million each from founders and angels, R&D syndicates contributed $8.8 and $18 million respectively to two firms, and three other firms had investments of approximately $600 000 from industry partners. It is worthy of note that a single company made small investments in three of the firms, which used that money to develop both a technology and a business plan that could be taken to IPO. Various governments contributed another $8 million overall, in the form of grants.

> Financial support for the firms prior to IPO came from several directions. Universities, granting agencies and scientists … After the technologies were transferred into the start-ups, the firms relied on a combination of government funding, venture capital, and research and development syndicates, as well as on continued university support in some instances.

4. Management and Boards

One of the concerns with technology-based firms is that the technology and the scientists behind it will exercise too much influence over the direction of the business. This may be true at the time of company formation, but by IPO the boards of the young biotechs emphasised a business background, as illustrated in Table 5.1. The mixture of science and business backgrounds in the management and boards of the biotechnology IPO firms has changed somewhat since IPO, again as illustrated in Table 5.1. While boards have been relatively stable, there has been a trend towards somewhat smaller boards and a larger proportion of non-executive directors. The nearly 50 per cent turnover among CEOs may be surprising, given that the companies had been listed only for an average of 3.5 years by the end of 2003.

Understandably, the boards of these relatively small companies still exhibit a very strong Australian composition. However, in our discussions with managers it was obvious that the firms had been and were continuing to strengthen the international content of their boards by adding directors with overseas biotechnology or pharmaceutical experience.

None of the firms reported any significant difficulty in finding qualified and willing board members, and all were able to hire or contract all the scientific staff they could afford. There is, however, a reported shortage of experienced senior managers. In America and Europe, large pharmaceutical and consumer product firms are the breeding grounds for start-up biotech managers. There are no such large firms native to Australia, and the overseas firms' presence here is generally limited to a sales or manufacturing organisation that takes its lead from overseas. Thus there is relatively little opportunity for managers to gain experience at developing a major new product or managing a brand. Bringing experienced expatriate Australians home is difficult, given the difference in salaries and the improved but still unfavourable exchange rate, although local firms continue to try and, in some cases, succeed. (On the other hand, overseas firms also stalk good Australian managers, particularly those sent abroad to open an offshore office or establish a sales force.) Without doubt the passage of time will lead to a larger pool of experienced managers, but if the sector continues to expand at the pace of the last few years then the situation might not improve.

Table 5.1: Management at IPO and in 2003

Management category	Status at IPO	Status at 30/06/2002	Status at 31/12/2003
CEO			
– Science background	10	6	7
– Business background	7	8	11
– Combined science/business	3	8	5
– Looking for a CEO	4	2	1
– Number of CEOs replaced since IPO	–	6	11
Chair			
– Non-executive	15	13	15
– Executive	9	10	7
– Looking for a Chair	–	1	2
– Number of Chairs replaced since IPO	–	7	9
Directors (including chairs)			
– Total number	122	115	112
– Non-executive	75	74	84
– MDs and PhDs	50	47	50
– Women	2	4	6
Average percentage of directors at IPO still on the Board	–	67%	63%

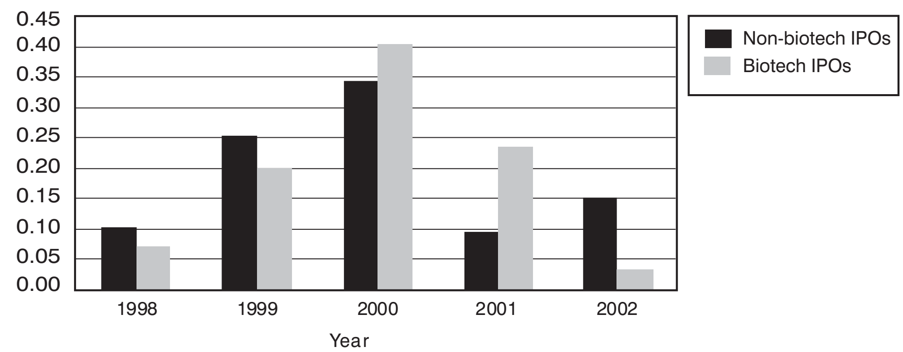
5. IPO Decision

Asked the reasons for doing an initial public offering when they did, all managers cited market conditions as the main motivation. Favourable market conditions and public interest in new technology created a readiness by ASX investors to embrace biotechnology IPOs. In almost every case, however, the decision was also motivated by the difficulty or even perceived impossibility of raising funds from venture capital firms or other private sources. Faced with a public market willing to fund new companies and venture capitalists unwilling to do so, managers took the best route available to raise the funds they needed. Many of these companies felt that going to the public markets was their only viable option for moving ahead. As one CEO put it, 'Our venture capital was the stock market'. In more than one instance the IPO decision was also pushed by shareholders looking for an exit strategy – venture capital firms, universities and sometimes inventors who saw the IPO as a chance to capture value and gain liquidity.

6. Characteristics of the IPOs

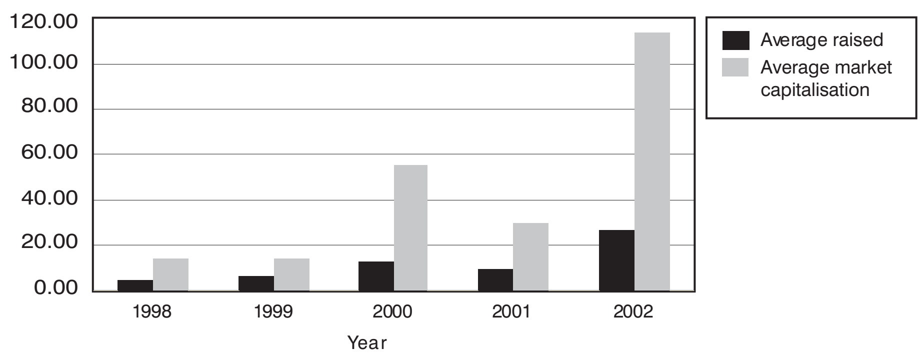
The wave of biotechnology IPOs exhibited a small lag compared to the overall pattern of IPOs on the ASX, as shown in Figure 5.2.

Figure 5.2: Proportion of the 1998–2002 IPOs by year



Both the amount raised and market capitalisation after IPO were related to the date of the IPO and reflect the general characteristics of the market at the time, as shown in Figure 5.3. The obvious outlier is 2002 when just one firm listed, but at a significant valuation.

Figure 5.3: Amount raised and market capitalisation by year



One of the common perceptions in the industry is that biotechnology firms went to IPO too soon in their development, driven by an inability to secure venture capital funding. While the scarcity of venture funding did encourage the IPOs, we found that the average age[2] of firms at IPO for Australian biotech companies was 6.5 years compared to 4.7 for the non-biotech sample firms and 5.9[3] for US biotechs.

Interestingly, we found that age was not a good predictor of firm performance either at IPO or after. Age at IPO was not significantly related to the market value of the firm at IPO, the amount raised, most recent six months' earnings, or share price performance from IPO to present. Even revenue at IPO was not significantly correlated to the amount raised.

Although they may have been older, Australian biotechs were significantly under-resourced compared to their American counterparts (see Table 5.2). They received neither large infusions of cash, nor large valuations at IPO. Although they compare favourably with other ASX IPOs, their value and funding are less than 10 per cent of those of the US firms. The obvious implication is that Australian firms have to manage differently and possibly compete in different ways to their US counterparts.

Table 5.2: Comparison of ASX biotechnology IPOs with samples of others

Characteristics at IPO	ASX biotech IPOs (A$ 000 000)	ASX non-biotech IPOs (A$ 000 000)	US biotech IPOs (US$ 000 000)
Amount raised	10.5	28.3 (13.4)*	85.0
Market capitalisation	39.2	69.1 (33.4)	375.1
per cent of the firm sold	31.7%	41.8%	22.7%

(Note: Values with two very large non-biotech IPOs removed)

7. Disclosures at IPO: What Did Firms Tell Investors

Biotechnology investment involves inherent risks, which are somewhat mitigated by strong intellectual property protection, value propositions and management teams. We assessed the position of the firms at IPO and what they told potential investors about their position and future. There was considerable variation in the information reported to investors in terms of both technology assessment and future spending.

Intellectual Property

Much of the value of biotechnology firms rests in the knowledge embedded in their patents, products and people. One indicator of a firm's ability to capture value from that knowledge is the patent portfolio that it holds or licenses in. Seventeen of the firms held or licensed existing patents while four firms had patents pending. For three firms there was no indication of existing or pending patents.

Business Models

The business models identified in the IPO prospectuses for these firms reflect both the small size of the firms and the significant resources needed to take a biotechnology product through regulatory approval to an end product. All firms with a major or minor emphasis on drug discovery and development had a strategy of adding value to initial discovery research and then licensing the technology to a large pharmaceutical partner. Only the six firms in diagnostic or device businesses planned to take their products all the way through to the market. Two others planned to in-license promising pharmaceuticals from other firms.

Prospectus Disclosures

In order to provide a return to shareholders, biotechnology firms must be able to:

- develop technology
- secure market acceptance and marketing capabilities for the technology
- capture the value of the technology through intellectual property rights.

For potential investors, assessing a firm's ability to achieve these is difficult. Australian biotechnology firms addressed this uncertainty to differing degrees in their prospectuses. Many of the firms employed outside specialists to assess their technologies, the market and value of the firm or of lead products, and the intellectual property position, as illustrated in Table 5.3. Sixteen provided an overall market and technology valuation report, and fourteen provided a dollar value for the firm or its lead product(s). Valuations reported ranged from A$25.2 million to A$90 million and averaged A$44.1 million. Except for one outlier at 6.4, the ratio of estimated valuation to IPO market capitalisation ranged from 0.52 to 2.07. Usually, but not always, firms that provided technology valuations also provided IPO reports. Seven firms provided technology reports by experts in the field, designed to provide the reader with more knowledge about the status of the technology. Three firms provided no outside assessments and two others provided only IP reports.

Table 5.3. Information provided in ASX biotech prospectuses

Information included In prospectus	Number of firms reporting (out of 24)
Technical audits and valuations	
Overall market and company valuation	16
(11 completed by the same consultant)	
Technology assessment	7
Intellectual property report	17
Revenue and spending projections	
Revenue	6
R&D spending	18
Net income	1

8. IPO Projections, Funding and Future Needs

Forecasting future revenue for a new biotechnology product is particularly challenging. The uncertainty around future revenues is apparent in the information provided to prospective investors. Twelve companies either had sales at IPO or projected reaching the market within two years, but only half of those gave actual forecasts of revenue. All firms had a much better handle on R&D spending, and 18 of 24 provided projected R&D spending for the first two years after IPO, projecting spending just under A$6 million on average.

Biotechnology firms tend to be built on the promise of undeveloped science and unproven technologies. This means that in most cases they must plan for several years of losses before becoming profitable, generating revenues either through the sale or licensing of their technologies or through actual product sales. An examination of funds raised relative to R&D spending for the first two years reveals that 15 of the 18 firms with R&D projections raised more than enough to cover R&D. Two firms raised about half of projected spend and one firm raised only 18 per cent. When operating expenses are added, two more firms drop below 99 per cent of projected expenses.[4] Thus six of the 18 firms reporting expenses would require positive earnings or an additional round of funding within two years to carry out the plans specified in their prospectuses. These firms are at higher risk than those with better coverage. Average share price increase for these firms was about 15 per cent lower than for the group of firms that reported more than two years of coverage. Interestingly, the five firms that did not report future spending included three of the top four firms in terms of share performance and this group significantly outperformed the rest.

9. What Has Happened Since IPO

The companies have definitely progressed since their IPOs, but are far from being economic powerhouses. On average they employed 33 people, had revenue of $5.6 million and a loss of $5.5 million in the 2002–2003 financial year.[5] The firms spent an average of almost $3.5 million per year on research and development – about 70 per cent of their average revenue. Since much of the R&D spending goes to organisations external to the firms, their employment impact is understated. By comparison, the ASX sample firms on average employed 162 people, had $35 million in revenue, and made $3.7 million in profits. Only three of these firms reported any R&D spending at all, and only one reported more than $250 000.

10. Business Models – Redefinition Based on Funding and Technology Success

The business models of the biotechnology firms have undergone a significant shift from IPO to present. At IPO, many firms had broad and somewhat vague value propositions. Companies typically cited developments in several areas with numerous projects at varying stages of their life cycles. Firms had also planned to raise additional funds in the future as they passed specific milestones. As time progressed, managers realised that they could not maintain all of the projects successfully, and by now there has been a marked sharpening of focus and trimming of projects. Most firms now have two or three main projects and a few others simmering on the back burner.

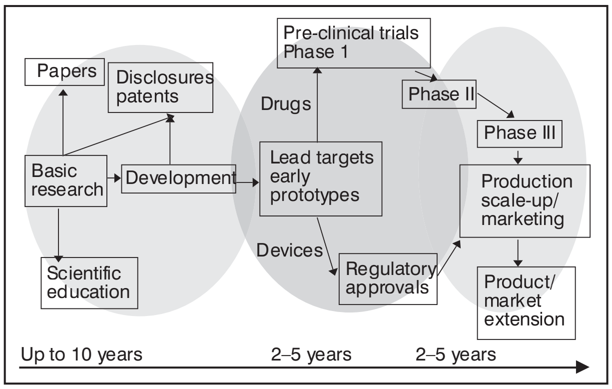
The inherently risky nature of early stage biotechnology development means that there will be technology failures. It was apparent that while managers recognised the risk, their planning did not always include adequate strategies for coping with failure.

The current funding drought has also been an incentive for many of these firms to redefine their business models. With cash reserves depleting and no easy way to raise more, managers have shifted their focus, moving revenue generation activities to the forefront. In some cases, this has meant providing services and products to other biotechnology firms. The products ranged from reagents to recombinant proteins and the services from manufacturing to consulting. In other cases, firms have generated revenue through early licensing or sale of their leading technologies. For many managers it was a necessary, but not the preferred, development path. The cost and time frames associated with human health markets, combined with the funding shortage, has led to a shift towards markets that can be entered more easily and quickly such as functional foods, nutraceuticals, over-the-counter drugs and animal health.

The inherently risky nature of early stage biotechnology development means that there will be technology failures. It was apparent that while managers recognised the risk, their planning did not always include adequate strategies for coping with failure. 'We planned [only] for success,' stated one manager. Technology failures caught many companies by surprise. The sample included several cases of such failures. The impact on the firms varied, depending on their technology portfolio and capital structure. Two companies were built on single technologies, and failures were therefore catastrophic. Both companies exited biotechnology and entered entirely new lines of business, employing the remaining capital in their firms to make the change. In other cases, the impacts of failure were less severe but the managers went through agonising periods redefining the company and its businesses.

Companies are also facing a completely different partnering and licensing environment today than they were a few years ago, as illustrated in Figure 5.4. Pharmaceutical companies are looking to acquire licenses to targets that have proven their worth in clinical trials, preferably Phase II. Since biotechnology companies have to take their products further, they are also looking for more advanced development targets, biotechnologies with proof of concept already proven.

Figure 5.4: The altered environment for biotechnology



11. Financial Performance since IPO

Between 1998 and 2002, Australian investors entrusted just over A$250 million to these biotech firms as they became public. Did they invest wisely? Although the shares of these firms will continue to rise and fall, one thing is clear: as investments, biotechnology IPOs do not deserve to be lumped in with dot-coms. The first observation is all of the ASX biotechnology IPO firms are still in business and independent, although one, Sirtex, was the subject of an acquisition attempt by an American firm and, as noted earlier, two firms have exited the biotechnology industry. By comparison, 1 of the 48 non-biotech IPOs have already been acquired, gone broke, or had trading of their shares suspended.

Following their initial public offerings, the shares of the 24 biotechs have risen or fallen in almost exactly the same proportion as those of all IPOs on the ASX:

Table 5.4: Changes in share price from IPO to 12 September 2003

Year	Total IPOs	Gainers	% Gainers	Losers	Even
2002–03	55	27	49.1%	26	2
2001–02	61	22	36.1%	38	1
2000–01	122	51	41.8%	69	2
1999–00	155	71	45.8%	84	0
1998–99	53	31	58.5%	20	2
TOTALS 1998–2003	**446**	**202**	45.3%	**237**	7
Biotech IPOs 1998 – 2002	24	11	45.8%	13	0
Random sample of non-biotech IPOs	45	16	35.6%	28	1

(Data sources: *Australian Financial Review, ASX)*

The big difference in share performance shows up in the extent of the rise or fall. An investor who bought $1000 worth of shares in each of the 24 biotech IPOs at listing would have owned, as of 12 September 2003, shares worth $61 061, an increase of more than 150 per cent. An investor in our matched set of 45 ASX non-biotech IPOs would now hold shares worth 7 per cent less than the amount invested, and an investor who put an equal amount into the All Ordinaries at the time of each biotech IPO would have gained just over 2 per cent. The 24 listed companies resemble a typical venture capital portfolio, from which some companies will go bust, most will be moderately successful, and a few will return 10 or 20 times the amount invested. This resemblance is not accidental; most of the 24 companies told us in interviews that they went public largely because they were unable to raise the funds they needed from other sources, including venture capital. Had they been seeking funds in a different phase of the market, these companies might well have become part of venture capital portfolios and remained there for some years until a trade sale or public listing took place.

Firms that offered no projections for revenue or expenses performed much better than average.

12. Shareholder Returns and Cash Flow Projections

Earlier we noted that firms raising less than two years' projected expenses would be at higher risk than those raising more. Examining shareholder returns reveals that the shareholders of those riskier firms have fared marginally worse on average than those investing in firms raising more (see Table 5.5). An interesting result was that the firms that offered no projections for revenue or expenses performed much better than average. Of five firms not reporting, three were huge successes with share price increases of 1220 per cent, 428 per cent and 305 per cent. The non-projecting firms far outpaced the others. Although the five firms did not offer financial projections, three of those did provide independent valuations of their firms, created using a discounted cash flow method.

Table 5.5: Shareholder returns and IPO cash flow projections

Category	Non-reporting	Raised < 2 years expenses	Raised > 2 years expenses
Number of firms	5	6	12
Number with positive shareholder returns	3	2	2
Average return	367.6%	–19.9%	–5.6%

The company reports indicate that in the 2002–2003 financial year just one of the 22 companies – Sirtex – was profitable. However, six others reduced their losses from the previous year. The other 15 lost more than in the previous year, suggesting that they are still in a relatively early phase of their development or are ramping up production. Four of the companies, although not yet profitable, reported their first sales to customers in the year just ended. Of those that were already making sales, only half showed increases in sales compared to the previous year, again indicating the early stage of the companies' development – and perhaps some market risk around their initial products.

Table 5.6: Revenue, expense, and earnings after tax for biotechnology IPOs*

	Average Revenue	Average Expenses	Average Loss after Tax
Full year ending 30 June 2002	6 149 591	10 450 955	–4 203 283
Half year ending 31 Dec. 2002	3 457 580	5 841 520	–1 713 088
Ratio half to full	0.56	0.56	0.41
Full year ending 30 June 2003	5 443 227	11 926 795	–5 474 739
Ratio 2003 to 2002	0.89	1.14	1.30

(Note: These figures exclude NSL Health and Network, which have exited the biotechnology sector.)

On the other hand, six of the companies reported no sales to customers during the year. This does not mean that these companies had no cash coming in – some received government research grants, and many earned interest on the money they had already raised, in addition to the cash-generating activities described earlier. (In fact, the category 'revenue from ordinary activities' in some of the company reports also included tax refunds, sale of plant and equipment, insurance settlements, and other inflows that are unlikely to be repeated in future years.) Interestingly, the market does not seem particularly concerned about the lack of sales – the shares of the six companies that have yet to make a sale have risen, on average, almost 500 per cent since IPO, and five of the six have successfully sold shares in the secondary market in 2003.

For many young companies, of course, cash is more important that profits. After adjusting the companies' expenses for non-cash items (depreciation and amortisation, for example), it appears that two firms – again Sirtex, and also Compumedics – are generating cash from operations. The others are burning cash to a greater or lesser extent, and must rely on savings and secondary raisings to supply the cash required to keep the business moving forward. Comparing these companies' cash burn rate to their cash supply as of the end of the year showed that the average company had, as of 1 July 2003, 20 months of cash left. Nine companies had less than one year's cash, six had between one and two years' supply, and five had more than two years' worth. Only seven of the companies had more cash at the end of this financial year than at the end of the previous financial year, but eight had more than at the mid-point of the financial year, suggesting the impact either of raising funds or of cutting expenses.

We tested the firms' ability to cover future expenses from cash plus investments using the following formula:

$$\text{Number of years' expense coverage} = \frac{(\text{Annualised revenue} + \text{cash} + \text{investments})}{\text{Annualised expenses}}$$

It is apparent from the results in Table 5.7 that the overall cash position of firms is a concern. At the end of the 2002–2003 financial year, nine firms had less than one year's cash left and another six had less than two years of cash, meaning that almost two-thirds of the firms had less than two years' cash available.

Table 5.7: Expense coverage for biotech IPO firms

Number of years' expense coverage	Number of firms as at 30 June 2003
Exited biotech	2
0–0.5	2
0.5–1	7
1–2	6
2–5	4
> 5	1
Cash flow positive	2

(Source: Company reports adjusted for non-cash items.)

Attempts to cut spending almost inevitably centre on scaling back research and development, the major expenditure for most of the young biotechs. As noted earlier, rather than reducing the depth of their research, these companies have tended to reduce the breadth. Compared to the very broad R&D programs spelled out in their prospectuses, the companies' current efforts are substantially more focused, partially because some of their pursuits reached dead ends, but primarily because of the need to focus their limited resources on their best opportunities.

Raising funds in the secondary market has become more popular as the market has improved. In calendar year 2003, 13 of the 22 biotech companies raised funds by selling additional shares, including sales sold when options were exercised. Ten companies made such offerings in the new financial year; importantly, these companies include eight of the nine whose cash reserves at the end of the previous financial year had dwindled to less than 12 months' supply.

13. Benefits for Australians: Wealth Created for Investors

For the pre-IPO investors and to a lesser extent, some inventors and universities, the IPOs created significant wealth. The IPOs raised $250 million but created a combined market capitalisation of $950 million. The $88 million of pre-IPO investment plus the biotechnology intellectual property injected into these firms was transformed into $700 million in new wealth. Since IPO, the combined market capitalisation for the biotech firms has grown by $250 million, just slightly greater than the total of $165 million raised in subsequent funding rounds plus $19 million in government grants received or promised. By comparison, the IPOs of the firms in the ASX non-biotech sample raised $ 1.3 billion and created a combined market capitalisation of $3.2 billion (with 56 per cent of funding and market capitalisation from just two firms). Since IPO, their market capitalisation has increased by just $226 million, almost $150 million less than the $374 million they received in follow-on investments. Their slight devaluation does not compare to that experienced by investors in US biotechs, who saw their combined market capitalisation cut from US$34 billion to US$18 billion.

14. Returns to Australia

What about returns for Australia as a nation? The economic future of developed countries depends to a great extent on knowledge-based industries. Australian governments at every level are betting heavily on the future of biotechnology as a means of increasing national and regional wealth. From this perspective the results are mixed. Biotechnology is not a panacea for unemployment. The biotechnology firms in our study currently employ about 33 people each, compared to 162 for firms from the broader ASX IPO sample. However, many biotechnology jobs are highly skilled in nature, and therefore well paid.

In addition, these firms support significant research expenditures. Leaving aside the two firms that have exited the biotech sector, the remaining 22 companies in the sample spent an average of $3.5 million on R&D in the 2002–2003 fiscal year. That level of spending represents an average 18 per cent of the market capitalisation of the firms. From another perspective, of the 16 companies that had sales revenue in the 2002–2003 financial year, five spent more than twice their revenue on R&D, while another four spent between one and two times their revenues, and six spent between 10 per cent and 100 per cent of revenues. Clearly, most of these young biotechs are still early-stage companies, whose cash-burning R&D engines will need frequent stoking. The dearth of industry-based research has been consistently identified as one of the major stumbling blocks of Australian innovation performance. The biotech firms are making a significant contribution to Australia's R&D capabilities and activity. The flip side is evident in the non-biotech sample firms, where the total research expenditure for all 45 companies in the latter half of 2002 totalled just $4 million, with all but $250 000 coming from one firm.

What about returns for Australia as a nation? … Australian governments at every level are betting heavily on the future of biotechnology as a means of increasing national and regional wealth. From this perspective the results are mixed.

15. View of the Australian Biotechnology Sector

The crash of biotechnology stocks, and the (incorrect) perception of their close association with information technology stocks, has meant that there is currently little opportunity for Australian biotechnology firms to raise money in the public markets. Finding additional funding is a concern for most of the senior managers we spoke to. The consensus was that there would be some reorganisation of the sector as firms run out of cash. However, the managers did feel that there were great opportunities in Australia in terms of the science. They also were unanimous that no firm could make it by focusing on the Australian market alone. To be truly successful, Australian biotechnology firms need to think globally, sourcing the best technologies and capabilities in the world, targeting large foreign markets, and partnering with international firms.

At IPO the companies we studied were 6.5 years old on average. Many of the companies in the group are now more than a decade old – and almost all are still not profitable. Moreover, two-thirds of the firms lost more money, and ended up with less cash, last year than the year before, suggesting that they might not yet have turned the corner towards self-sufficiency. While not unusual in the biotech sector, this situation creates challenges for the firms and their investors. Firms continue to focus on revenue generation but, with the share market once again interested in the biotech sector, they are well advised to raise more money while they can. The structure of the sector appears to support consolidation through acquisition by larger firms, suggesting that Australian biotechs that want to retain their identity must quickly turn their attention to issues of cash flow, profitability and eventually scale.

Clearly, a biotechnology company whose R&D results fall behind expectations could find itself in a downward spiral – low revenue, little cash, and no way to reduce spending except by cutting R&D, which might accelerate the spiral. If the company's share price has fallen significantly, then raising additional funds may require selling a large number of shares, if indeed investors can be found at all. This scenario has raised questions about the possibility of consolidation across the sector on the basis of mergers and acquisitions.

The basis on which consolidation would take place is not immediately obvious. While some of the 22 companies are targeting the same diseases (obesity, psoriasis, and various cancers, for example), their approaches to these diseases differ substantially. It is not clear, therefore, that there are many scientific synergies to be attained. From an operational perspective, none of the companies has developed a sales or distribution network that could readily be shared; indeed, the companies often rely on third parties to sell and distribute their products, especially in overseas markets. Consolidation might take place on the basis of superior management – firms with better managers could conceivably buy up firms that were less well managed, and achieve improved results through the application of superior managerial techniques. However, the senior managers we spoke to unanimously felt that they already had plenty to do running their existing firms, without taking on the additional responsibility of fixing up another organisation.

The structure of the sector appears to support consolidation through acquisition by larger firms, suggesting that Australian biotechs that want to retain their identity must quickly turn their attention to issues of cash flow, profitability and eventually scale.

Another avenue of consolidation would be with firms outside the biotechnology sector. Although such combinations are often viewed with scepticism – the stereotypical image is of a mining company, already transformed into a dot-com, now undergoing a second reincarnation as a biotech – there could be sensible combinations of companies that have more opportunities than cash with those in the opposite situation. Naturally, the senior management and boards of the combining organisations would have to be consolidated and refined in order to suit the needs of the resulting company. The outcome could be positive for shareholders as well as for the future of the biotech sector as a whole. Recent examples of such combinations, not involving companies in the sample, are Imugene (formerly Vostech Limited), Benitec (formerly Queensland Opals), and Australian Cancer Technology (formerly Exodus Minerals).

Perhaps a more likely outcome is vertical consolidation – acquisition by a larger 'upstream' company, for example a large pharmaceutical, and perhaps one with which the biotech has an established research or marketing relationship. Many Australian biotechs have such alliances already, and the knowledge shared in the course of working together could smooth the path to consolidation. The combined market capitalisation of the 22 companies as at 12 September was less than $2 billion, making the average market cap, even given the recent share market increase, less than $90 million – a small amount for a large organisation to pay. Although much concern has been expressed about the 'loss' of Australian companies to overseas ownership, vertical consolidation may, in some cases, represent the best outcome for shareholders, employees and the commercialisation of Australian intellectual property. Most of these companies are too small to fund their journey through the entire regulatory approval process, much less the cost of establishing production and distribution systems needed to complete the commercialisation process.

16. Role of Government

Managers were relatively uniform in their split views of government. All liked receiving grants and felt that the grants had contributed to their success and image. In many cases, grants had been instrumental in securing additional industry funding. On the other hand, all managers stated that government policies and programs should not drive strategy. Business opportunities had to stand on their own merit. Grants might make implementation easier but should not change the initial decision. They also wanted as little interference in their ongoing operations as possible.

The firms also received significant government support before and after IPO. Many of the firms were supported and protected within universities for up to several years before moving to their own premises. Seven of the companies have received START grants totalling $13.7 million, ranging from $245 000 to $4.9 million. Other programs, for example Biotechnology Innovation Fund (BIF) grants, have been used less frequently and with lower funding rates. The lower utilisation of the BIF program reflects the stage of development of these firms. For many, the proof of concept studies typically supported by BIF were completed prior to the introduction of the program. The amounts needed to complete the development were much larger. All firms took advantage of the R&D tax credit system.

17. Recommendations

Our research findings and analysis lead us to a set of recommendations for the Australian Stock Exchange, universities and other research organisations, biotechnology managers, and governments. In some cases these are recommendations *not* to take a given action that has been proposed in the press or elsewhere. Note that the recommendations are based on the subset of the biotechnology population that we studied. Further analysis would be required to extend the recommendations to the entire population. These recommendations reflect out personal opinions and not those of the ASX, AGSM or any other organisation.

17.1 ASX

Public listing was a critical step in the development of these companies. That step had implications both for the companies and for their investors.

- We found no justification for creating a separate set of listing requirements for biotechnology companies. The earlier attempt to create a ‘second board’ for start-up companies did not succeed, and the environment has not changed in a way that would encourage trying again.
- Do not exempt biotechnology companies from the continuous disclosure regime required of all companies listed on the ASX. We found no evidence that such disclosure puts Australian firms at a disadvantage compared to competitors overseas, and continuous disclosure is an important part of maintaining investor confidence.
- We believe that every prospectus for a biotechnology IPO should contain an assessment of the underlying science by an independent expert. However, we would not make this mandatory. The absence of an assessment of the science, IP, or patent portfolio will send a signal to prospective investors. In a similar vein

We found no justification for creating a separate set of listing requirements for biotechnology companies. The earlier attempt to create a ‘second board’ for start-up companies did not succeed, and the environment has not changed in a way that would encourage trying again.

we would not recommend the licensing or other regulation of experts who assess the science, IP, or patent portfolio of companies doing an IPO. At the present time, there is not a professional organisation in the biotechnology sector whose membership requirements would guarantee the qualifications of its members to carry out such assessments, and creating and enforcing new licensing requirements would be a complicated task. In many cases, prospective investors will be able to use the reputations of the firms to which these experts belong as proxies for the quality of the experts themselves.

- Consider changing the regulations for post-IPO funding to encourage private investments in public equity. Such changes would extend to all ASX listed firms, not just biotechs, and might include the ability to offer downside protection, reset and anti-dilution provisions, board seats, convertible securities, and so on.

One very large issue for universities and research institutions was the widespread naivety of most scientists concerning the commercialisation process and the broader issue of what is required to develop, fund and manage a business. This puts many start-ups at risk since scientists are frequently in charge of the business at the earliest stage of its life.

17.2 Universities and other Research Institutions

Several issues related to relationships between research institutions and private companies were raised during the interviews. Beyond the often-cited concerns over slow response times, different time horizons, and valuation, several other issues warrant the following recommendations.

- One very large issue for universities and research institutions was the widespread naivety of most scientists concerning the commercialisation process and the broader issue of what is required to develop, fund and manage a business. This puts many start-ups at risk since scientists are frequently in charge of the business at the earliest stage of its life. We first recommend implementing mechanisms to educate and instil in scientists an understanding of the importance of developing the business model and target markets in addition to the technology plan. However, it is also important to involve professional managers in the project as soon as possible. Developing a network of qualified managers and directors who may be brought in on a project basis is an important first step.
- Clarify goals, strategies, policies and procedures related to the ownership of the IP created by employees and students. Publicise these widely within the institution and to outside stakeholders as well.
- Create a single point of contact for those outside the organisation with regard to IP commercialisation. The lack of such a contact, and the concomitant run-around experienced by companies, has been a common criticism.
- Establish a decision-making process to determine whether a piece of IP should be commercialised, and if so whether licensing, spinning out or another form of commercialisation should be pursued. For spin-outs, consider bringing in outside management at an early stage of the company's development.
- Act with a visible sense of urgency, in the knowledge that innovations in biotechnology face market risks as well as technology risks.
- Consider options for raising private capital to support early-stage research. The Westscheme Enterprise Fund at Murdoch University in Western Australia, and Uniseed at the universities of Melbourne and Queensland, are interesting models that warrant careful study by other universities and research institutes.

17.3 Biotechnology Managers

There is a relative scarcity of individuals in Australia with significant professional biotechnology management experience. Attracting managers from other markets will be important to the future of the sector. From our interviews with the managers of the biotechnology IPO companies a few common management themes were evident.

- Focus is critical in any small organisation. Managers should be careful to focus limited resources on a few key projects where the organisation has definite advantages.
- Although focus is essential, it is risky to concentrate on a single product and one market. Creating a small portfolio of projects, balanced with regard to risk and reward, provides some flexibility.
- Have a contingency plan. It is extremely unlikely that everything will work out exactly as expected. Understand the implications of failure in any area.
- In the current environment, raise money whenever possible at reasonable cost, and bring in revenue sooner rather than later.
- Plan your exit strategy – IPO, trade sale, merger and so on – from the beginning. Different planned exits require different strategic and tactical plans.
- Surround yourself with the best possible people for the board of directors, management and scientific staff. If it is not possible to hire these people full time, consider contracting with them rather than settling for second best.

17.4 Governments

Public policy and government bodies can play different roles in the development of young biotechnology companies. Managers stated that they absolutely did not believe that government programs should change corporate direction, but that their role was to support that direction. This included:

- Creating an environment conducive to new biotechnology development:
  - Support for fundamental research – Since biotechnologies generally originate in research institutions as a result of basic research, continued support for fundamental research is vital to the creation of new biotechnologies and the development of scientists needed to turn those technologies into commercial opportunities.
  - Simplification of regulations and coordination with those of major markets – ensuring that Australian standards are recognised throughout the world. This is not the case at this time.
- Provision of financial and other support:
  - Tax regulations – The research tax credit was widely applauded by managers. The changes to investment tax rules are also seen as a positive step. Concerns were raised over treatment of options.
  - Grants and loans – START, BIF and other programs are well regarded in the biotechnology sector and have provided a lifeline to more than one struggling company. It is important to maintain a consistent policy approach to these programs so that companies can plan for the long term.

There is a relative scarcity of individuals in Australia with significant professional biotechnology management experience. Attracting managers from other markets will be important to the future of the sector.

– Services – The companies generally found Austrade useful as a means of making contact with potential customers or partners. They also found the coordinated Australian approach for events such as the annual Bio conference of benefit.

- Channelling biotechnology industry development – Most managers did not feel that it was the role of governments to pick winning and losing sub-sectors in the sector. This has not been an area that governments have excelled in the past.

A number of other recommendations arose from the study.

- Specify program and policy goals that are truly meaningful, rather than just easy to measure.
- Include commercialisation potential and plans in the criteria for START, BIF and other grants at the national and state level. These grants have made a difference to the companies in our study.
- Find ways to channel the energy that is currently being dissipated in rivalries between the states into creating advantages for Australia as a whole.
- Develop and maintain consistent, long-term policies and programs that will add value during the lengthy period from invention to market.

Managers stated that they absolutely did not believe that government programs should change corporate direction, but that their role was to support that direction. This included creating an environment conducive to new biotechnology development.

18. Conclusion

There is little doubt that the comparatively easy access to cash until 2002 resulted in a number of firms becoming public before they were perfectly ready, either from a corporate or a technology perspective. Equally, there are firms successfully meeting customer needs today that might not have survived under other market conditions. Their IPOs provided the resources that managers needed to advance for both the technologies and the business models. For some firms, going public was a major, and somewhat traumatic, event. Systems, processes and procedures all had to change, and more importantly senior managers had to change as well. The transparency and equity required of a public firm did not always come easily. For other firms, those that we would describe as having been 'born public', the IPO was an exciting but not difficult event, representing the achievement of another expected milestone in the corporate plan. These firms had intended from the start to become public, and had adopted the systems and behaviours of a public company very early on.

The jury is still out on how many of the 1998–2002 IPO firms will survive to become significant industry players. As we look around the industry we find firms that have exited, others that have changed their business models in response to technological delays or failures, and some that have never veered from their initial plan, thanks to a combination of technological success, good partnerships, good management and at least a bit of good luck.

Endnotes

1 The suport of the Australian Stock Exchange, the Australian Business Foundation and the AGSM is gratefully acknowledged, as is the assistance of the senior managers who participated in interviews. The views and opinions expressed herein are those of the authors, not necessarliy those of the supporting institutions or of those interviewed.

2 Age was time from date of incorporation to date of IPO.

3 Approximate age as US incorporation dates provided on the year of incorporation.

4 Note that only 11 of the 18 firms reporting R&D spending also projected operating expenditures, but our estimates were that only one additional firm would drop below 99 per cent.

5 These figures exclude NSL Health and Network, which have exited the biotechnology sector.

6. Optimising Tertiary Education for Innovating Australia

Gavin Moodie

1. Introduction

This chapter considers how Australian tertiary education may be optimised to contribute to national innovation. It argues that the concentration of Australia's innovation policy on research, and particularly on research in universities, has skewed policy and effort away from its potential to increase productivity. Furthermore, concentrating research to maximise knowledge production has to be balanced by its dispersion to promote knowledge diffusion. Just as importantly, it is necessary to develop the interaction of research units and enterprises, suppliers, consultants, training institutions and associated bodies that comprise the innovation system or cluster in each field. While some clusters seem to develop serendipitously, although over a long time, the process may be strengthened and quickened by coordination. The chapter closes by canvassing coordinating mechanisms.

The concentration of Australia's innovation policy on research, and particularly on research in universities, has skewed policy and effort away from its potential to increase productivity. Concentrating research to maximise knowledge production has to be balanced by its dispersion to promote knowledge diffusion.

2. Objectives for Higher Education and Vocational Education and Training

There is no national policy for tertiary education: policy is set and normally considered separately for higher education and vocational education and training. Contributing to national innovation is only one of several purposes of Australian higher education. In its *Higher Education Report for the 2003 to 2005 Triennium* the Australian Department of Education, Science and Training (2003, p. 1) says that the Government regards higher education as contributing to the fulfilment of human and social potential and to the advancement of knowledge and social and economic progress. Of the five purposes of higher education stated by the department, three are to develop individuals, one is to advance knowledge and understanding and one is to aid the application of knowledge and understanding to the benefit of the economy and society. The department states the Government's objectives somewhat more precisely:

> The overarching objectives of the Government's policies for higher education are to:
>
> - expand opportunity;
> - assure quality;
> - improve universities' responsiveness to varying student needs and industry requirements;
> - advance the knowledge base and university contributions to national innovation; and
> - ensure public accountability for the cost-effective use of public resources.
>
> (Department of Education, Science and Training 2003, p. 1)

These objectives are relatively recent, having been first stated in 1999 when the Department first published its annual report on funding and other developments for the forthcoming triennium in its current form. They were somewhat restated in the Commonwealth's *Higher Education Support Act 2003* passed by Parliament late in the year. One of the four objects of the Act is '(c) to strengthen Australia's knowledge base, and enhance the contribution of Australia's research capabilities to national economic development, international competitiveness and the attainment of social goals'. Contributing to national innovation is therefore not the dominant or even always explicit Government objective for higher education.

The Australian National Training Authority specifies four objectives for vocational education and training in its *National Strategy for Vocational Education and Training 2004–2010:*

> 1. Industry will have a highly skilled workforce to support strong performance in the global economy.
> 2. Employers and individuals will be at the centre of vocational education and training.
> 3. Communities and regions will be strengthened economically and socially through learning and employment.
> 4. Indigenous Australians will have skills for viable jobs and their learning culture will be shared.
>
> (ANTA 2003a, p. 1)

Innovation appears in one of 12 strategies, contributing to the first goal of training industry's workforce:

> 6. Enable training providers and brokers to partner with industry to drive innovation.
>
> - Research and development generates new knowledge and skills, and new ways to apply them.
> - Training drives innovation in the workplace.
> - Registered training organisations and brokers improve the performance of businesses through working with supply chains, skill eco-systems, industry clusters, research centres and global networks.
>
> (ANTA 2003a, p. 9)

ANTA complains that Australian innovation policy concentrates on 'high-end' R&D, leaving out vocational education and training. Ferrier, Trood and Whittingham report that vocational education and training has been involved only marginally if at all in Australia's cooperative research centres, which they say are a small but crucial element in the national innovation system.

ANTA (2003b, p. 2) complains that Australian innovation policy concentrates on 'high-end' R&D, leaving out vocational education and training. Ferrier, Trood and Whittingham (2003, p. 16) report that vocational education and training has been involved only marginally if at all in Australia's cooperative research centres, which they say are a small but crucial element in the national innovation system in their strong commitment to applied research and to the implementation and/or commercialisation of research. However, ANTA (2003b, p. 6) acknowledges that vocational education and training is still at the early stages of engaging with the issues and the national innovation system. It is therefore worth considering how one might optimise Australian tertiary education to contribute to national innovation and assess the extent to which this may be compatible with other objectives for the sector.

3. Innovation Is Mainly About Improving General Productivity, Not University Research

Australian public policy has had an early if initially faltering interest in innovation. Interest was first stimulated by Barry Jones, a sometime Commonwealth minister for science, who first published his influential *Sleepers, Wake!: Technology and the Future of Work* in 1982. This book, which had its fourth edition in 1995, did much to promote thinking about the implications of the knowledge economy for Australia. By 1987 Australian public policy on innovation was still rudimentary, fragmented and ineffectual. This is illustrated by Australia's mishandling of the proposal of the Japanese Ministry for International Trade and Industry to establish in Australia a multi-function polis (MFP). The MFP was to be a high-tech manufacturing and residential development, but Australia failed to take advantage of the opportunity through a lack of vision (Baines 2000) and 'political incompetence, self-seeking and cupidity' (Sorensen 1998).

Innovation is a much broader concept than research and development (R&D), although the outcomes of R&D are among its most powerful expressions.

By the early 1990s innovation had become a political slogan with the then prime minister Bob Hawke's vision of establishing Australia as a 'clever country'. However, by the end of the decade the Business Council of Australia, which is an association of the chief executives of most of Australia's biggest companies, was concerned that Australia has allowed its commitment to innovation to slip. Its solution was to engage the Commonwealth Government in mounting an innovation summit in February 2000.

The background paper for the innovation summit prepared by the Department of Industry, Science and Resources defined innovation as 'the process that incorporates knowledge into economic activity'. It elaborated:

> In common use innovation denotes both the process of transformation of an idea into a marketable product or service and the resultant new product, process or service. Historically, it encompasses evolutions in technology from the industrial revolution to the current 'information age'. Practically it is about change within individual firms and organisations. From the perspective of government, it is about change in the way people live and work and build on the foundation of the country's knowledge base and national prosperity.
>
> In short, innovation is about putting ideas to work. It is a process by which firms, industry and governments add value through successful exploitation of a new idea for the benefit of a part or whole of business, industry or the nation. It spans a range of ideas-based improvement processes, including technological change, and improvements in organisational, financial and commercial activities.
>
> Innovation covers 'the million little things' which improve the operation of firms or other institutions … It is a much broader concept than research and development (R&D), although the outcomes of R&D are among its most powerful expressions.
>
> Innovation is also about the exploitation of know-how – ideas acquired from a broad range of sources. Technology transfer and technology acquisition, its adoption and adaptation, frequently prove to be a faster way of acquiring know-how than through R&D. Know-how about organisational and other

commercially relevant innovation activities is likely to be acquired, through experience rather than research.

(Department of Industry, Science and Resources 1999, p. 9)

The Department's position is supported by Lundvall and Borrás (1997, p. 133) who observe that 'Incremental technical innovation based on learning, diffusion of technology and organisational change are certainly more important for the performance of any single national or regional economy than major innovations'.

Notwithstanding the insistence in the innovation background paper that innovation is not just about research and development, the recommendations in the final report of the innovation summit implementation group concentrated heavily on research and development. Of the summit's key recommendations costed by the group, 78 per cent of additional expenditure was recommended on research and development – 60 per cent on increased funding for research in higher education and 18 per cent to support industry research and development through increased tax concessions. The Government's response *Backing Australia's Ability – An Innovation Action Plan for the Future* concentrated even more heavily on research and development, almost all in higher education institutions. Of the $2.8 billion committed over five years, 91 per cent was for higher education, 4 per cent for R&D tax concessions and 5 per cent to compensate somewhat for the transfer of Commonwealth funding from public to private schools (Commonwealth of Australia 2001).

Higher education's capture of innovation policy was complete in May 2003 when the Minister for Education, Science and Training Dr Brendan Nelson (2003) issued *Our Universities: Backing Australia's Future.* He announced that 'A comprehensive evaluation of the effectiveness of the Knowledge and Innovation reforms' would consider only the operation of the main university research block grant schemes:

> … to ensure that the policy framework for Australia's competitive research funding is effective. This evaluation will focus on the operation of the Institutional Grants Scheme, Research Infrastructure Block Grants and the Research Training Scheme. In particular, it will assess the validity of current research performance indicators, their weightings in the performance formula, their effect on particular disciplines, universities and student groups, and the effectiveness and impact of the current transition arrangements.

(Nelson 2003, p. 33)

Committing almost all of the Commonwealth's innovation effort to higher education research fails to redress what seems to be a structural problem in Australia's national innovation system. We note from the Table 6.1 that while Australian governments provide 17 per cent more of the country's funding for research and development than the average for members of the OECD, Australian business contributes 18 per cent less than the OECD average. Australian higher education does 10 per cent more of the country's research and development than the OECD average, but Australian business does 23 per cent less than the OECD average. As a consequence, Australia has an extraordinary 40.7 higher education researchers per 10 000 members of the labour force, 2.5 times the OECD average. Of the other OECD countries only Finland (41.9 higher education researchers

Incremental technical innovation based on learning, diffusion of technology and organisational change are certainly more important for the performance of any single national or regional economy than major innovations.

per 10 000 workers) exceeds Australia and only Sweden (35.5) otherwise comes close. Australian business researchers are less than half the OECD average representation per 10 000 workers and are growing slower than the OECD average.

It seems that this is not entirely a failure of business. Australian governments' direct investment in business research and development is 4.6 less than the OECD average, and its indirect investment (including tax expenditures) is almost three times less the OECD average.

Table 6.1: R&D by business and higher education, Australia and selected OECD comparators, 2001

Measure	Australia	Canada	EU	OECD	UK	US
R&D expenditure as % of GDP	1.53	1.94	1.93	2.33	1.90	2.82
% R&D funds from government	46	31	35	29	30	27
% R&D funding from business	46	42	56	64	46	68
% R&D done by higher ed.	27	30	21	17	21	14
% R&D done by business	47	57	64	70	67	74
Higher ed. researchers per 10 000 workers	40.7	21.1	18.3	16.5	17.0	13.2
Business researchers per 10 000 workers	1.7	3.3	2.9	4.1	3.2	6.9
Growth of business researchers 1991–2001	2.09	6.41	2.91	3.62	1.54	3.27
Direct govt funding of business R&D as % of GDP	0.03	0.04	0.10	0.14	0.13	0.25
% of business R&D financed by government	3	4	8	8	10	11

(Source: OECD (2003), OECD (2002) figure 3.8 p. 115, figure 310, p. 117)

While there isn't necessarily any virtue in being at or above the OECD average on every indicator, being so skewed from OECD averages in the higher education and business research and development sectors raises questions for Australia. And it suggests that if, possibly for very good reasons, Australia continues to concentrate its research and development so heavily in universities, that special measures may be desirable to ensure that at least some of this effort is devoted to business' direct interests.

4. Selectivity, Scale, Concentration and Diffusion

Research funding is allocated selectively when choices are made between priorities or between researchers, but this does not necessarily concentrate resources in larger groups. Research funding may be more selectively allocated to active or productive researchers, but they may still work alone or in very small groups, or be widely dispersed among departments or institutions. Selectivity is considered desirable in research funding because less benefit is obtained by allocating resources to research that is less productive, of lower quality or to areas that are less important. The extraordinarily high number of higher education researchers per 10 000 workers in Australia compared with almost every other OECD country may very well be an argument for greater selectivity in allocating research resources (presumably in this case mostly time), but it is not necessarily an argument for greater concentration of research.

The term 'critical mass' is used to argue for several quite different outcomes. Its original meaning is in physics: the minimum amount of fissile material needed to maintain a nuclear chain reaction. By analogy it may be extended to the organisation of research as the threshold value for size (Evidence Ltd 2003a, p. 21) – the minimum size of a research unit to maintain a viable or good research program. Johnson (1994, p. 34) concludes that there is a threshold effect in many fields of the physical sciences below which the amount or quality of the research performance is reduced. He estimates the threshold at from three to five academic researchers plus postdoctoral fellows, postgraduate students and technical staff. Johnson (1994, p. 31) further reports evidence 'that the optimal size of a research group is about six fully qualified scientists working in the same problem area with perhaps another dozen support staff, graduate students and postdoctoral fellows … [and] as many foreign visitors as can be accommodated.'

While the minimum size of a successful research group may be quite small and the optimal size not much bigger, there may nevertheless be a scale effect. Larger research groups may be more successful or productive per researcher than smaller research groups, and one might expect that this scale effect plateaus or even becomes negative for groups larger and much larger than the optimal size. Evidence Ltd (2003b) tested the existence of a scale effect by examining data from the United Kingdom's research assessment exercise for 2001. Evidence Ltd (2003a, p. 22) notes that the unit of analysis 'is therefore not necessarily an academic department but is the group of staff submitted by a university to an RAE Unit of Assessment. These will usually be from one academic resource centre (department or school) but they may include cognate researchers from other schools and one school may be split into two or more units of assessment'.

Evidence Ltd (2003a, p. 23) found that big units on average perform more effectively in research than small units, but there is a great variation in the performance of small units. Many small units perform worse than large units, but some perform at a standard comparable with the largest. This pattern produced a statistically significant correlation between unit size and research income per full-time equivalent (fte) staff, PhD awards per fte staff, publication output per full-time equivelant staff and research performance or impact measured by average citations per paper (Evidence Ltd 2003a, p. 23). However, Evidence Ltd (2003b, p. 63) reports a very large amount of residual variance even where there is a strong correlation, indicating many exceptions to the otherwise strong pattern.

Evidence Ltd found this broad pattern across a wide range of disciplines not only in the sciences but also in the arts and humanities. Evidence Ltd (2003a, p. 23) concludes that 'there are size factors associated with research performance and they evidently occur across many disciplines but causation, correlation or consequence cannot be determined at this stage.' This is because 'small units that become good at research acquire the resources to become large units. Conversely, large units that do badly at research lose resources and decline in size as well' (Evidence Ltd, 2003a, p. 24).

Johnson (1994) concludes that there is a threshold effect in many fields of the physical sciences below which the amount or quality of the research performance is reduced. He estimates the threshold at from three to five academic researchers plus postdoctoral fellows, postgraduate students and technical staff.

Evidence Ltd cites several earlier studies which found no clear evidence that unit size contributes to research achievement:

> Johnston notably comments that 'the widespread introduction of policies of resource concentration around the world are found to have been based on little examined assumptions and in operation to be at times counter-productive'. Cohen argued that the size of groups and their productivity simply increased proportionally and that there was no reliable evidence for the existence of a size or a range of sizes for research group that maximized output per unit of size. Seglen found no correlation between group size and productivity for Norwegian microbiologists. Rey-Rocha similarly concluded that team size among Spanish geologists did not appear to be as important for scientific productivity as the status of team members.
>
> (Evidence Ltd 2003b, p. 50)

Concentrating research resources in units of appropriate size and of the highest quality may maximise research productivity and quality on the criteria normally used to assess research performance, but it may reduce the community's benefit from research.

Evidence Ltd's finding of a scale effect for research may reflect the particular dynamics of the United Kingdom's research assessment exercise – its reward for a particular construction of research establishing path dependence (Geuna 1999, p. 171) or its construction of data that generates a scale effect. Alternatively, it may reflect the particular way the research assessment exercise constructs units of assessment, which don't necessarily correspond with actual research teams. Evidence Ltd (2003a, p. 22) notes that 'research units may be teams, laboratories, departments, schools or institutions. Because these different kinds of units may bring research together in different ways their scale relationship with research performance should be studied separately. For example, a team is made up of various numbers of individuals, a department consists of individuals in one or more teams and a university is home to many people in a smaller or larger number of departments. If we considered scale factors solely in relation to full-time equivalent staff across these different organisational layers then we would be obscuring essential structural information.'

If there were a general scale effect for research it would be an argument for concentrating research resources until each research unit were of the optimum size. But notwithstanding a common misapprehension, a scale effect for research would not be an argument for concentrating research by institution. There is little evidence of an economy of scope in research production – that a research team in one field benefits by being organisationally linked to teams in other fields, or even that research benefits from being produced jointly with teaching (Geuna 1999, p. 27). Research units of appropriate size and great quality may be located within universities which do not have many other such units. Some 54 units with the highest ratings of 5 or 5* in the United Kingdom's 2001 research assessment exercise were in institutions with three or fewer units rated so highly (HERO 2001). Conversely, universities that have numerous research units of appropriate size and high quality also support research units of indifferent quality and sub-optimal size.

Concentrating research resources in units of appropriate size and of the highest quality may maximise research productivity and quality on the criteria normally used to assess research performance, but it may reduce the community's benefit from research. This is because research has to be incorporated in the productive process to generate economic benefits. Lundvall and Borrás (1997, p. 154) argue that knowledge production at universities needs to be integrated more closely with the innovation process, since as Lundvall (1992, pp. 8–9) had earlier observed, innovation blurs the conceptually distinct but in practice continuous stages of invention, innovation and diffusion. Concentrating research expertise distant from their sites of potential use may inhibit the diffusion of research as quickly and as thoroughly as desirable. This is supported by Moussouris (1998, pp. 93–4) who argues that there is too much concentration on research 'breakthroughs' and too little attention to the importance of research diffusion in generating economic development.

> While participants in the new 'competitiveness debate' generally acknowledged the contribution of *elite* models of higher education to sustain the R&D that underlays technological innovation – eg the MIT or Stanford exemplars of a 'world class' research university fueling the rise of whole new industries and high-tech districts – a new research stream emerging at this time also pointed out that this elite model appears incomplete from an economic development perspective.
>
> Indeed, a major problem associated with the concentrated human capital investments that characterise this 'R&D-intensive' model is that overall it fails to acknowledge the import of diffusing skills broadly throughout the workforce in order to generate the incremental improvements in technologies, products, and processes which generally occur 'downstream' of the initial breakthrough-stage of an industry's development. As cross-national research went on to explore to what extent the broad-based, *diffusion-oriented* education/training policies of Europe and Japan support the flexible, 'high-performance' production methods that facilitate continuous adaptation to both economic and technical change, concomitant efforts to pinpoint US workforce skills 'deficits' focussed not on at the top end of the occupational pyramid but at various points along the middle to bottom end.

(Moussouris 1998, pp. 93–4.
Emphases in the original; references omitted.)

Moussouris argues that there is too much concentration on research 'breakthroughs' and too little attention to the importance of research diffusion in generating economic development.

As Salter and Martin (2001, p. 512) observe paraphrasing the OECD, 'knowledge and information abound, it is the capacity to use them in meaningful ways that is in scarce supply. Often this *capacity* is expensive to acquire and maintain' (emphasis in the original). Rosenfeld (1998, p. 4) argues that in the United States 'community colleges are particularly helpful to small and midsized enterprises, since they are better positioned to reach them than universities, consultants, and service agencies, many of which prefer not to bother with "know-how" needs that may not be technologically challenging or of a scale that can be sufficiently profitable'. Part of the explanation for the high productivity of much of Australian agriculture may be the broad diffusion of research and innovation through the applied research laboratories, demonstration farms and extension, and outreach activities of state departments of agriculture. In contrast there is no comparable applied research laboratories and diffusion, demonstration and outreach for secondary industries in which Australia's performance has generally been much weaker.

Clusters

An important institution for diffusing research and innovation is clusters of 'interconnected companies, suppliers, service providers and associated institutions in a particular field' (Porter and Ketels 2003, p. 19).

> Increasing productivity through more sophisticated ways of competing depends on parallel changes in the microeconomic business environment. The business environment can be understood in terms of four interrelated areas: the quality of factor (input) conditions, the context for firm strategy and rivalry, the quality of local demand conditions, and the presence of related and supporting industries. Because of their graphical representation the four areas have collectively been referred to as the 'diamond'.
>
> Clusters constitute one facet of the diamond, but they are best seen as a manifestation of the interaction of all the diamond's elements. Clusters are geographically proximate groups of interconnected companies, suppliers, service providers, and associated institutions in a particular field, linked by commonalities and complementarities. Clusters such as IT in Silicon Valley or high-performance cars in Southern Germany can be concentrated in a particular region within a larger nation, and sometimes in a single town. Other clusters are national and sometimes stretch across borders into adjacent countries, such as southern Germany and German-speaking Switzerland. Proximity must be sufficient to allow efficient interaction and flow of goods, services, ideas, and skills across the cluster.

(Porter and Ketels 2003, pp. 19, 27)

An important institution for diffusing research and innovation is clusters of 'interconnected companies, suppliers, service providers and associated institutions in a particular field'

Porter (1998) and Porter and Ketels (2003, p. 27) argue that 'clusters affect competitiveness in three broad ways: 'First, clusters increase the *level of productivity* at which constituent firms can operate … Second, clusters increase the capacity for *innovation and productivity growth* … Third, clusters stimulate and enable new business *formation* that further supports innovation and expands the cluster' (emphases in the original). However,

> Only a small number of clusters tend to be true innovation centers. Others may tend to specialize in producing products aimed at particular market segments, or be manufacturing centers. Still other clusters can be regional assembly and service centers. Firms based in the most advanced clusters often seed or enhance clusters in other locations as they disperse some activities to reduce risk, access cheaper inputs, or seek to better serve particular regional markets. The challenge for an economy is to move first from isolated firms to an array of clusters, and then to *upgrade the sophistication of clusters to more advanced activities.*

(Porter and Ketels 2003, pp. 19, 28. Emphasis in the original.)

Clusters are normally located within a relatively small geographic area, at least in the early stages of innovation. Salter and Martin (2001, p. 518) cite studies showing that 'research collaboration within a country is strongly influenced by geographic[al] proximity; as distance increases, collaboration decreases, suggesting that research collaboration often demands face-to-face interaction.' This is because innovation relies on tacit knowledge picked up in the informal sharing of knowledge and ideas in 'dense' networks of firms and other relevant institutions such as universities (Salter and Martin, 2001, p. 524). Rosenfeld (1998, pp. 1–2) argues that the close proximity and spatial interdependence of clusters create 'collective externalities' that allow participants to transact business more cheaply and easily, achieve a scale that attracts specialised services and resources, resolve problems more quickly and efficiently, and learn sooner and more directly about new technologies and practices.

Geographic proximity may become less important as an industry matures. Salter and Martin (2001, pp. 527, 519, 528) postulate that 'the value of geographic spillovers and untraded interdependencies varies over time'. They may be particularly important when the direction of technological development is uncertain, increasing the importance of tacit knowledge and of direct interactions in interpreting and applying new information. Gesling (1992, pp. 122–3) distinguishes between phase 1A innovation – 'swarming', when proximity is important, from phase 1 B innovation – 'strategic networking', when proximity is less important and partners are sought from throughout the nation and world.

While there have been several studies of the significance of the size of research teams in maximising research quality and productivity, there has been little work on the minimum and optimal size of clusters for fostering innovation. The prominent clusters are very large indeed and even the smallest of the existing US biotech clusters is bigger than the whole of Australia's biotechnology industry (Commonwealth of Australia, Ernst & Young and Freehills 2001). The logical conclusion to establish one big cluster is unlikely in Australia, and in any case it may also be undesirable since it would compromise tertiary education's other objectives. In the next section we consider what structures have been proposed for Australian tertiary education and what may be possible and desirable to contribute to innovation.

While there have been several studies of the significance of the size of research teams in maximising research quality and productivity, there has been little work on the minimum and optimal size of clusters for fostering innovation.

5. Structuring Tertiary Education

Most discussion of the form of tertiary education in Australia is of supra-institutional forms, known in Australia as sectors and in the United States as segments. International comparisons are confused by differences in the denotation of 'higher education'. In the United States 'higher education' includes the non-baccalaureate granting two-year or community colleges, the closest Australian analogue of which are now known as vocational education and training providers, formerly institutes of technical and further education. In the United Kingdom 'higher education' includes the 'franchise' programs of the non baccalaureate granting colleges of further education that contribute to baccalaureates awarded by universities. The United Kingdom also includes in 'higher education' the recently established foundation degrees that are similar to the US' associate degrees in being at least one year duration, less than standard baccalaureates, and generally having less theoretical orientation than standard baccalaureates.

Research-intensive University Sector

One of the most longstanding, sophisticated, largest and influential structures of tertiary education is California's segmentation into the research-intensive University of California, the comprehensive California State University and the open access California Community College System. There has been no formal distinction between research intensive and comprehensive higher education institutions in Australia since 1988 and in the United Kingdom since 1994, but the universities with the biggest research incomes have formed self-selected informal groups – the group of 8 in Australia and the Russell group in the United Kingdom. These groups argue for increased concentration of research funding in their institutions, which on some arguments amounts to a reintroduction of a formal distinction or 'binary divide' between a research intensive and a comprehensive higher education sector. These claims are marked by a dotted line in Table 6.2, which probably reflects the big research universities' aspirations more than reality but nonetheless does not concede them the formal distinction they seek.

Table 6.2: Formal (———) and informal (··········) designation of tertiary education sectors in California, the United Kingdom and Australia

Distinctive feature	California	United Kingdom	Australia
Research intensive	University of California	Russell group	Group of 8
Comprehensive baccalaureate-granting	California State University	Other universities	Other universities
Open access	California Community College System	Further education colleges	Vocational education and training providers

OBC

A common progression from promoting the formal designation of a research-intensive sector of higher education is to advocate the concentration of research funding in an even more select group of high-performing research universities. This seems to be the natural outcome of competition, including competition for a significant proportion of research funding (Geuna 1999). However, it is now being proposed as explicit government policy. The recommendations of the Roberts Review (2003) in the United Kingdom of the future for research assessment would lead to the further concentration of research funding in the 'research-intensive' institutions. The then UK minister for higher education, Margaret Hodge, suggested that research might be limited to a group of elite universities, perhaps not going much beyond the 'golden triangle' of Oxford, Cambridge and the London institutions (MacLeod 2003a), although the new minister Alan Johnson may be rethinking this policy (MacLeod 2003b).

In Australia the attention of big business and other elite opinion has been attracted by the observation of the Vice-Chancellor of the university with the biggest research funding, the University of Melbourne, that Australia probably does not currently have a university that ranks in the top 100 in the world (Gilbert 2001). However, the aspiration for Australia to have one or two universities in the world top 100 seems unrealistic when one notes that to fund just the University of Melbourne at the same rate as Harvard University would require the Commonwealth to almost double its current allocation to higher education (Griffith University 2002, p. 3).

Both proposals are not for a new form of tertiary education, but for the establishment of an even more selective group of super research-intensive universities within the existing organisational form. The limit to these proposals is the concentration of research in one big centre or 'flagship' institution as it is commonly expressed in the United States. As the Australian National University (ANU) (2002, p. 6) pointed out in its submission to the recent Commonwealth review of higher education, this was the initial rationale for the establishment of the ANU in 1957 (Foster and Varghese 1996). In those days the existing Australian universities conducted little or no research and did not award the PhD, then regarded as a dangerous German innovation all the more suspicious since it had been adopted in the United States.

As we have seen, there is no evidence of an economy of scale or scope for research at the institutional level, and concentrating research in one or perhaps a select few institutions would limit research diffusion to the immediate locale of the centre, and it would relegate the rest of Australia to provincial status, which is unlikely to be acceptable in a federation. What may be acceptable is concentrating research in each broadly defined field in a national centre, but dispersing centres geographically. This would gain the benefits of scale in each field, but would locate each centre throughout the country so that each jurisdiction can be the centre of something. Two possibilities for combining concentration and dispersal are considered: matrix and hub and spoke.

Matrix

Davis (Griffith University 2002, pp. 36–7) proposes that institutions be encouraged to develop new institutional types through multiple contestable funding. This would be achieved by establishing an institutional teaching performance fund of $271 million and an institutional community service and equity performance fund of $271 million to complement the institutional grants scheme of $271 million, which would be renamed the institutional research performance fund.

In Davis' scheme institutions would be allowed to compete for two but not three performance funds, thereby requiring them to choose one of three options to maximise their institutional performance: research and teaching, research and community service, or teaching and community service (Griffith University 2002, p. 37). Davis' scheme, which has universities concentrating on two of their three broad roles, may be generalised as a matrix where the selection may be made by field of research, innovation cluster or indeed any other salient characteristic. This is illustrated in Table 6.3.

Concentrating research in one or perhaps a select few institutions would limit research diffusion to the immediate locale of the centre … What may be acceptable is concentrating research in each broadly defined field in a national centre ... but dispersing centres geographically.

Table 6.3: Matrix organisation of tertiary education

	Activity A	Activity B	Activity C
Institution A	–	–	
Institution B	–		–
Institution C		–	–

The matrix form is more sophisticated than most other proposals to structure Australian tertiary education, but is probably still too crude to optimise the sector's contribution to innovation. This is because it would require a dichotomous decision whether an institution should participate seriously or not in an activity such as a research field or cluster. While its implementation would probably be more nuanced, at least diagrammatically the matrix doesn't allow for institutions to be moderately involved in an activity, or involved in only part of an activity.

Hub and spoke

A more sophisticated elaboration of the matrix is the hub and spoke. In this form one institution would be designated the hub of an activity such as research in a specified field, but other institutions and their staff and students would be able to apply for support to access the hub's facilities and other fixed resources. While the hub of each activity would be unambiguously located at just one institution, the extent of other institutions' participation may range from partnership to perfunctory, and that may change over time. It would also be possible to make the hub of each activity a different size, depending on its importance, and to vary that from time to time.

With these flexibilities it would be possible to construct the allocation of hubs (whether by competition or otherwise) so that each university had a reasonable prospect of hosting at least one hub, while one would expect that the institutions with considerable accumulations of academic capital would host a disproportionate number of hubs. It would also allow institutions to be spokes to as many hubs as they could attract funding or fund from their internal resources. The current organisational form in Australian higher education closest to the hub and spoke is cooperative research centres. However, these centres coordinate research programs, whereas research hubs in this model would be mainly concerned with developing facilities and coordinating access to them.

One institution could be designated the hub of an activity such as research in a specified field, but other institutions and their staff and students would be able to apply for support to access the hub's facilities and other fixed resources.

It would also be possible to give hubs a broader role than just supporting research to support research diffusion and innovation generally. This would open the possibility for businesses, trade associations, vocational education and training institutions and others to participate either as hubs or spokes.

6. Coordination

Karmel (2001) argues for the re-establishment of 'an independent statutory body standing between the universities and the government along the lines of the commissions which operated successfully from 1959 to 1987'. Karmel argues that such a body is needed to protect intellectual freedom by insulating universities from direct government control or influence, and to inform public policy on higher education by undertaking 'objective analysis' unaffected by political/electoral considerations. Such a body would also at least be highly desirable to coordinate
any more sophisticated organisation of higher education such as the matrix and hub-and-spoke forms described above.

But the need for national coordination extends well beyond higher education. We have noted that vocational education has not been included in the national innovation policy, or in cooperative research centres, one of the Commonwealth Government's only mechanisms to engage higher education research with its end users. This is but one manifestation of the divide between higher education and vocational education and training (Wheelahan 2000) which is unusually deep in Australia (Moodie 2003, p. 55). Balaguer and colleagues (2003) argue that Australia's innovation systems are highly dispersed geographically, sectorally and organisationally. They argue that this limits potential economies of scale in innovation and production and risks fragmentation – the sub-critical concentration of knowledge production resources. They add that 'the demand for new knowledge is also dispersed, which may impede the development of effective links between potential suppliers and users of knowledge' (Balaguer et al. 2003, p. 17).

There are a number of ways this could be done. Innovation could be coordinated nationally by sector. Separate bodies could be established to coordinate higher education, tertiary education (higher education and vocational education and training), and a mechanism could be established to foster the agglomeration and coordination of elements of the national innovation system, say by industry sector or cluster. Alternatively, the basic unit of coordination could be geographic. The Victorian and UK governments propose to coordinate tertiary education and industry development through local learning and employment networks (State of Victoria 2002) and regional development agencies (Secretary of State for Education and Skills 2003a, 2003b). In Australia this would build on an earlier attempt to coordinate national development through regional development councils. Some still exist and are useful for regional consultation, but they have never been given a coordinating role.

Like much of northern continental Europe, Germany has a coordinated market economy in contrast to the liberal market economies of wealthy Anglo countries (Hall and Soskice 2001). Nonetheless, its trade associations may be a useful model. These comprise business, employees and government, and are organised as national bodies with regional chapters. They share information and coordinate investment, and provide research, in training and other pre-competitive and shared infrastructure (Culpepper 2001). This close coordination produces a generally high alignment of higher education, training and employment, but it makes changing any part of the system difficult, slow and uncertain. As a consequence, Germany's higher education and training is considered inflexible and resistant to change (Huisman and Kaiser 2001, p. 63). This would fail to meet Whitley's (2003, p. 1017) preference for a system that can focus research but flexibly change its focus: 'Systems that are able to mobilise large numbers of specialists to deal with new intellectual goals and problems, and to train researchers in new techniques and ideas at relatively short notice, seem likely to produce a wide variety of knowledge and skills that could be useful to firms dealing with high levels of technical uncertainty.'

Australia's national innovation policy has become preoccupied almost exclusively with research, and particularly with research in universities. This is part of a long and general practice of Australian governments to concentrate research policy on universities and major publicly funded research agencies to the relative neglect of research in industry.

7. Conclusion

We have seen that Australia's national innovation policy has become preoccupied almost exclusively with research, and particularly with research in universities. This is part of a long and general practice of Australian governments to concentrate research policy on universities and major publicly funded research agencies (the Australian Institute of Marine Science, the Australian Nuclear Science and Technology Organisation, the Commonwealth Scientific and Industrial Research Organisation, and the Defence Science and Technology Organisation) to the relative neglect of research in industry. When Australian governments have considered industrial research it has been at the prompting of public research figures to increase the tax concession for expenditure on research, much of which is spent in universities and other public research agencies.

This distortion in public policy has concentrated Australia's research funding and activity heavily in the public sector in comparison with US, OECD and European Union averages. There may be good reasons for maintaining the heavy concentration of Australian research in universities, but if Australia is to have a strong national innovation system, special measures will be needed to direct at least some of this effort to business' direct interests. In its background for the innovation summit the Department of Industry, Science and Resources (1999, p. 7) argued that Australia's history, geography and its federal government structure have resulted in a national innovation system that is highly fragmented and frequently operates at a sub-optimal scale. The Department argued that the innovation system exhibits too few links and/or active coordination across all the players, despite the best intentions of the recent past. The Department's (1999, p. 8) first recommendation to the summit therefore was to encourage greater interaction among the players in the system.

Of the ways of organising tertiary education considered in this chapter, only the matrix and the hubs and spokes methods are likely to provide the scale and interaction that the Department of Industry, Science and Resources believes is desirable to contribute to the national innovation system. The matrix is more readily implementable but would make a lesser contribution to national innovation. The hubs and spokes would make a greater contribution but would be correspondingly harder to implement. A cautious approach would be to implement a matrix initially with a view to evolving it to the greater sophistication of hubs and spokes.

> This distortion in public policy has concentrated Australia's research funding and activity heavily in the public sector. … if Australia is to have a strong national innovation system, special measures will be needed to direct at least some of this effort to business' direct interests.

Whatever form is chosen it seems likely that some coordinating mechanism would be needed to manage the transition to the new form and to coordinate the several participants in a national innovation system. As Karmel (2001) has argued, an independent statutory body is needed in higher education to implement government policy but filter out party and electoral interests. A higher education statutory body could be part of a larger coordinating mechanism as the Higher Education Council was part of the National Board of Employment, Education and Training (Dawkins 1988, p. 12). Alternatively, a higher education statutory body could be organisationally separate from the mechanism that coordinates the national innovation system, although of course one would expect them to pursue complementary and mutually reinforcing policies.

References

Australian National Training Authority (ANTA) 2003a, *Shaping our Future: National Strategy for Vocational Education and Training 2004–2010*, <http://www.anta.gov.au/images/publications/national_strategy_final.pdf>.

Australian National Training Authority (ANTA) 2003b, *Innovation through Partnerships*, <http://www.anta.gov.au/images/publications/Innovation_ideas_action.pdf>.

Australian National University (2002) *Submission in Response to the Ministerial Discussion Paper* 'Higher Education at the Crossroads', submission 323, <http://www.backingaustraliasfuture.gov.au/submissions/crossroads/pdf/323.pdf>.

Baines, C. 2000, *Multifunction Polis: Lost City of Opportunity*, <http://www.asto.com.au/News00/MFP_postmortem.htm>, accessed 11 August 2003.

Balaguer, A. et al (2003) *Innovation Systems in Australia*, ANU, Canberra. <http://ngsm.anu.edu.au/research/working_%20paper_%205.doc>

Commonwealth of Australia 2001, *Backing Australia's Ability – An Innovation Action Plan for the Future*, <http://backingaus.innovation.gov.au/statement/pm_speech.htm>.

Commonwealth of Australia, Ernst & Young and Freehills (2001) Australia Biotechnology 2001. <http://www.biotechnology.gov.au/library/content_library/BA_BiotechnologyReport2001a.pdf>.

Culpepper, Pepper D. 2001, 'Employers, Public Policy, and the Politics of Decentralised Cooperation in Germany and France', in Hall, Peter A. and Soskice, D. (eds) *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford University Press, Oxford.

Dawkins, The Hon. J. S., MP 1988, *Higher Education: A Policy Statement* ('the White Paper') Australian Government Publishing Service, Canberra.

Department of Education, Science and Training 2003, *Higher Education Report for the 2003 to 2005 Triennium*, <http://www.detya.gov.au/highered/he_report/2003_2005/default.htm>.

Department of Industry, Science and Resources 1999, *Shaping Australia's Future Innovation – Framework Paper*, <http://www.industry.gov.au/library/content_library/Shaping.pdf>.

Evidence Ltd 2003a, *Funding Research Diversity – Summary Report. The Impact of Further Concentration on University Research Performance and Regional Research Capacity*, A report for Universities UK, <http://www.universitiesuk.ac.uk/bookshop/downloads/funding_sum.pdf>.

Evidence Ltd 2003b, *Funding Research Diversity. A Technical Report Supporting a Study of the Impact of Further Concentration on University Research Performance and Regional Research Capacity* (written by Jonathan Adams and David Smith), Universities UK, London, <http://www.universitiesuk.ac.uk/bookshop/downloads/funding_tech.pdf>.

Ferrier, F., Trood, C. and Whittingham, K. 2003, *Going Boldly into the Future: A VET Journey into the National Innovation System*, National Centre for Vocational Education Research, Leabrook, <http://www.ncver.edu.au/research/proj/nr9036_vol1.pdf>.

Foster, S. G. and Varghese, M. M. 1996, *The Making of the Australian National University*, Allen & Unwin, St Leonards.

Gesling, L. 1992, 'Innovation and the Development of Industrial Networks', in Lundvall, B.-Å. (ed.) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter Publishers, London, pp. 116–28.

Geuna, A. 1999, *The Economics of Knowledge Production: Funding and the Structure of University Research*, Edward Elgar Publishing Limited, Cheltenham.

Gilbert, A. 2001, 'The Idea of a University: Enterprise or Academy', paper presented to the Manning Clark symposium, Canberra, 25 July 2001, <http://www.unimelb.edu.au/vc/present/manningclark.pdf>.

Griffith University 2002, The Griffith Model for Reform of Australian Higher Education. Response to the Commonwealth's discussion papers 'Higher Education at the Crossroads', <http://www.backingaustraliasfuture.gov.au/submissions/issues_sub/pdf/i257.pdf>.

Hall, P. A. and Soskice, D. 2001, 'An Introduction to *Varieties of Capitalism', in Hall, P. A. and Soskice, D. (eds) Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford University Press, Oxford.

Higher Education and Research Opportunities in the United Kingdom (HERO) 2001, *2001 Research Assessment Exercise: The Outcome*, <http://195.194.167.103/Results/all/all.xls>.

Huisman, J. and Kaiser, F. (eds) 2001, *Fixed and Fuzzy Boundaries in Higher Education. A Comparative Study of (Binary) Structures in Nine Countries*, <http://www.awt.nl/nl/pdf/as19.pdf>.

Innovation Summit Implementation Group 2000, *Innovation: Unlocking the Future*, Final report of the innovation summit implementation group, <http://www.industry.gov.au/archive/summit/isigreport.pdf>.

Johnson, R. 1994, 'Effects of Resource Concentration on Research Performance', *Higher Education*, 28: 25–37.

Jones, B. 1982, *Sleepers, Wake!: Technology and the Future of Work*, Oxford University Press, Melbourne.

Karmel, P. 2001, 'Public Policy and Higher Education', *Australian Journal of Management*, 26, pp. 123–43.

Lundvall, B.-Å. 1992, 'Introduction' in Lundvall, B.-Å. (ed.) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter Publishers, London.

Lundvall, B.-Å. and Borrás, S. 1997, *The Globalising Learning Economy: Implications for Innovation Policy*, report based on contributions from seven projects under the TSER programme DG XII, Commission of the European Union, Brussels, <http://www.cordis.lu/tser/src/globec.htm>.

MacLeod, D. 2003a 'Government Hints at Research Elitism', *EducationGuardian.co.uk*, Monday, 9 June, <http://education.guardian.co.uk/RAE/story/0,7348,973997,00.html>.

MacLeod, D. 2003b, 'Minister Hints at Research Rethink', EducationGuardian.co.uk, Wednesday, 10 September, <http://education.guardian.co.uk/RAE/story/0,7348,973997,00.html>.

Moodie, G. 2003, 'The Missing Link in Australian Tertiary Education: Short-cycle Higher Education', *International Journal of Training Research*, vol. 1, no. 1, 44–63.

Morris, N. 2002, 'The Developing Role of Departments', *Research Policy* 31 817–833, <http://www.elsevier.com/locate/econbase>.

Moussouris, L. 1998, 'The Higher Education – Economic Development "Connection" in Massachusetts: Forging a Critical Linkage?', *Higher Education,* 35: 91–112.

Nelson, B. 2003, *Our Universities: Backing Australia's Future,* Commonwealth of Australia, Canberra, <http://www.backingaustraliasfuture.gov.au/policy.htm>.

Organisation for Economic Co-operation and Development (OECD) 2002, *Science, Technology and Industry Outlook,* OECD, Paris, <http://www1.oecd.org/publications/e-book/9202141E.PDF>.

Organisation for Economic Co-operation and Development (OECD) 2003, *The Science, Technology and Industry (STI) Scoreboard 2003,* OECD, Paris, <http://www1.oecd.org/publications/e-book/92-2003-04-1-7294/>.

Porter, M. E. 1998, 'Clusters and Competition: New Agendas for Companies, Governments, and Institutions', in *On Competition,* Harvard Business School Press, Cambridge.

Porter, M. E. and Ketels, C. H. M. 2003, *UK Competitiveness: Moving to the Next Stage,* (UK) Department of Trade and Industry economics paper no. 3, <http://www.dti.gov.uk/economics/paper3-porter-ketels.pdf>.

Roberts, G. 2003, *Review of Research Assessment,* report by Sir Gareth Roberts to the UK funding bodies, <http://www.ra-review.ac.uk/>.

Rosenfeld, S. A. 1998 *Community College/Cluster Connections: Specialization and Competitiveness in the U.S. and Europe,* Teachers College, Columbia University, New York, <http://www.tc.columbia.edu/~iee/ccrc/PAPERS/rosenfl1.pdf>.

Salter, A. J. and Martin, B. R. (2001) 'The Economic Benefits of Publicly Funded Basic Research: A Critical Review', *Research Policy* 30 (2001) 509–32, <http://www.elsevier.com/locate/econbase>.

Secretary of State for Education and Skills 2003a, *The Future of Higher Education,* Cm 5735, <http://www.dfes.gov.uk/highereducation/hestrategy/pdfs/DfES-HigherEducation.pdf>.

Secretary of State for Education and Skills 2003b, *21st Century Skills – Realising our Potential: Individuals, Employers, Nation,* Cm 5810, <http://www.dfes.gov.uk/skillsstrategy/docs/fulldoc.pdf>.

State of Victoria (Department of Education and Training) 2002, *Local Learning and Employment Networks,* <http://www.llen.vic.gov.au/llen/>.

Sorensen, A. 1998, *Regional Development Policy,* <http://www.une.edu.au/geoplan/gp345/sld179.ht>, accessed 11 August 2003.

Wheelahan, L. 2000, *Bridging the Divide: Developing the Institutional Structures that Most Effectively Deliver Cross-sectoral Education and Training,* National Centre for Vocational Education Research, Adelaide.

Whitley, R. 2003, 'Competition and Pluralism in the Public Sciences: The Impact of Institutional Frameworks on the Organisation of Academic Science', *Research Policy* 32 1015–29, <http://www.elsevier.com/locate/econbase>.

About CEDA

CEDA Office Bearers

Patron
M NEWMAN, AC
Chairman
Australian Stock
Exchange Ltd

Board of Directors

National President and
Chair of the Board
I DEVESON, AO

Directors

D ADAMSAS
Deputy Chief Executive
Officer and
Chief Financial Officer
Leighton Holdings Limited

R BESLEY
Managing Partner
Hogan Besley Boyd

P DOYLE
Chief Executive Officer
Hella Australia Pty Ltd

D EDWARDS, AM
Chief Executive Officer
CEDA

J FLOYD
Chief Executive Officer
Australian Motoring
Services Pty Ltd

G FRANKLIN
Managing Director
The Heat Group Pty Ltd

N HATHERLY
Managing Director
RNH Consulting

J HEARD
Director
J H Heard Pty Ltd

A KLOEDEN
Chief Executive Officer
Serco Australia Pty Ltd

D McKENZIE
Executive Dimensions

V NISSEN
Managing Director,
Australia and New Zealand,
Manpower Services

J POULSEN
Partner
Minter Ellllison, Perth

P RUTHVEN
Executive Chairman
IBISWorld Pty Ltd

T TAPPENDEN
Chair of Audit Committee,
CEDA
Director

Prof D YERBURY, AO
Vice Chancellor
Macquarie University

Research Committee Chair
P RUTHVEN
Executive Chairman
IBISWorld Pty Ltd

International Relations
Committee Chair
PROF D YERBURY, AO
Vice-Chancellor
Macquarie University

CEDA Board Of Governors

Victoria

Paul Andersen
Hon John Button
Prof. Adrienne Clarke, AO
Julian Clarke
Laureate Professor Peter
Doherty, AC, FAA, FRS
Peter Duncan
Rt Hon. Malcolm Fraser,
AC, CH
Hon. Sir James Gobbo,
AC, CVO
Prof. Brian Howe
Margaret Jackson, AC
Hugh Morgan, AO
Linda Nicholls
Sir Arvi Parbo, AC
Prof. David Penington, AC

New South Wales

Dr Klaus Albrecht
Tim Besley, AC
The Hon John Fahey, AC
Prof. Donald Gibson
The Hon. Nick Greiner, AC
The Hon. Robert J L Hawke,
AC
Meredith Hellicar
Paul Kelly, AO
Helen Lynch, AM
David Mortimer
Ken J Moss
John Phillips, AM
Richard F E Warburton
Peter J Wills, AC

State Presidents

New South Wales
D McKENZIE
Executive Dimensions

Victoria
J FLOYD
Chief Executive Officer
Australian Motoring
Services Pty Ltd

Queensland
R BESLEY
Managing Partner
Hogan Besley Boyd

South Australia
R CHAPMAN
Managing Director
Bank SA

Western Australia
J POULSEN
Partner
Minter Ellllison, Perth

Tasmania
T BURBURY
Tasmania Manager
GHD Pty Ltd

Australian Capital Territory
PROFESSOR G WITHERS, AO
Professor of Public Policy
Australian National
University

Northern Territory
I KEW
Chief Executive Officer
Northern Territory
Airports Pty Ltd

Patron, Northern Territory
T EGAN, AM
Administrator of the
Northern Territory

CEDA Offices

VICTORIA
Level 5, 136 Exhibition Street
Melbourne Vic 3000
GPO Box 2117T Melbourne Vic 3001
Tel (61 3) 9662 3544
Fax (61 3) 9663 7271
E-mail info@ceda.com.au

NEW SOUTH WALES
Level 9, 275 George Street
Sydney NSW 1043
GPO Box 2100 Sydney NSW 1043
Tel (61 2) 9299 7022
Fax (61 2) 9299 7020
E-mail infoSydney@ceda.com.au

QUEENSLAND
Level 1
10 Market Street
Brisbane Qld 4000
GPO Box 2900
Brisbane Qld 4001
Tel (61 7) 3229 9955
Fax (61 7) 3229 8166
E-mail Brisbane@ceda.com.au

SOUTH AUSTRALIA
67 Payneham Road
College Park SA 5069
Tel (61 8) 8363 2128
Fax (61 8) 8363 3805
Mobile 0414 631 442
E-mail Adelaide@ceda.com.au

WESTERN AUSTRALIA
PO Box 8623
Perth Business Centre WA 6849
Tel (61 8) 9228 2155
Fax (61 8) 9228 2166
Mobile 0412 920 282
E-mail Perth@ceda.com.au

TASMANIA and NORTHERN TERRITO-RY
Enquiries should be directed
to the Victorian office
Visit CEDA on the Internet at
www.ceda.com.au

CEDA

Visit CEDA on the Internet at
www.ceda.com.au